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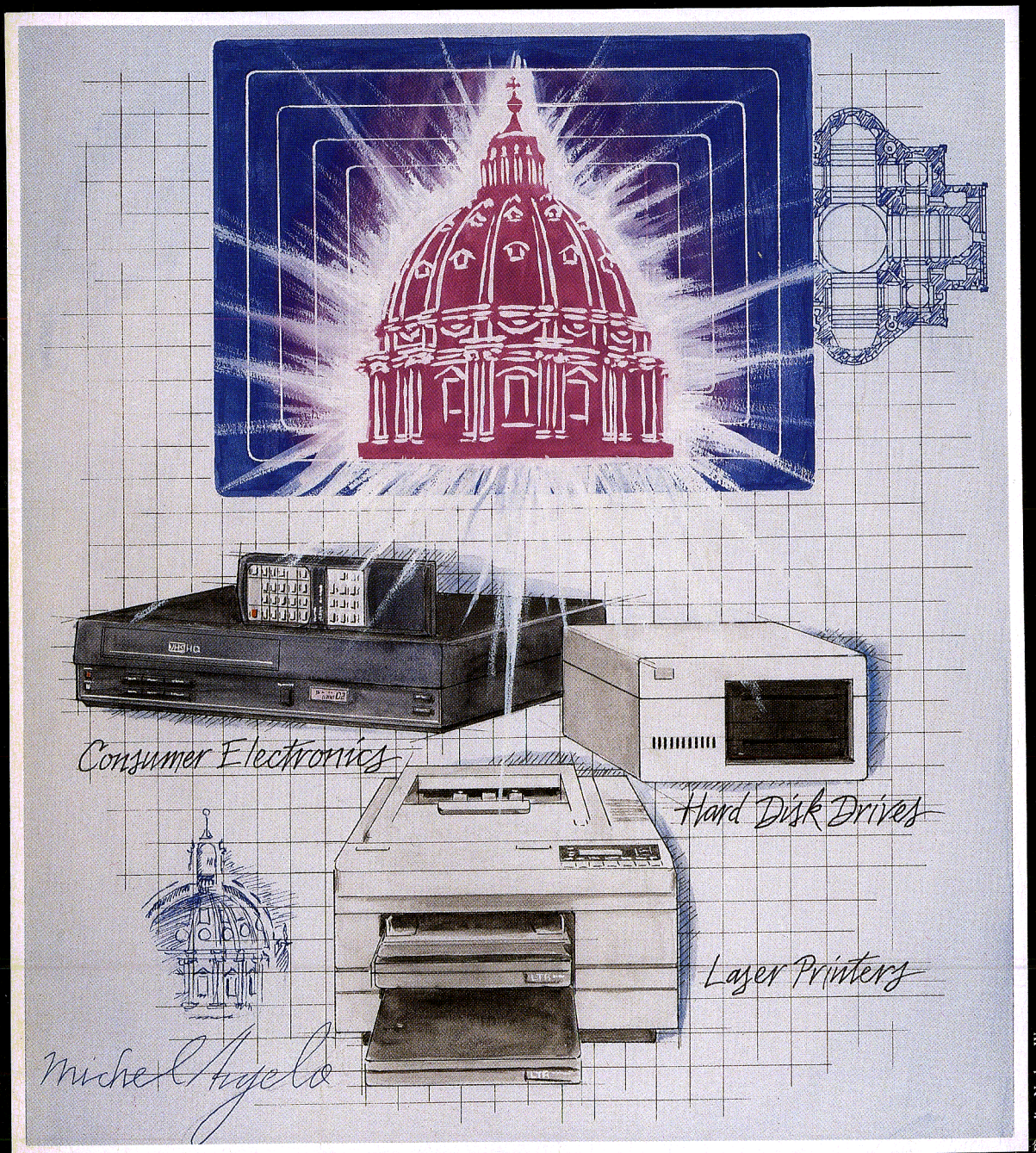

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APPLICATION NOTE

AP-24

February 1977

1

Application Techniques for the MCS-48™ Family

Lionel Smith
Microcomputer Applications

98-413A

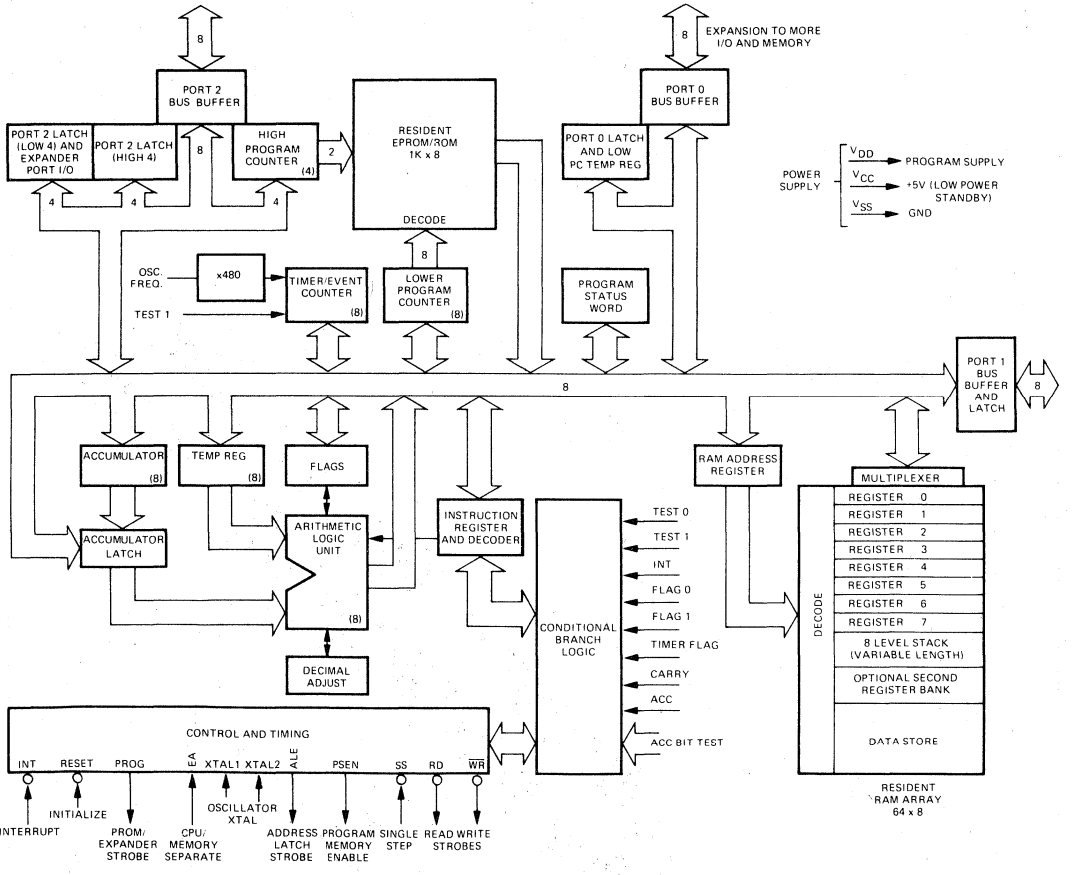
INTRODUCTION

The INTEL® MCS-48™ family consists of a series of seven parts, including three processors, which take advantage of the latest advances in silicon technology to provide the system designer with an effective solution to a wide variety of design problems. The significant contribution of the MCS-48 family is that instead of consisting of integrated microcomputer components it consists of integrated microcomputer systems. A single integrated circuit contains the processor, RAM, ROM (or PROM), a timer, and I/O.

This application note suggests a variety of application techniques which are useful with the MCS-48. Rather than presenting the design of a complete system it describes the implementation of "subsystems" which are common to many microprocessor based systems. The subsystems described are analog input and output, the use of tables for function evaluation, receiving serial code, transmitting serial code, and parity generation. After an overview of the MCS-48 family these areas are discussed in a more or less independent manner.

THE MCS-48™ FAMILY

The processors in the MCS-48 family all share an identical architecture. The only significant difference is the type of on board program storage which is provided. The 8748 (see Figure 1) includes 1024 bytes of erasable, programmable, ROM (EPROM), the 8048 replaces the EPROM with an equivalent amount of mask programmed ROM, nd the 8035 provides the CPU function with no on board program storage. All three of these processors



MCS-48™ Internal Structure

INSTRUCTION SET

	Mnemonic	Description	Bytes	Cycle
Accumulator	ADD A,R	Add register to A	1	1
	ADD A, @R	Add data memory to A	1	1
	ADD A, =data	Add immediate to A	2	2
	ADDC A, R	Add register with carry	1	1
	ADDC A, @R	Add data memory with carry	1	1
	ADDC A, =data	Add immediate with carry	2	2
	ANL A, R	And register to A	1	1
	ANL A, @R	And data memory to A	1	1
	ANL A, =data	And immediate to A	2	2
	ORL A, R	Or register to A	1	1
	ORL A, @R	Or data memory to A	1	1
	ORL A, =data	Or immediate to A	2	2
	XRL A, R	Exclusive Or register to A	1	1
	XRL A, @R	Exclusive or data memory to A	1	1
	XRL A, =data	Exclusive or immediate to A	2	2
	INC A	Increment A	1	1
	DEC A	Decrement A	1	1
	CLR A	Clear A	1	1
	CPL A	Complement A	1	1
	DA A	Decimal Adjust A	1	1
	SWAP A	Swap nibbles of A	1	1
	RL A	Rotate A left	1	1
	RLC A	Rotate A left through carry	1	1
	RR A	Rotate A right	1	1
	RRC A	Rotate A right through carry	1	1
Input/Output	IN A, P	Input port to A	1	2
	OUTL P, A	Output A to port	1	2
	ANL P, =data	And immediate to port	2	2
	ORL P, =data	Or immediate to port	2	2
	INS A, BUS	Input BUS to A	1	2
	OUTL BUS, A	Output A to BUS	1	2
	ANL BUS, =data	And immediate to BUS	2	2
	ORL BUS, =data	Or immediate to BUS	2	2
	MOVD A, P	Input Expander port to A	1	2
	MOVD P, A	Output A to Expander port	1	2
	ANLD P, A	And A to Expander port	1	2
	ORLD P, A	Or A to Expander port	1	2
Registers	INC R	Increment register	1	1
	INC @R	Increment data memory	1	1
	DEC R	Decrement register	1	1
Branch	JMP addr	Jump unconditional	2	2
	JMPP @A	Jump indirect	1	2
	DJNZ R, addr	Decrement register and skip	2	2
	JC addr	Jump on Carry = 1	2	2
	JNC addr	Jump on Carry = 0	2	2
	J Z addr	Jump on A Zero	2	2
	JNZ addr	Jump on A not Zero	2	2
	JT0 addr	Jump on T0 = 1	2	2
	JNT0 addr	Jump on T0 = 0	2	2
	JT1 addr	Jump on T1 = 1	2	2
	JNT1 addr	Jump on T1 = 0	2	2
	JF0 addr	Jump on F0 = 1	2	2
	JF1 addr	Jump on F1 = 1	2	2
	JTF addr	Jump on timer flag	2	2
	JNI addr	Jump on $\overline{INT}$ = 0	2	2
	JBb addr	Jump on Accumulator Bit	2	2

	Mnemonic	Description	Bytes	Cycles
Subroutine	CALL	Jump to subroutine	2	2
	RET	Return	1	2
	RETR	Return and restore status	1	2
Flags	CLR C	Clear Carry	1	1
	CPL C	Complement Carry	1	1
	CLR F0	Clear Flag 0	1	1
	CPL F0	Complement Flag 0	1	1
	CLR F1	Clear Flag 1	1	1
	CPL F1	Complement Flag 1	1	1
Data Movers	MOV A, R	Move register to A	1	1
	MOV A, @R	Move data memory to A	1	1
	MOV A, =data	Move immediate to A	2	2
	MOV R, A	Move A to register	1	1
	MOV @R, A	Move A to data memory	1	1
	MOV R, =data	Move immediate to register	2	2
	MOV @R, =data	Move immediate to data memory	2	2
	MOV A, PSW	Move PSW to A	1	1
	MOV PSW, A	Move A to PSW	1	1
	XCH A, R	Exchange A and register	1	1
	XCH A, @R	Exchange A and data memory	1	1
	XCHD A, @R	Exchange nibble of A and register	1	1
	MOVX A, @R	Move external data memory to A	1	2
	MOVX @R, A	Move A to external data memory	1	2
	MOVP A, @A	Move to A from current page	1	2
	MOVP3 A, @A	Move to A from Page 3	1	2
Timer/Counter	MOV A, T	Read Timer/Counter	1	1
	MOV T, A	Load Timer/Counter	1	1
	STRT T	Start Timer	1	1
	STRT CNT	Start Counter	1	1
	STOP TCNT	Stop Timer/Counter	1	1
	EN TCNTI	Enable Timer/Counter Interrupt	1	1
	DIS TCNTI	Disable Timer/Counter Interrupt	1	1
Control	EN I	Enable external interrupt	1	1
	DIS I	Disable external interrupt	1	1
	SEL RB0	Select register bank 0	1	1
	SEL RB1	Select register bank 1	1	1
	SEL MB0	Select memory bank 0	1	1
	SEL MB1	Select memory bank 1	1	1
	ENTO CLK	Enable Clock output on T0	1	1
	NOP	No Operation	1	1

Figure 2. 8048/8748/8035 Instruction Set

operate from a single 5-volt power supply. The 8748 requires an additional 25-volt supply only while the on board EPROM is being programmed. When installed in a system only the 5-volt supply is needed. Aside from program storage, these chips include 64 bytes of data storage (RAM), an eight bit timer which can also be used to count external events, 27 programmable I/O pins and the processor itself. The processor offers a wide range of instruction capability including many designed for bit, nibble, and byte manipulation. The instruction set is summarized in Figure 2.

Aside from the processors, the MCS-48 family includes 4 devices: one pure I/O device and 3 combination memory and I/O devices. The pure I/O device is the 8243, a device which is connected to a special 4 bit bus provided by the MCS-48 processors and which provides 16 I/O pins which can be programmatically controlled.

The combination memory and I/O devices consist of the 8355, the 8755, and the 8155. The 8355 and the 8755 both provide 2,048 bytes of program storage and two eight bit data ports. The only difference between these devices is that the 8355 contains masked program ROM and the 8755 contains EPROM. The 8155 combines 256 bytes of data storage (RAM), two eight bit data ports, a six bit control port, and a 14 bit programmable timer.

Figure 3 shows the various system configurations which can be achieved using the MCS-48 family of parts. It should also be noted that eight of the processors' I/O lines have been configured as a bidirectional bus which can be used to interface to standard Intel peripheral parts such as the 8251 USART (for serial I/O), the 8255A PPI (provides 24 I/O lines) and the complete range of memory components.

More detailed information concerning the MCS-48 family can be obtained from the "MCS-48 Microcomputer User's Manual" which provides a complete description of the MCS-48 family and its members. A general familiarity with this document will make the application techniques which follow easier to understand.

ANALOG I/O

If analog I/O is required for a MCS-48™ system there are many alternatives available from the makers of analog I/O modules. By searching through their catalogs it is possible to find almost any combination of features which is technically feasible. Perhaps the best example of such modules are the MP-10 and MP-20 hybrid modules recently introduced by Burr-Brown Research Corporation. The MP-10 provides two analog outputs and the MP-20 provides 16 analog inputs. Both of these units were

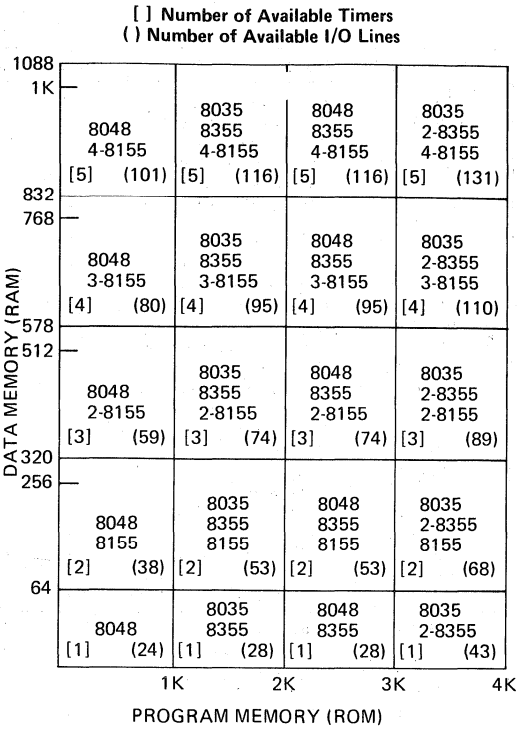


Figure 3. The Expanded MCS-48™ System

specifically designed to interface with microprocessors.

A block diagram of the MP-10 is shown in Figure 4. It consists of two eight bit digital to analog converters, two eight bit latches which are loaded from the data bus, and address decoding logic to determine when the latches should be loaded. The D/A converters each generate an analog output in the range of 10 volts with an output impedance of 1Ω. Accuracy is ±0.4% of full scale and the output is stable 25μsec after the eight bit binary data is loaded into the appropriate latch. The latches are loaded by the write pulse ($\overline{WR}$) whenever the proper address is presented to the MP-10. The lower two addresses (A_0 and A_1) are used internally by the device. Addresses A_2 & A_3 are compared with the address determination inputs B_2 and B_3. If their signals are found to be equal, and if addresses A_4-A_{13} are all high, then the device is selected and one of the latches will be loaded. Address bit A_1 selects between output 1 and output 2. If address bit A_0 is set then the initialization channel of the DIA is selected. In order to prepare for operation a data pattern of 80_H must

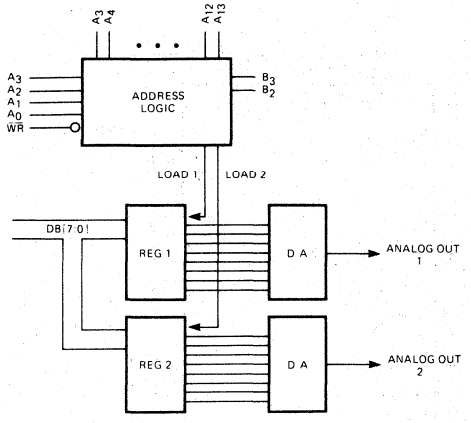


Figure 4. MP-10 Block Diagram

be output to this channel following the reset of the device.

A block diagram of the MP-20 analog to digital converter is shown in figure 5. This unit consists of a 16 input analog multiplexer, an instrumentation amplifier, an eight bit successive approximation analog to digital converter, and control logic. The 16 input multiplexer can be used to input either 16 single ended or 8 differential inputs. The output from the multiplexer is fed into the instrumentation amplifier which is configured so that it can easily be strapped for single ended 0-5 volt inputs, single ended ±5 volt inputs, or differential 0-5 volt signals. Provisions are made for an external gain control resistor on the amplifier. The gain control equation is:

$$G = 2 + \frac{50k\Omega}{R_{ext}}$$

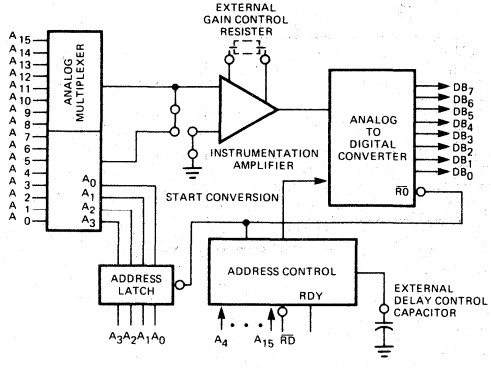


Figure 5. MP-20 Analog Subsystem

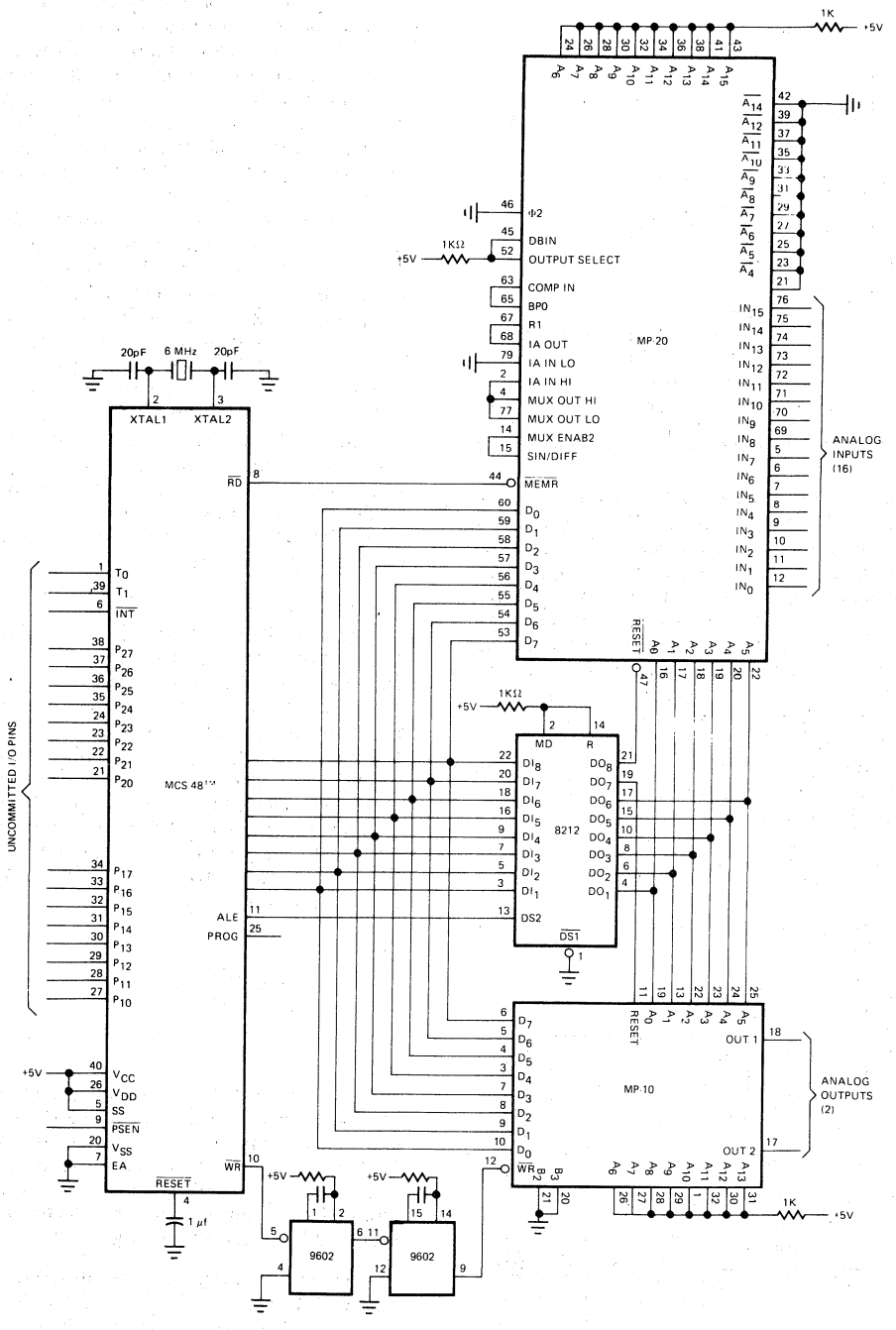
With no R_{ext} ($R_{ext} = \infty$) the gain is two and the input is 0-5 or ±5 volts full scale. Adding an external resistor results in higher gain so that low level (±50mV) signals from thermocouples and strain gauges can be accommodated. The output from the amplifier is applied to the actual A/D converter which provides an eight bit output with guaranteed monotonicity and an accuracy of ±0.4% of full scale. Note that this accuracy is specified for the entire module, not just for the converter itself. The control logic monitors address lines A_{15} through A_4 to determine when the address of the unit has been selected. An address that the unit will respond to is determined by 11 address control pins, labeled $\overline{A4}$ through $\overline{A14}$. If one of these pins is tied to a logic 0 then the corresponding address pin must be high in order for the unit to be selected. If the pin is tied to a logic 1 then the corresponding address pin must be low. If the address of the module is selected when $\overline{MEMR}$ pulse occurs, the lower four addresses (A_3-A_0) are stored in a latch which addresses the multiplexer. The coincidence of the proper address and $\overline{MEMR}$ also initiates a conversion and gates the output of the converter on to the eight bit data bus.

The control logic of the MP-20 was designed to operate directly with an MCS-80™ system. When a $\overline{MEMR}$ occurs and a conversion is initiated the MP-20 generates a READY signal which is used to extend the cycle of the 8080A for the duration of the conversion. READY is brought high after the conversion is complete which allows the 8080A to initiate a conversion and read the resulting data in a single, albeit long, memory or I/O cycle. The conversion time of the MP-20 depends on the gain selected for the amplifier. With no external resistor ($R = \infty$) the gain is two and the conversion time is 35 μsec. For $R = 510\Omega$ the gain is:

$$G = 2 + \frac{50k\Omega}{.51k\Omega} \cong 100$$

and the conversion time becomes 100μsec. These settling times are specified in the MP-20 data sheet and range from 35 to 175 microseconds. The READY timing is controlled by an external capacitor. For a gain of 2 no external capacitor is required but if higher gains are selected a capacitor is needed to extend the timing.

A schematic showing both the MP-10 D/A and the MP-20 A/D connected to the 8748 is shown in Figure 6. This configuration, which consists of only four major components, gives an excellent example of what modern technology can do for



MCS-48™ Based Analog Processor

the system designer. The four components provide:

a. An eight bit microprocessor
b. 64 bytes of RAM
c. 1024 bytes of UV erasable PROM
d. A timer/event counter
e. 16 digital I/O pins
f. 2 testable input pins
g. An interrupt capability
h. 16 eight bit analog inputs
i. 2 eight bit analog outputs

The MCS-48 communicates with the D/A and A/D converters in a memory mapped mode (i.e., it treats the devices as if they were external RAM). By setting an address in either R_0 or R_1 and then executing a MOVX the software can transfer data between the accumulator and the analog I/O. When the MCS-48 executes the MOVX instruction it first sends the eight bit address out on the bus and strobes it into the 8212 latch with the ALE (Address Latch Enable) signal. After the address is latched, the MCS-48 uses the same bus to transfer data to or from the accumulator. If data is being sent out (MOVX @Rj, A) the $\overline{WR}$ strobe is used; if the data is being moved into the accumulator (MOVX A, @Rj) the $\overline{RD}$ strobe is used. The one shots on the $\overline{WR}$ line are used to delay the write strobe of the MCS-48 to meet the data set up specifications of the MP-10.

In order to provide reset capability for the analog devices without dedicating an I/O pin from the MCS-48, special addresses are used as reset channels. Executing any MOVX with an address of 0XXXXXXX will reset the A/D module; a similar operation with an address of X1XXXXXX will reset the D/A; a MOVX with an address of 01XXXXXX will reset both devices. All data transfers are accomplished with the upper two bits of the address field equal to 10. A summary of the addressing of the analog devices is shown in Table 1. Notice that except for an initialization channel for the D/A (which must be written to following a reset to initialize its internal logic) all channels involve some form of data transfer.

Table 1. Analog Interface Addresses

INPUT OR OUTPUT	
0XXX XXXX	Reset A/D
X1XX XXXX	Reset D/A
INPUT	
0011 nnnn	Read A/D Channel nnnn
OUTPUT	
1011 0001	Initialize D/A
1011 0000	Write Channel 1
1011 0010	Write Channel 2

As was mentioned previously, the MP-20 was designed to use the READY line of the 8080A. Obviously this presents a problem since the MCS-48 does not support a READY line (with its attendant requirement of entering WAIT state). The necessity of a READY input can be overcome by performing a read operation to set the channel address, waiting the required delay (35 μsec for a gain of two) and then performing a second read to actually obtain the data. The second read will read in the data from the channel selected by the first read irrespective of the channel selected for the second read. Thus it is possible to use the second read to set up the channel for the third read. Each read can read in the current channel and select the next channel for conversion.

The MP-20 is shown in Figure 6 strapped to input 16 single ended ±5 volts signals. Programs which were used to test this configuration are shown in Figure 7. The first of these programs uses the D/A converter to generate sawtooth waveforms by outputting an incrementing value to the D/A converters. The second program scans the analog inputs and stores their digital values in a table located in RAM.

```
LOC  OBJ        SEQ        SOURCE STATEMENT

                    0
                    1
                    2 ; ----------------------------
                    3 ; TEST PROGRAM FOR ANALOG OUTPUT
                    4 ;   THIS PROGRAM OUTPUTS A SAW-
                    5 ;   TOOTH WAVEFORM BY OUTPUTING
                    6 ;   AN INCREMENTING PATTERN.
                    7 ; ----------------------------
                    8
                    9 ; -------
                   10 ; EQUATES
                   11 ; -------
                   12
00B3                13 INITCH  EQU     0B3H    ; D/A INITIALIZATION CHANNEL
0080                14 INITDT  EQU     80H     ; D/A INITIALIZATION DATA
00B0                15 DATCH   EQU     0B0H    ; D/A DATA CHANNEL
                   16
                   17 ; ------------
                   18 ; START OF TEST
                   19 ; ------------
0100               20         ORG     100H
                   21                         ; INITIALIZE D/A
0100 2380          22 START:  MOV     A,#INITDT
0102 B0B3          23         MOV     R0,#INITCH
0104 90            24         MOVX    @R0,A
                   25                         ; TEST LOOP-OUTPUT SAWTOOTH
0105 B0B0          26 LOOP:   MOV     R0,#DATCH
0107 17            27         INC     A
0108 90            28         MOVX    @R0,A
0109 2405          29         JMP     LOOP
                   30                         ; END OF PROGRAM
                   31         END
```

Figure 7a. D/A Exercise Program

```
LOC  OBJ        SEQ     SOURCE STATEMENT

                  0
                  1
                  2 ; ---------------------------------------
                  3 ; TEST PROGRAM FOR ANALOG INPUT
                  4 ;   THIS PROGRAM SCANS THE INPUT CHANNELS
                  5 ;   AND STORES THE READINGS IN A TABLE
                  6 ;   STARTING AT BUFF.
                  7 ; ---------------------------------------
                  8
                  9 ; -------
                 10 ; EQUATES
                 11 ; -------
                 12
0020             13 BUFF    EQU     20H     ; START OF BUFFER
000F             14 MAXCH   EQU     15      ; NO OF ANALOG INPUTS
00B0             15 AINCH   EQU     0B0H    ; BASE ADDRESS OF ANALOG INPUTS
0005             16 TICK    EQU     5       ; EXECUTION TIME OF DJNZ
                 17
                 18 ; -------------
                 19 ; START OF TEST
                 20 ; -------------
0100             21         ORG     100H
                 22                         ; SETUP TO SCAN ANALOG INPUTS
0100 B92F        23 START:  MOV     R1,#BUFF+MAXCH
0102 BB0F        24         MOV     R3,#MAXCH
0104 B8BF        25         MOV     R0,#(AINCH+MAXCH)
                 26                         ; SELECT CHANNEL 15
0106 88          27         MOVX    A,@R0
                 28                         ; WAIT >40 MICROSECONDS
0107 BC08        29         MOV     R4,#40/TICK
0109 EC09        30         DJNZ    R4,$
                 31                         ; NOW SCAN ANALOGS
010B C8          32 LOOP:   DEC     R0
                 33                         ; GET DATA
010C 88          34         MOVX    A,@R0
                 35                         ; MOVE INTO BUFFER
010D A1          36         MOV     @R1,A
                 37                         ; DECREMENT BUFFER POINT
010E C9          38         DEC     R1
                 39                         ; PAD 20 MICROSEC
010F BC04        40         MOV     R4,#20/TICK
0111 EC11        41         DJNZ    R4,$
                 42                         ; LOOP UNTIL DONE
0113 EB0B        43         DJNZ    R3,LOOP
                 44                         ; REPEAT TEST FOREVER
0115 2400        45         JMP     START
                 46                         ; END OF PROGRAM
                 47         END
```

Figure 7b. A/D Exercise Program

TABLE LOOKUP TECHNIQUES

In the previous section the interface between analog I/O devices and the MCS-48™ was discussed. In many applications involving analog I/O one quickly finds that nature is inherently nonlinear, and the mathematics involved in 'linearizing it' can tax the computational power of the microprocessor, particularly if it has other tasks to perform. Problems of this nature are good candidates for the use of tables.

As an example of how tables can be used as part of an analog output scheme, consider a system which requires an MCS-48 to output a variable frequency sinusoidal waveform. One method of performing this function would be to use the timer to generate an interrupt at a fixed rate of 256 times the desired output frequency. At each interrupt the appropriate value of the sine function could be calculated from the MacLaurin series:

$$\text{Sin } x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} \cdots \frac{(-1)^k \, x^{2k+1}}{(2K+1)!}$$

Where K is chosen to be large enough to provide the required accuracy.

The above calculation, although conceptually simple, would be time consuming and would severely limit the possible output frequencies which could be obtained. As an alternative to calculating these values in real time, the values could be precalculated off line and stored in a table. Upon each interrupt the MCS-48 would merely have to retrieve the appropriate value from the table and output it to the D/A converter. the MCS-48 provides a special instruction which can be used to access data in a table. If the table is stored in the last 256 bytes of the first kilobyte of MCS-48 memory then the table lookup can be performed by loading the independent variable (time in this case) into the accumulator and executing the instruction.

MOVP3 A, @ A

This instruction uses the initial contents of the accumulator to index into page 3 of program storage. The location pointed to is read and the contents placed in the accumulator. If (as is often the case) a table of fewer than 256 entries is required, then the table can be located in any page of program memory and the instruction:

MOVP A, @ A

can be used to retrieve data from the table. This instruction operates in the same manner as does the previous instruction except that the current page of program storage is assumed to contain the table.

If it is possible to devote slightly more of the microprocessor's time to the table look up process, then a much smaller table can often be utilized by taking advantage of interpolation to determine values of the function between values which are actual entries in the table. As an example of this

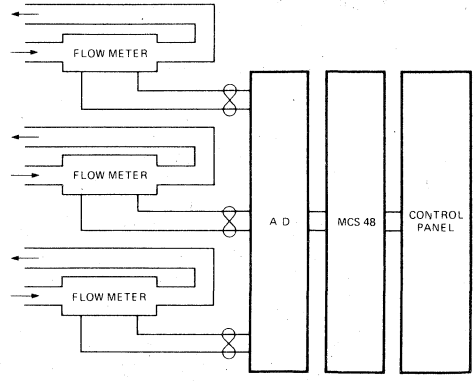


Figure 8. Flow Monitoring System

process consider the hypothetical system shown in Figure 8. The purpose of this system is to measure the flow through the three pipes, add them, and display the total flow on the control panel. The system consists of three flow meters which generate a differential voltage which is some function of flow, an A/D system with at least three differential inputs, an MCS-48, and a control panel. The schematic shown in Figure 6 could easily become part of this system, with the spare digital I/O of the MCS-48 used as an interface to the control panel. The simplicity of this system is clouded by the flow transducers, which are assumed to be not only nonlinear but also to require individual calibration (this is not an unreasonable assumption for a flow transducer). By using a table look up process and an 8748 the flow transducers can be calibrated and the results of the calibration tests stored directly in tables in the 8748. (The 8748 has a PROM in place of the ROM of the 8048 and thus makes such 'one off' programming practical.)

The results which might be obtained from calibrating one of the flow meters is shown in Figure 9. The results are plotted as gals/hour versus the measured voltage generated by the transducer. The voltage is shown in hexadecimal form so that it corresponds directly to the digital output of the analog to digital converter. The flow required to generate seventeen evenly spaced voltages (0H-100H in steps of 10H) has been measured and plotted. This information is shown in tabular form in Figure 10. It is necessary to generate a program which will convert any measured input from 00H to FFH into the flow in units which can be interpreted by a human operator. This can easily be done by simple interpolation.

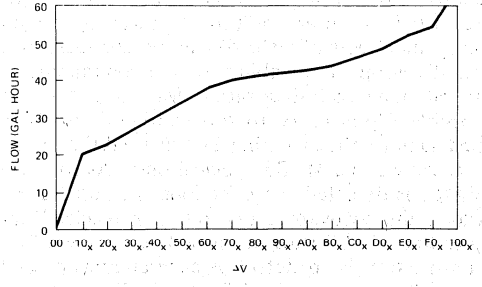


Figure 9. Flow Calibration Curve

TRANSDUCER VOLTAGE (HEX)	00	10	20	30	40	50	60	70	80	90	A0	B0	C0	D0	E0	F0	100
MEASURED FLOW (GAL HOUR)	0	10	22	26	30	34	38	40	41	42	43	45	48	49	53	56	63

Figure 10. Tabulated Flow Data

The eight bits of independent variable (voltage) can be looked on as two four bit fields. The most significant four bits (7-4) will be used to retrieve one of the table values. The lower four bits (3-0) will be used to interpolate between this value and the value retrieved from the next higher location in the table. If the upper four bits are given the symbol I and the lower four bits the symbol N, then the interpolation can be expressed as:

$$F(x) = F(I) + \frac{N}{16}\,[F(I+1) - F(I)]$$

Where x is the measured voltage and F(x) is the corresponding flow.

If, as an example, the transducer voltage was measured as 48H then the flow (ref. Figure 10) would be:

$$F = 30 + \frac{8}{16}\,(34-30) = 32$$

A subroutine which implements this calculation is shown in Figure 11. Before it is called the independent variable (V) is placed in the accumulator and register R1 is set to point at the first value in the table. Aside from simple additions and subtractions the only arithmetic required is to multiply two values and then divide them by 16. The multiplication is handled via a subroutine which is also shown in Figure 11. The division by 16 can be performed by a four place right shift followed by a rounding operation. The routine shown will handle a monotonic increasing function of a single independent variable. Fairly simple modifications are required for nonmonotonic functions. Functions of two variables can be handled by interpolating on a plane rather than along a straight line. Although this is more time consuming, requiring an interpolation for each of the independent variables and a third to interpolate the final answer, it still provides a simple means of quickly calculating the required function. The use of tables can offer a powerful technique for function evaluation to the designer.

RECEIVING SERIAL CODE–BASIC APPROACHES

Many microprocessor based systems require some form of serial communication. Serial communication is extensively used because it allows two or more pieces of equipment to exchange information with a minimal number of interconnecting wires. The minimization of interconnecting wires results in simpler, cheaper, interconnects because fewer (or smaller) cables and connectors are required. Since the required number of drivers and receivers required is reduced, it can become economically feasible to provide much higher noise immunity

```
LOC  OBJ      SEQ     SOURCE STATEMENT

                1 ;*****************************************
                2 ;
                3 ;       APPROX
                4 ;         AT ENTRY R1 POINTSAT TABLE
                5 ;                 A HAS INDEPENDENT VARIABLE
                6 ;
                7 ;*****************************************
                8 ; -------
                9 ; EQUATES
               10 ; -------
               11
0000           12 RX0     EQU     R0      ; POINTER 0
0001           13 RX1     EQU     R1      ; POINTER1
0002           14 AEX     EQU     R2      ; EXTENSION OF A REGISTER
0003           15 COUNT   EQU     R3      ; COUNTER
0004           16 TEMP    EQU     R4      ; TEMP STORAGE
               17
               18 ; -------------
               19 ; APPROXIMATION
               20 ; -------------
               21
0100           22         ORG     100H
               23                         ; POINT RX0 AT TEMP
0100 B004      24 APPROX: MOV     RX0,#TEMP
               25                         ; TEMP=N AND 0FH
               26                         ; A=P AND 0FH
0102 B000      27         MOV     @RX0,#0
0104 30        28         XCHD    A,@RX0
0105 47        29         SWAP    A
               30                         ; RX1=BASE+A
0106 69        31         ADD     A,RX1
0107 A9        32         MOV     RX1,A
               33                         ; RX1=TABLE(P)
               34                         ; A=TABLE(P+1)
0108 E3        35         MOVP3   A,@A
0109 29        36         XCH     A,RX1
010A 17        37         INC     A
010B E3        38         MOVP3   A,@A
               39                         ; A=TABLE (P+1)-TABLE(P)
010C 37        40         CPL     A
010D 69        41         ADD     A,RX1
010E 37        42         CPL     A
               43                         ; A=N*A/16
010F 341D      44         CALL    MULT
0111 B002      45         MOV     RX0,#AEX
0113 30        46         XCHD    A,@RX0
0114 47        47         SWAP    A
0115 2A        48         XCH     A,AEX
0116 7219      49         JB3     ADJUST
0118 2A        50         XCH     A,AEX
0119 2A        51 ADJUST: XCH     A,AEX
011A 17        52         INC     A
               53                         ; A=A+TABLE(P)
011B 69        54         ADD     A,RX1
               55                         ; RETURN

LOC  OBJ      SEQ     SOURCE STATEMENT

011C 83        56         RET
               57
               58
               59 ; --------
               60 ; MULTIPLY
               61 ; --------
               62                         ; SET UP COUNT AND AEX
011D BB08      63 MULT:   MOV     COUNT,#8
011F BA00      64         MOV     AEX,#0
               65                         ; CLEAR CARRY
0121 97        66 LOOPA:  CLR     C
               67                         ; IF MULTIPLIER (0) <> 1 THEN SHIFT PRODUCT
0122 122B      68 LOOPB:  JB0     SSUM
0124 2A        69         XCH     A,AEX
0125 67        70         RRC     A
0126 2A        71         XCH     A,AEX
0127 67        72         RRC     A
               73                         ; LOOP UNTIL DONE
0128 EB22      74         DJNZ    COUNT,LOOPB
012A 83        75         RET
               76                         ; ELSE ADD MULTIPLIER AND SHIFT PRODUCT
012B 2A        77 SSUM:   XCH     A,AEX
012C 60        78         ADD     A,@RX0
012D 67        79         RRC     A
012E 2A        80         XCH     A,AEX
012F 67        81         RRC     A
               82                         ; LOOP UNTIL DONE
0130 EB21      83         DJNZ    COUNT,LOOPA
0132 83        84         RET
               85
               86
               87 ; --------------------
               88 ; TABLE TO TEST PROGRAM
               89 ; --------------------
               90
0300           91         ORG     300H
               92
0300 00        93 TABLE:  DB      00      ; THIS TABLE IS FROM FIG 10
0301 0A        94         DB      10
0302 16        95         DB      22
0303 1A        96         DB      26
0304 1E        97         DB      30
0305 22        98         DB      34
0306 26        99         DB      38
0307 28       100         DB      40
0308 29       101         DB      41
0309 2A       102         DB      42
030A 2B       103         DB      43
030B 2D       104         DB      45
030C 30       105         DB      48
030D 31       106         DB      49
030E 35       107         DB      53
030F 38       108         DB      56
0310 3F       109         DB      63
              110
              111         END
```

Figure 11. Table Lookup With Interpolation

with more sophisticated (and expensive) line terminators. The final, and usually most persuasive, argument in favor of serial communication is that it may be the only method available to accomplish the job. The obvious example of this is telecommunications where it is necessary to encode parallel information into serial format in order to communicate via the telephone network. The intent of this section is to show how the facilities of the MCS-48™ can be brought to bear on the problem of serial communication.

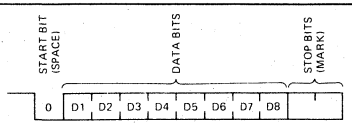


Figure 12. Serial ASCII Code

Probably the most common form of serial communication is that used by the obiquitous Teletype-serial ASCII. This format, shown in Figure 12, consists of a START bit (0 or SPACE) followed by eight data bits which are in turn followed by two STOP bits (1 or MARK). In actual practice the eighth data bit usually consists of even parity on the remaining seven data bits; for the purposes of this discussion the eighth bit will be considered only as data. A minor variation of this format deletes one of the STOP bits. An algorithm which might be used to sample serial data under software control using a microprocessor is shown in Figure 13. The basic intent of this algorithm is to minimize the effects of distortion and transmission rate variations on the reliability of the communication by sampling each data bit as close to its center as possible. Upon entry to this routine the software first samples the incoming data in a tight loop until it is sensed as a MARK (logical one). As soon as a MARK is detected, a second loop is entered during which the software waits until the received data goes to a SPACE (logical zero). The purpose of this construction is to detect as accurately as possible the leading edge of the START bit. This instant of time will be used as a reference point for sampling all of the following bits in the character. After sensing the leading edge of the START bit a wait of one half the expected bit time is implemented. The period of the incoming signal is called P for convenience. At the end of this wait the serial line is tested—if it is MARK then the START bit was

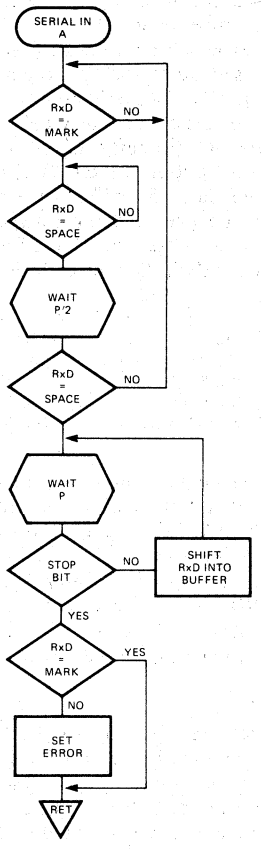


Figure 13. Sample Serial Input Routine

invalid and the process is reinitialized. If the line is still a SPACE, then the START bit is assumed to be valid and a delay of one bit time is started. At the completion of the delay the first data bit is sampled and a new delay of one bit time is initiated. This process is repeated until all eight data bits have been sampled. The last bit sampled is checked to determine if it is a valid STOP bit (a MARK). If it is, the character is assumed to be valid; if it is not, the character has a framing error and is probably invalid. A listing of a program which implements the above procedure is shown in Figure 14.

A disadvantage of the approach outlined in Figure 13 is that while the processor is inputting data serially it must totally dedicate itself to this task. Accurate timing can only be maintained if the program remains in a tight wait loop without allowing itself to be diverted to other functions. During reception of a character from a Teletype the processor will spend only a 100μsecs or so processing data and the rest of the 100 millisecs waiting to do the processing at the right time. This lack of efficiency (approximately 0.1%) in the utilization of processing power is why devices such as the 8251 USART find broad application in microprocessor systems.

```
LOC  OBJ        SEQ        SOURCE STATEMENT

                    0 ; ****************************
                    1 ;
                    2 ;       SIMPLE SERIAL INPUT
                    3 ;       -THIS CODE ASSUMES RXD IS
                    4 ;        CONNECTED TO PIN T0
                    5 ;
                    6 ; ****************************
                    7
                    8 ; -------
                    9 ; EQUATES
                   10 ; -------
                   11
0002                12 COUNT  EQU     R2      ; COUNTER
0008                13 BITNO  EQU     8       ; NO OF BITS TO RECEIVE
0002                14 DLYHI  EQU     2       ; HI DLY COUNT
00A4                15 DLYLO  EQU     0A4H    ; LO DLY COUNT
                   16
0100                17        ORG     100H
                   18                        ; LOOP UNTIL RXD=MARK
0100 2600          19 SERIN: JNT0    $
                   20                        ; NOW LOOP UNTIL RXD=SPACE
0102 3602          21        JT0     $
                   22                        ; WAIT 1/2 BIT TIME
0104 341C          23        CALL    HBIT
                   24                        ; IF FALSE START REINTIALIZE
0106 3600          25        JT0     SERIN
                   26                        ; ELSE SET BIT COUNT
0108 BA09          27        MOV     COUNT,#BITNO+1
                   28                        ; WAIT 1 BIT TIME
010A 341C          29 LOOP:  CALL    HBIT
010C 341C          30        CALL    HBIT
                   31                        ; DECREMENT COUNT
                   32                        ; -IF ZERO EXIT WITH CARRY SET ON
                   33                        ; -FRAMING ERROR
010E EA15          34        DJNZ    COUNT,LOAD
0110 97            35        CLR     C
0111 3614          36        JT0     EXIT
0113 A7            37        CPL     C
0114 83            38 EXIT:  RET
                   39                        ; LOAD DATA
0115 97            40 LOAD:  CLR     C
0116 2619          41        JNT0    LLLA
0118 A7            42        CPL     C
0119 67            43 LLLA:  RRC     A
                   44                        ; AND LOOP
011A 240A          45        JMP     LOOP
                   46
                   47 ; ----------------------
                   48 ; DELAY ONE HALF BIT TIME
                   49 ; ----------------------
                   50
                   51                        ; SET UP LOOP
011C BC02          52 HBIT:  MOV     R4,#DLYHI
                   53                        ; LOOP UNTIL TIME DONE
011E BBA4          54 HLOOP: MOV     R3,#DLYLO
0120 EB20          55        DJNZ    R3,$
0122 EC1E          56        DJNZ    R4,HLOOP
0124 83            57        RET
                   58                        ; END OF PROGRAM
                   59        END
```

Figure 14. Simple Serial Input

The 8251 USART is simple to interface to the MSC-48. Figure 15 shows such an interface. The USART requires a high speed clock (CLK), an initilization signal (RESET), data clocks (TxC and RxC), and data in order to operate. A circuit showing the connection of an 8748 to an 8251 USART is shown in Figure 15. In the circuit shown the high speed clock (which is used for internal sequencing by the USART) is provided by con-

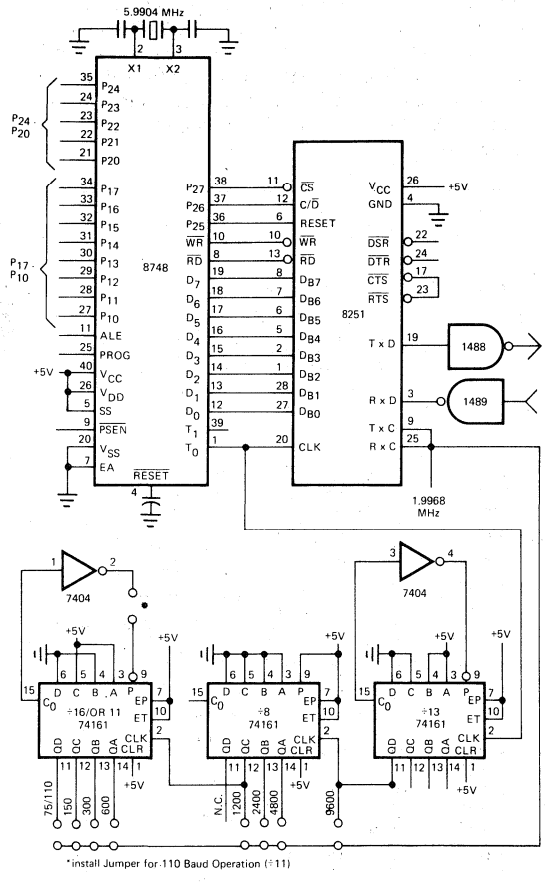


Figure 15. MCS-48™ to 8251 Interface

necting the CLK signal of the USART to the T_0 pin of the MCS-48. The T_0 pin of the MCS-48 can either be used as a directly testable input pin or it can become, under program control, an output pin which oscillates at one third of the crystal frequency. (Note that once this pin is designated by the software to be an output it will remain so until the system is reset.) In Figure 15 the crystal frequency is 5.9904 MHz so the clock provided to the 8251 is 1.9968 MHz, which conforms to its specifications.

The initialization signal to the USART (RESET) is provided programmatically by manipulation of bit 5 of port 2. It was necessary to place the reset of the 8251 under program control for two reasons. The first reason is that the MCS-48 does not supply a reset signal to other devices. The reason for this is that it was felt to be more useful to provide another pin of I/O function instead of a RESET OUT signal from the MCS-48. Although this situation could have been circumvented by the use of an externally generated reset which drove both the MCS-48 and the 8251, the second reason for program control of the reset to the USART still stands. The USART requires the presence of the CLK signal during reset in order to properly initialize itself. The ENT0 CLK instruction which the MCS-48 must execute before the 8251 will receive the CLK can obviously not be executed until after the system reset has ended. Reset of the USART can be accomplished by the following code segment:

```
        ENT0    CLK             ;TURN ON CLOCK
        ORL     P2, #00100000B  ;START RESET
        M0V     R2, #DELAY      ;DELAY USART
LOOP:   DJNZ    R2, LOOP        ;RESET TIME
        ANL     P2, #11011111B  ;END RESET
```

This code first enables the clock, then asserts the reset signal of a time period determined by the constant DELAY. The delay invoked is (10 + 5*DELAY) microseconds for DELAY >0. The USART requires a reset of approximately 6 CLK periods so DELAY is chosen to be 1 which ensures adequate reset timing. Note that for delays this short, NOP instructions could also be used to time the pulse.

The data clocks required by the USART are provided by the modem if the USART is operated in the synchronous mode. In the more common asynchronous mode, however, these clocks must be provided by circuitry associated with the 8251.

The 5.9904 MHz crystal was chosen because the resulting 1.9968 MHz clock to the USART can be evenly divided to provide transmit and receive clocks to the USART. Assuming the USART is in the x16 mode (i.e. it requires data clocks 16 times the baud rate) the 1.9968 MHz signal can be divided by 13 to generate the proper clock rate for 9600 baud operation. This 9600 baud clock can be further divided to give 4800, 2400, 1200, 600, and 300 baud signals. The 1200 baud signal can be divided by 11 to give a 109.1 baud signal which is within 1% of the 110 baud required by Teletypes.

The MCS-48 communicates with the 8251 in a memory mapped mode (i.e. as if the 8251 were external RAM). The instructions available to do this are MOVX ∂Rj, A which stores the contents of the accumulator at the external RAM location addressed by Rj (j=0 or 1), and its complement, the MOVX A, @ Rj instruction which moves data from the external RAM into the accumulator. Since the MCS-48 multiplexes addresses and data on the same eight bit bus an external latch would be required in order to address the USART with

```
LOC  OBJ       SEQ     SOURCE STATEMENT

                  0 ;-------------------------------
                  1 ; SERIAL TEST
                  2 ;  THIS CODE INTIALIZES THE USART
                  3 ;  AND TRANSMITS AN INCREMENTING
                  4 ;  PATTERN. HARDWARE SHOWN IF FIG 15.
                  5 ;-------------------------------
                  6
                  7 ; -------
                  8 ; EQUATES
                  9 ; -------
                 10
0020              11 MCLR   EQU    20H     ; USART RESET ADDRESS
0001              12 DLY    EQU    01H     ; USART RESET DELAY
007F              13 UCON   EQU    7FH     ; USART CONTROL ADDRESS
00CE              14 MODE   EQU    0CEH    ; USART MODE
0021              15 CMD    EQU    21H     ; USART CMD
007F              16 STAT   EQU    7FH     ; USART STATUS
0001              17 VAL    EQU    R1      ; TEST VALUE
00BF              18 MASK   EQU    0BFH    ; CHANGES CMD TO DATA CHANNEL
                  19
0100              20        ORG    100H
                  21                       ; TURN ON CLOCK
                  22                       ; AND RESET USART
0100 75           23 TEST:  ENT0   CLK
0101 BA20         24        ORL    P2,#MCLR
0103 BA01         25        MOV    R2,#DLY
0105 EA05         26 LOOP:  DJNZ   R2,LOOP
0107 9ADF         27        ANL    P2,#(NOT MCLR)
                  28                       ; SELECT USART CONTROL
0109 237F         29        MOV    A,#UCON
010B 3A           30        OUTL   P2,A
                  31                       ; SEND MODE AND COMMAND
010C 23CE         32        MOV    A,#MODE
010E 90           33        MOVX   @R0,A  ; (CONTENTS OF R0 UNIMPORTANT)
010F 2321         34        MOV    A,#CMD
0111 90           35        MOVX   @R0,A
                  36                       ; DO FOREVER
                  37                       ;   SELECT USART STATUS
                  38                       ;     IF TXRDY=1 THEN
                  39                       ;     DO;
                  40                       ;       OUTPUT VALUE;
                  41                       ;       INCREMENT VALUE;
                  42                       ;     END;
                  43                       ;   END;
0112 237F         44 TLP:   MOV    A,#STAT
0114 3A           45        OUTL   P2,A
0115 80           46        MOVX   A,@R0  ; (CONTENTS OF R0 UNIMPORTANT)
0116 67           47        RRC    A
0117 E612         48        JNC    TLP
0119 F9           49        MOV    A,VAL
011A 9ABF         50        ANL    P2,#MASK
011C 90           51        MOVX   @R0,A
011D 19           52        INC    VAL
011E 2412         53        JMP    TLP
                  54                       ; END OF PROGRAM
                  55        END
```

Figure 16. 8251 Test Program

R0 or R1. In order to minimize the circuitry in Figure 15 an approach utilizing some of the I/O pins of the MCS-48 to address the 8251 was chosen instead. By connecting the chip select ($\overline{CS}$) input of the 8251 to bit 7 of port 2 (P27) and similarly connecting the C/$\overline{D}$ address line of the 8251 to bit 6 of port 2 (P26) it is possible to address the 8251 without using R0 or R1. The instruction sequence to access the 8251 is to first reset P27 and set P26 to the appropriate state, use a MOVX instruction to perform the appropriate operation, and then finally set P27 to deselect the 8251. As a concrete example of this addressing, Figure 16 shows the code necessary to initialize the 8251 and output an incrementing test pattern on a status driven basis.

If more than one 8251 were to be added to the MCS-48, or if other types of peripheral circuitry would be required (e.g. an 8253 timer to generate the data clocks) it would probably become desirable to add the circuitry necessary to use R0 or R1 to address the peripheral devices. The circuitry which has to be added to Figure 15 in order to make use of R0 or R1 to address the USART is shown in Figure 17. Note that only the changes to Figure 15 are shown. The additional component required is the 8212 eight bit latch. This latch is loaded, whenever a valid address is on the bus by the Address Latch Enable (ALE) signal provided by the MCS-48. During an external read or write cycle this address is used to address the 8251 in a linear select mode. In the circuit shown, the 8251 will be selected by any address with bit 1 a logical zero (XXXXXX0X) and the selection of control or data transfer (C/$\overline{D}$) will be based on bit zero of the address obtained from R0 or R1. Figure 18 shows the program of Figure 16 modified to utilize the addressing inherent in the MOVX instructions.

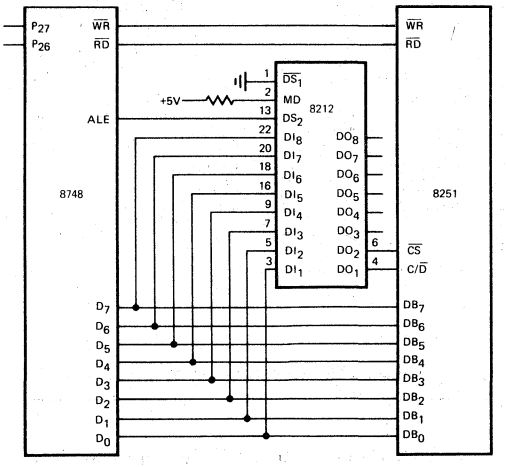


Figure 17. Modified MCS-48 to 8251 Interface

RECEIVING SERIAL CODE—A MORE SOPHISTICATED ALGORITHM

Although the USART does an admirable job of performing the serial I/O function for the MCS-48™, there are some situations where it can not be used. These situations may be caused by economic factors, such as an extremely cost sensitive design, or because the code which must be utilized cannot be accommodated by the USART. An example of of such a code will be discussed later. Recall that the principal objection to the approach to serial input shown in Figure 13 was that it consumes much of the processor's power by merely spinning in loops in order to wait preset time delays.

```
LOC  OBJ       SEQ       SOURCE STATEMENT

                  0 ; ---------------------------------
                  1 ; SERIAL TEST
                  2 ;  THIS CODE INTIALIZES THE USART
                  3 ;  AND TRANSMITS AN INCREMENTING
                  4 ;  PATTERN. HARDWARE SHOWN IF FIG 17.
                  5 ; ---------------------------------
                  6
                  7; -------
                  8; EQUATES
                  9; -------
                 10
0020             11 MCLR   EQU    20H     ; USART RESET ADDRESS
0001             12 DLY    EQU    01H     ; USART RESET DELAY
0003             13 UCON   EQU    03H     ; USART CONTROL ADDRESS
00CE             14 MODE   EQU    0CEH    ; USART MODE
0021             15 CMD    EQU    21H     ; USART CMD
0003             16 STAT   EQU    03H     ; USART STATUS
0001             17 VAL    EQU    R1      ; TEST VALUE
0000             18 DATA   EQU    00      ; USART DATA ADDRESS
                 19
0100             20        ORG    100H
                 21                       ; TURN ON CLOCK
                 22                       ; AND RESET USART
0100 75          23 TEST:  ENT0   CLK
0101 BA20        24        ORL    P2,#MCLR
0103 BA01        25        MOV    R2,#DLY
0105 EA05        26 LOOP   DJNZ   R2,LOOP
0107 9ADF        27        ANL    P2,#(NOT MCLR)
                 28                       ; SELECT USART CONTROL
0109 2303        29        MOV    A,#UCON
                 30                       ; SEND MODE AND COMMAND
010B 23CE        31        MOV    A,#MODE
010D 90          32        MOVX   @R0,A   ; (CONTENTS OF R0 UNIMPORTANT)
010E 2321        33        MOV    A,#CMD
0110 90          34        MOVX   @R0,A
                 35                       ; DO FOREVER
                 36                       ;    SELECT USART STATUS
                 37                       ;       IF TXRDY=1 THEN
                 38                       ;       DO;
                 39                       ;          OUTPUT VALUE;
                 40                       ;          INCREMENT VALUE;
                 41                       ;       END;
                 42                       ;  END;
0111 2303        43 TLP:   MOV    A,#STAT
0113 80          44        MOVX   A,@R0   ; (CONTENTS OF R0 UNIMPORTANT)
0114 67          45        RRC    A
0115 E611        46        JNC    TLP
0117 F9          47        MOV    A,VAL
0118 B800        48        MOV    R0,#DATA
011A 90          49        MOVX   @R0,A
011B 19          50        INC    VAL
011C 2411        51        JMP    TLP
                 52                       ; END OF PROGRAM
                 53        END
```

Figure 18. Modified 8251 Test Program

The timer resident on the MCS-48 provides a solution to this problem. Instead of spinning in a loop the program can set the timer for a given interval, start it, and proceed to other tasks. When the timer overflows, an interrupt will be generated to notify the software that the present time period has elapsed. An extension of the algorithm of Figure 13 which uses the timer in this fashion in shown in Figure 19. This algorithm is identical to the preceding one up until the detection of the leading edge of the start bit. At this point the timer is set to one half of the bit time (P) and a return is made to the calling program which can start additional processing. At the completion of this time interval a timer overflow interrupt is generated. When the first interrupt is detected, the serial line is checked to ensure that it is in a spacing condition (valid START bit). If it is, the timer is set to P (to sample the middle of the first data bit) and a return is made to the program which was running when the interrupt occurred. If the serial line has returned to the MARK state, a status flag is set to indicate an error and a return is made. On subsequent interrupt detection, the data is sampled, the timer is reinitiated, and control is returned to the program which was running when the interrupt occurred. When the last (i.e. STOP) bit is detected a completion flag is set and a return is made to the program running when the timer overflow occurred. By periodically checking the error and completion flags the running program can determine when the interrupt driven receive program has a character assembled for it.

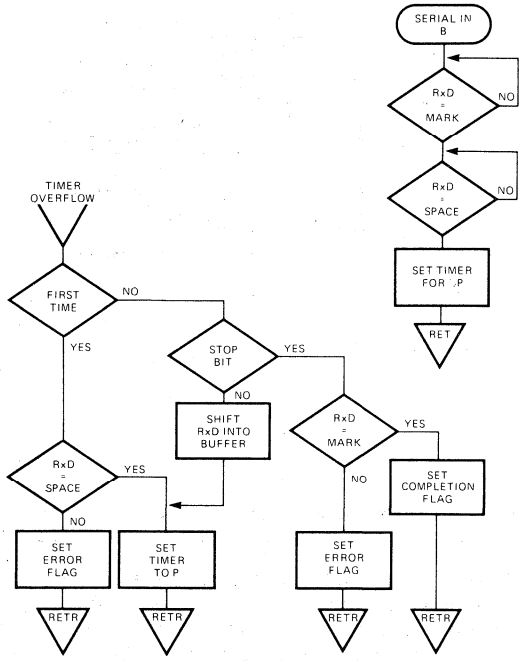


Figure 19. Improved Serial Input Routine

Using the timer to implement time delays as shown in Figure 19 results in considerable savings in processing time; two problems remain, however, which must be solved before an adequate software solution to the problem of receiving serial code can be found. The first problem is that even though the delays between bit samples are implemented via the timer rather than program loops the loop construction is still used to detect the leading edge of

the START bit. Although this results in the waste of processing power, the second problem is even more serious. For longer messages the required accuracy of the clocks becomes more and more stringent. Using the sampling technique discussed a cumulative error of one half a bit time in the time at which a bit sample is taken will result in erroneous reception. The maximum timing error which can be tolerated and yet still allow proper detection of an 11 bit ASCII character is then:

$$Emax = \frac{0.5*BIT\ TIME}{CHARACTER\ TIME} - \frac{0.5P}{11\ P} = 4.5\%$$

where P is the period of single bit. The corresponding calculation for a 32 bit character yields:

$$Emax = \frac{0.5P}{32\ P} = 1.6\%$$

Since this calculation does not allow for distortion on the signals, it is obvious that either extremely stable clocks will be required or a more tolerant algorithm must be devised. This problem is particularly serious at relatively high baud rates where the resolution of the counter (80μsecs with a 6 MHz crystal) becomes a significant percentage of the period of the received signal. At the 110 baud rate of the Teletype the 80μsec resolution of the clock allows a maximum accuracy of 0.33%; at 2400 baud this figure is reduced to 3.8%.

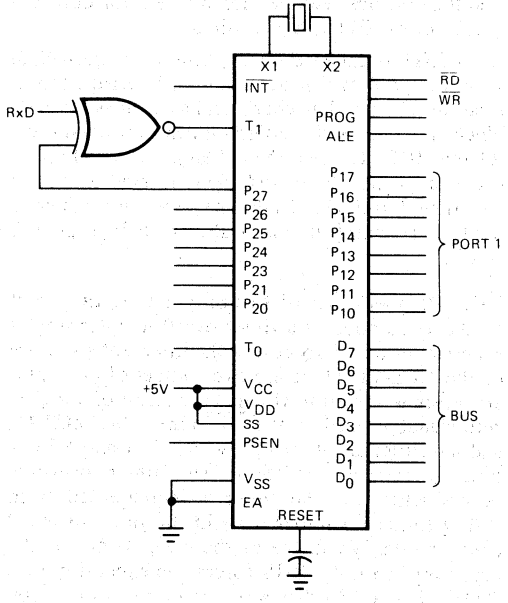


Figure 20. Detecting RxD Edges

Both efficient detection of the start bit and increased timing accuracy can be obtained if the MCS-48 can detect edges on the incoming received data (RxD). A hardware construct which allows this is shown in Figure 20.

The received data (RxD) is Exclusive NORed with bit seven of port two and fed into the TEST (T1) pin of the MCS-48. By manipulating P27 the program can now cause T1 to be either RxD or $\overline{RxD}$. (If P27 = 1 then T1 = RxD; if P27 = 0 then T1 = $\overline{RxD}$.) Note that not only can T1 be tested directly by the software but that it is the input which is used when the MCS-48 timer is in the event counter mode. The significance of this will be discussed later. The relationship between T1, P27, and RxD is given by the Boolean expression:

$$\overline{T1} = P27 \cdot \overline{RxD} + \overline{P27} \cdot RxD$$

Figure 21 flowcharts a means of utilizing this hardware construct to avoid the necessity of wasting time in program loops to detect the leading edge of the start bit. The receive operation is initialized when the program desiring to receive serial data calls the INIT subroutine (Figure 21a). Since INIT is going to manipulate the timer the first action it performs is to disable the timer overflow interrupt. Its next step is to set P27 to a logical 1. Setting P27 in this manner causes the TEST 1 input to the MCS-48 to follow $\overline{RxD}$. By setting up the receive circuitry in this manner a high to low transition will occur on TEST 1 when the RxD goes from the MARKING to SPACING state (i.e. the START

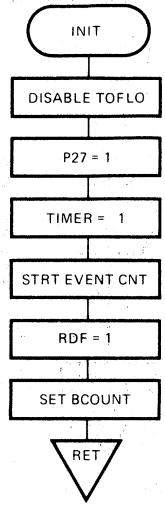


Figure 21a. Interrupt Driven Serial Receive Flowchart

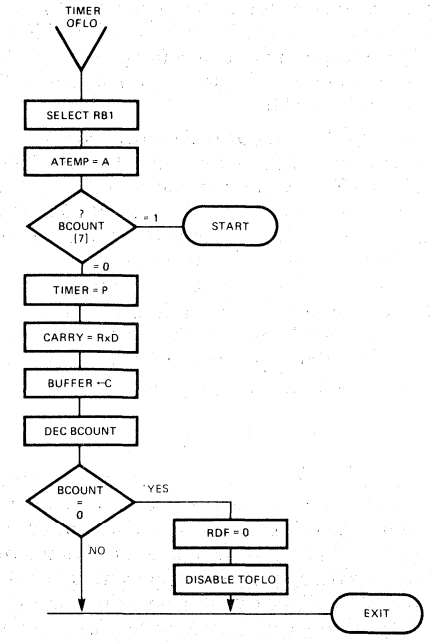


Figure 21b. Interrupt Driven Serial Receive Flowchart

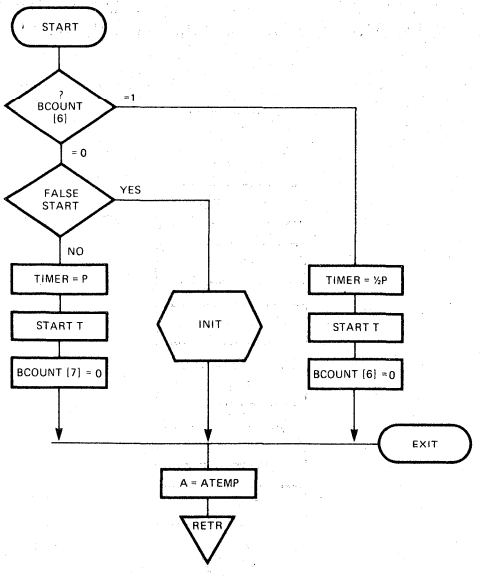
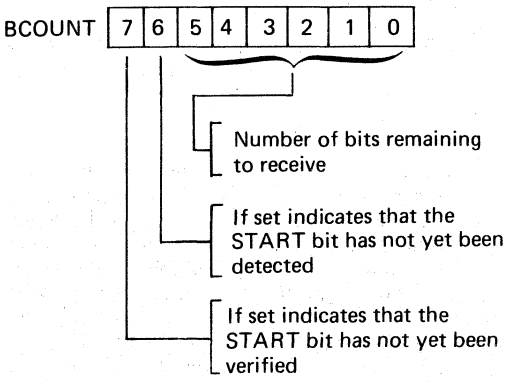


Figure 21c. Interrupt Driven Serial Receive Flowchart

bit occurs). By setting the timer to $0FF_H$ and enabling it in the event count mode, the INIT routine sets up the MCS-48 to generate a timer overflow interrupt on the next MARK to SPACE transition of RxD (the TEST 1 input doubles as the event counter input). Before returning to the calling program the INIT routine sets a flag (RDF) which will be cleared by the receive program when the requested receive operation is complete. INIT also sets a value into a register called BCOUNT. The receive program interprets BCOUNT as follows:



In order to request the reception of the 11 bit ASCII code INIT would set BCOUNT to 11001011B. The start bit has been neither verified nor detected and 11 bits (1011B) are required.

After INIT is called the reception of the individual serial data bits will proceed on an interrupt driven basis until a complete character has been assembled. When this occurs the interrupt driven program will set the RDF (Receive Done Flag) to a zero to indicate that it has completed the requested operation and then terminate itself. The procedure which is used to accomplish this is shown in Figures 21b and 21c.

Since all operations of this program are the result of the occurence of a timer overflow interrupt, it is necessary to briefly review the interrupt structure of the MCS-48. There are two sources of interrupt; an external interrupt which is the result of a logical zero signal applied to the $\overline{INT}$ pin of the MCS-48, and an internal interrupt which is caused by a timer overflow condition. The timer overflow occurs whenever the timer is incremented from $0FF_H$ to zero whether it be in the timer or event count mode. When one of these events occurs the hardware in the MCS-48 forces the execution of a CALL. This CALL has a preset address of location 3 if it is due to the external interrupt and location 7 if it is due to a timer overflow. If both of these

events occur simultaneously the external interrupt will take precedence. The CALL automatically saves the contents of the program counter for the running program and its PSW (program status word) on a stack the hardware maintains in RAM locations 8-23. Although the hardware saves the program counter and PSW, it remains the responsibility of any interrupt driven software to make absolutely certain that it does not modify any memory locations or registers which are being used by the main program. The most convenient way of ensuring this in the MCS-48 is to dedicate the second bank of registers (RB1) to the interrupt driven program. One of these registers has to be used to save the accumulator (which is not part of the register bank) but seven registers remain; including two which can be used as pointers to the rest of the RAM (R0 and R1). Note that if this approach is taken then these registers have to be allocated between the program which services the external interrupt and the one which services the timer overflow. This problem is somewhat alleviated by a hardware lockout which prevents the timer overflow interrupt from interrupting the external interrupt service routine and vice versa. This is implemented by locking out new interrupts between the time an interrupt is recognized and the time a RETR instruction is executed. The RETR instruction is like a normal RET (return from subroutine) except that the PSW as well as the program counter is restored. The RETR instruction can be very much thought of as a return from interrupt instruction in the MCS-48.

The receive program under discussion uses register bank 1 in the manner described. Whenever a timer overflow occurs (e.g. on the next MARK to SPACE transition of RxD after INIT is called), control is passed (by the hardware generated CALL) to the point labled TIMER OFLO in Figure 21b. This program segment immediately selects register bank 1 (RB1) and then saves the accumulator (A) in a location called ATEMP which is actually R7 of RB1. The program then tests bit seven of BCOUNT (R6 of RB1) to find out if a START bit has been verified (i.e. the edge of the START bit has first been detected and then verified to still be a SPACE one-half a bit time later. If BCOUNT [7] is a zero the START has been verified and the program proceeds to set the timer to P (the period of the serial bit), get the current serial data into the carry bit, and then shift the carry bit into a buffer. After saving the data the program decrements BCOUNT and tests it for zero. If BCOUNT is zero the receive operation is complete so the program sets RDF to a zero and disables timer overflow interrupts. Whether or not BCOUNT is zero, control is passed to EXIT where A is loaded with ATEMP and a RETR is executed. Note that since the state of the flip flop which selects RB1 is saved as part of the PSW, the execution of RETR automatically selects the register bank which was active when the interrupt occurred.

If BCOUNT [7] is still set when it is tested, control is passed to START (Figure 21c) where bit 6 is tested to determine if the START has been detected yet. If BCOUNT [6] is set it indicates that this is the first occurrence of a timer overflow since the receive process was initialized by the INIT subroutine. If this is so, the program assumes that the START bit has just started and therefore it sets the timer to one-half of a bit time (1/2 P), starts the timer in the timer mode, and clears BCOUNT [6] to indicate that the START bit has been detected. The next overflow will again result in the execution of the program in Figure 21b and again BCOUNT [7] will be found to be set. This time, however, BCOUNT [6] will be reset and the program will know that it should test the START bit to ensure that it is still a SPACE. This test is performed and if successful the timer is set for a bit period P and BCOUNT [7] is reset so that on the next occurrence of a timer overflow the program will know that it should start assembling serial bits into a character. If the test is unsuccessful, the subroutine INIT is used to reinitialize the receive program. In either case control is passed to EXIT where a return from interrupt mode occurs.

This receive program, listings of which appear in Figure 22, allows the reception of serial characters transparently to the main running software. After INIT is called the main program has only to check RDF periodically to find out if there is data in the buffer for it. It would be fairly easy to 'double buffer' this operation by providing a buffer which the receive program uses to deserialize the incoming code and a second buffer to store the assembled character. If the program would reinitialize itself upon completion, the reception of a string of characters could proceed in much the same way as it would if a status driven USART were being used.

Although this program solves the first problem of software controlled reception (lack of efficiency) the second problem—sensitivity to frequency variations—remains. An example of a code which would be susceptible to this problem is the 31,26 BCH code commonly used in supervisory control systems. (A supervisory control system is, in essence, a remote control system which allows a human or computer operator the control of a system via a serial communications link.) The BCH codes are used because of their error detection capabilities and are a class of cyclical redundancy

```
LOC  OBJ       SEQ       SOURCE STATEMENT

                  1
                  2 ; ****************************************
                  3 ;
                  4 ;       SERIAL INPUT USING THE MCS-48
                  5 ;        THIS CODE ASSUMES HARDWARE
                  6 ;        SHOWN IN FIG 20. TO USE
                  7 ;        THIS ROUTINE CALL INIT.
                  8 ;        WHEN RDF=0 THE ASSEMBLED
                  9 ;        CHARACTER WILL BE IN SERBUF
                 10 ; ****************************************
                 11
                 12 ; -------
                 13 ; EQUATES
                 14 ; -------
                 15
0007             16 ATEMP  EQU   R7     ; STORAGE FOR A DURING INTERUPT
0006             17 BCOUNT EQU   R6     ; CONTAINS NUMBER OF BITS IN MSG
0002             18 COUNT  EQU   R2     ; UTILITY COUNTER
0000             19 RX0    EQU   R0     ; POINTER
0008             20 BITNO  EQU   8      ; NUMBER OF BITS
0029             21 P      EQU   41     ; SAMPLE PERIOD
0020             22 SERBUF EQU   20H    ; SERIAL BUFFER
0024             23 RDF    EQU   24H    ; RECEIVE DONE FLAG
                 24
                 25 ; ---------------------------------------
                 26 ; CONTROL PASSED HERE WHEN TIMER OFLO OCCURS
                 27 ; ---------------------------------------
                 28
0007             29        ORG   07H
                 30                     ; /*ENTER INTERRUPT MODE*/
0007 D5          31 IMVEC: SEL   RB1
0008 AF          32        MOV   ATEMP,A
                 33                     ; IF BCOUNT(7)=0 THEN
0009 FE          34        MOV   A,BCOUNT
000A F223        35        JB7   START
                 36                     ; DO;
                 37                     ;    TIMER=P;
000C 23D7        38        MOV   A,#-P
000E 62          39        MOV   T,A
                 40                     ;    START TIMER
000F 55          41 SLLB:  STRT  T
                 42                     ;    /*CARRY=RXD*/
                 43                     ;    CARRY=P27 XNOR TEST1;
0010 0A          44        IN    A,P2
0011 F7          45        RLC   A
0012 5615        46        JT1   TISRD
0014 A7          47        CPL   C
                 48                     ;    /*SHIFT CARRY INTO BUFFER*/
                 49                     ;    RX0=SERBUF:
                 50                     ;    RSHFT MEM(RX0);
0015 B820        51 TISRD: MOV   RX0,#SERBUF
0017 20          52 SLOOP: XCH   A,@RX0
0018 67          53        RRC   A
0019 20          54        XCH   A,@RX0
                 55                     ;    BCOUNT=BCOUNT-1;
                 56                     ;    IF BCOUNT=0 THEN
001A EE3F        57        DJNZ   BCOUNT,SEXIT
                 58                     ;       DO;
                 59                     ;          RDF=0;
                 60                     ;          DISABLE EX INT;
                 61                     ;       END;
001C B824        62        MOV   RX0,#RDF
001E 27          63        CLR   A
001F A0          64        MOV   @RX0,A
0020 35          65        DIS   TCNTI
                 66                     ; END;
0021 043F        67        JMP   SEXIT
                 68                     ; ELSE
                 69                     ; DO;
                 70                     ;    IF BCOUNT(6)=0 THEN

0023 FE          71 START: MOV   A,BCOUNT
0024 D237        72        JB6   SLLC
                 73                     ;    DO;
                 74                     ;       IF TEST1=0 THEN
0026 5635        75        JT1   SLLD
                 76                     ;       DO;
                 77                     ;          TIMER=P;
                 78                     ;          START TIMER;
                 79                     ;          P27=0;
                 80                     ;          EN I
                 81                     ;          BCOUNT(7)=0;
                 82                     ;       END;
0028 23D7        83        MOV   A,#-P
002A 62          84        MOV   T,A
002B 55          85        STRT  T
002C 9A7F        86        ANL   P2,#7FH
002E 05          87        EN    I
002F FE          88        MOV   A,BCOUNT
0030 537F        89        ANL   A,#7FH
0032 AB          90        MOV   BCOUNT,A
0033 043F        91        JMP   SEXIT
                 92                     ;       ELSE
                 93                     ;       DO;
                 94                     ;          CALL INIT;
                 95                     ;       END;
0035 1441        96 SLLD:  CALL INIT
                 97                     ;    ELSE
                 98                     ;    DO;
                 99                     ;       TIMER=P/2;
                100                     ;       START TIMER;
                101                     ;       BCOUNT(6)=0;
                102                     ;    END;
0037 23EC       103 SLLC:  MOV   A,#-(P/2)
0039 62         104        MOV   T,A
003A 55         105        STRT  T
003B FE         106        MOV   A,BCOUNT
003C 53BF       107        ANL   A,#0BFH
003E AE         108        MOV   BCOUNT,A
                109                     ; END;
                110                     ; /*EXIT INTERUPT MODE*/
003F FF         111 SEXIT: MOV   A,ATEMP
0040 93         112        RETR
                113
                114 ; ----------------------------
                115 ; INTIALIZE ROUTINE-
                116 ;       STARTS RECEIVE PROCESS
                117 ; ----------------------------
                118
                119                     ; INIT:
                120                     ;    PROCEDURE;
                121                     ;       DO;
                122                     ;          DISABLE INTERRUPTS;
                123                     ;          P27=1;
                124                     ;          TIMER=-1;
                125                     ;          START EVENT COUNT;
                126                     ;          RDF=1;
                127                     ;          BCOUNT=0C0H OR BITNO
                128                     ;       END;
                129                     ;    END INIT;
0041 35         130 INIT:  DIS   TCNTI
0042 8A80       131        ORL   P2,#80H
0044 23FF       132        MOV   A,#-1
0046 62         133        MOV   T,A
0047 45         134        STRT  CNT
0048 B824       135        MOV   RX0,#RDF
004A B001       136        MOV   @RX0,#01H
004C B81E       137        MOV   RX0,#1EH      ; POINT AT BCOUNT
004E B0C8       138        MOV   @RX0,#(0C0H OR BITNO)
0050 25         139        EN    TCNTI
0051 83         140        RET
                141                     ;END OF PROGRAM
                142
                143        END
```

Figure 22. Interrupt Driven Serial Receive Program

codes such as those used in synchronous data communications (e.g. BISYNC or SDLC). BCH codes, named for their originators Bose, Chaudhuri, and Hocquenghem, are characterized by having a length of $n=2^m-1$. The number of redundant check bits can be mt where t is a positive integer (clearly $mt \leq n$). The 31,26 code fits this format with m=5 and and t=1. The length of each message is $n=2^5-1=31$ with 5*1 redundant bits, leaving 26 bits available for data transmission. With an appropriate polynominal BCH codes can detect all errors consisting of 2t error bits and all burst errors of mt or fewer bits. The 31,26 BCH code will therefore detect any erroneous messages with 1 or 2 errors or bursts of errors of less than 5 bits. The 31,26 format (shown in Figure 23) requires the reception of a start bit followed by 31 information bits, clearly beyond the capability of the USART but perhaps within reach of a program controlled approach using the MCS-48 itself.

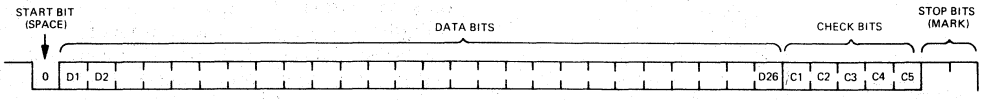


Figure 23. 31,26 BCH Code

A concept which reduces sensitivity to frequency deviations and thus allows the reception of longer codes is shown pictorially in Figure 24. The first line of this timing chart shows an alternative ones and zeros pattern on the RxD with a period of 5 milliseconds. The second line shows that by sampling at a period of exactly 5 milliseconds the data can be properly interpreted. The third and fourth lines show the effects of sampling with a period of six and four milliseconds respectively. In either case, an error occurs at the third sample where both periods result in sampling on an edge of the RxD signal. The third line of Figure 24 shows a hybrid sampling scheme which, based on some additional information, switches sampling periods between the two values. As can be seen in Figure 24, the data is sampled with a 4 millisecond period until the sampling begins to fall behind the data; at this point the sampling period is increased to six milliseconds and the sampling first catches up and then passes the center point of the data. As soon as this happens, the sampling period reverts to the 4 millisecond period and the cycle repeats. It can be seen that this scheme sets up a pattern which repeats indefinitely and the data can be successfully sampled. Note that the sampling pattern established is alternating periods of four and six milliseconds. The average period of this pattern, as might be expected, is 5msec. Line 5 of Figure 24 shows the effect of a change in transmission speed to a period of 5.5 msec with no change in the sampling time. The sampling is again successful but the new sampling pattern is 4-6-6-6; 4-6-6-6, etc. Note that the average sample is again equal to the period of the received data (5.5). While this scheme does seem to work, the question of what additional information is needed remains.

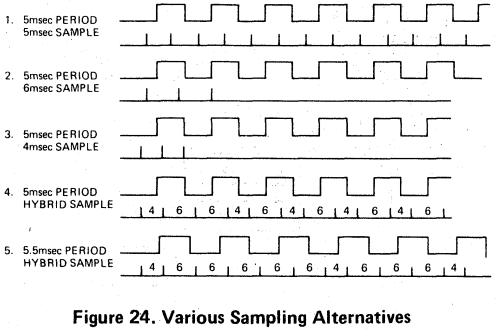


Figure 24. Various Sampling Alternatives

The MSC-48 must somehow decide when it is drifting out of synchronization and take corrective action. By referring back to Figure 24 it can be seen that if the MCS-48 could determine where the edges of RxD occurred with respect to its sampling times then the additional information would be available. As can be seen in the figure the choice of sampling period can be based on the following rule:

> *If an edge on the RxD line occurs during the first half of the current sampling period, then use the short period for the next sample. If an edge occurs during the second half of the period, then use the long sampling period for the next sample.*

If the data on the RxD line does not change, of course, the MCS-48 will drift out of synchronization just as the original algorithum did. As long as edges occur on TxD, however, synchronization can be maintained. To maximize the allowable time between edges, the following addition could be made to the above rule:

> *If no edge occurs on the RxD line during a sample, then change sampling period from short to long or vice versa.*

Note that this addition to the rule will result in using an average of the two sampling periods when no edge occurs for several bit times.

The edges of RxD can be easily detected by the use of the same structure (the Exclusive – NOR gate) which was added to the MCS-48 in Figure 20. This gate, which is used to detect the edge on RxD which begins the START bit, can naturally be used to detect any edge. Since the timer is being used to time the bit period, however, the event count input (T1) is not useful during the receive itself. By connecting the output of this gate, however, to the $\overline{\text{INT}}$ input to the MCS-48 (see Figure 25) it is possible to detect edges on RxD with the event counter when the program is trying to detect the START bit and by the external interrupt when the program is using the timer to control the sampling times.

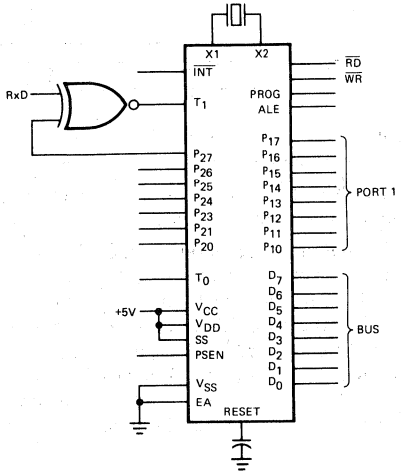
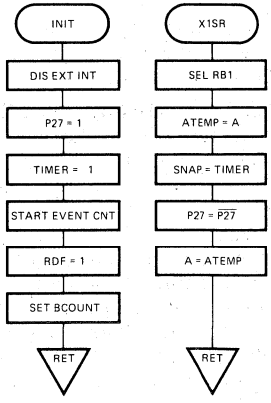


Figure 25. Modified Edge Detection

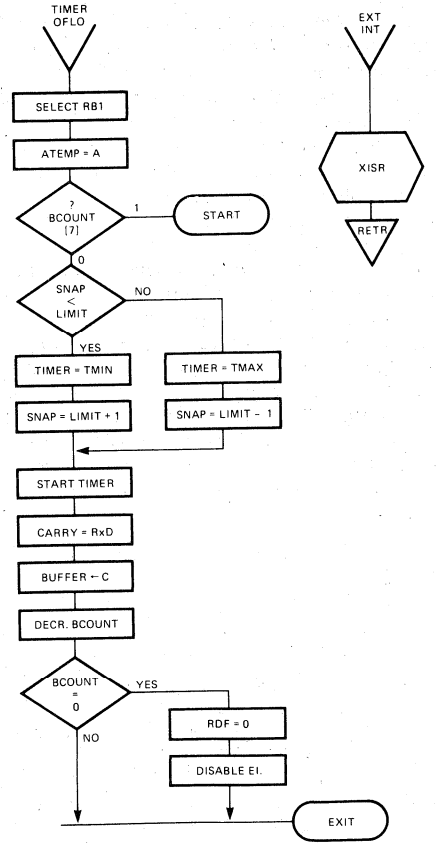
A modification to the program of Figure 21 which implements this new sampling algorithm is shown in Figure 26. The first deviation from the original program is the addition of a routine (XISR, Figure 26a which is called when an external interrupt occurs (i.e. when an edge occurs on RxD). This routine saves the status of the running program and then stores the current value of the timer register in a location called SNAP (R5 of RB1). After doing these operations the program complements bit 7 of port 2. Manipulating P27 in this manner will cause the Exclusive NOR gate to turn off the external interrupt and will set it up to generate another interrupt when the RxD line changes again (has another edge).



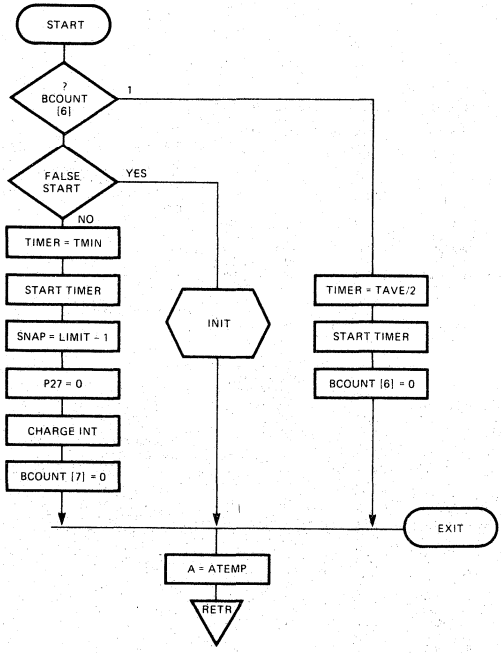
Hybrid Sampling Flowchart

Because of this edge detection it is important to condition RxD with hardware filters to ensure that the edges of RxD are clean. Any ringing will cause repeated CALLs to XISR and probable erroneous operation. The changes to the START process (Figure 26c) are two-fold; first the TIMER is set to one half the average of the two sample periods when the START bit is first detected (BCOUNT [6] = 1), and second the processing of the edge information is initialized by presetting SNAP and clearing P27.

SNAP is preset so that when the reception of data actually begins (Figure 26b BCOUNT [7] = 0), the decision block which tests SNAP against LIMIT will be initialized. This block actually compares the value in SNAP with a LIMIT value which is used to determine if the sampling point is ahead or behind the actual midpoint of the serial data. If the sampling is ahead then the timer is set for TMIN; if the sampling is behind then the timer is set for



Hybrid Sampling Flowchart



Hybrid Sampling Flowchart

TMAX. By presetting SNAP in the manner shown in the flowcharts the second rule of the algorithm, (*if no edge appears on the RxD line during a sample, then change the sampling periods short to long or vice versa*) is automatically met. If an edge occurs then XISR will modify SNAP, if XISR is not invoked between two samples then the choice of timer periods will alternate. The only other significant change to the algorithm is that the INIT routine must now lock out all interrupts, not just the timer overflow interrupt, while it is operating. A program which uses this algorithm to receive a 32 bit message is shown in Figure 27.

```
LOC  OBJ        SEQ     SOURCE STATEMENT

                  0
                  1 ; ************************************
                  2 ;
                  3 ;       SERIAL INPUT USING MCS-48
                  4 ;         THIS CODE ASSUMES HARDWARE
                  5 ;         SHOWN IN FIG 25. PROGRAM
                  6 ;         IS SIMILAR TO PREVIOUS
                  7 ;         ONE. A MORE SOPHISTICATED
                  8 ;         SAMPLING ALGORITHM IS USED
                  9 ;
                 10 ; NOTE:  A PL/M LIKE LANGUAGE WAS USED
                 11 ;        TO COMMENT THIS LISTING AND
                 12 ;        SEVERAL OTHERS IN THIS NOTE. NO
                 13 ;        COMPILER EXISTS FOR THE MCS-48.
                 14 ;        THE COMMENTS WERE 'HAND
                 15 ;        COMPILED' INTO ASSEMBLY CODE
                 16 ;;
                 17 ; ************************************
                 18
                 19 ; -------
                 20 ; EQUATES
                 21 ; -------
                 22
0007             23 ATEMP   EQU     R7      ; STORAGE FOR A DURING INTERUPT
0006             24 BCOUNT  EQU     R6      ; CONTAINS NUMBER OF BITS IN MSG
0005             25 SNAP    EQU     R5      ; TAKES TIMER SNAP SHOT ON RXD EDGE
0002             26 COUNT   EQU     R2      ; UTILITY COUNTER
0000             27 RXD     EQU     R0      ; POINTER
0020             28 BITNO   EQU     32      ; NUMBER OF BITS
0014             29 LIMIT   EQU     20      ; TEST VALUE FOR MIN/MAX SAMPLING
FFD5             30 TMAX    EQU     -43     ; MAX SAMPLE PERIOD
FFD9             31 TMIN    EQU     -39     ; MINIMUM SAMPLE PERIOD
FFEC             32 HALF    EQU     -20     ; HALF NOMINAL PERIOD
0020             33 SERBUF  EQU     20H     ; START OF SERIAL BUFFER
0024             34 RDF     EQU     24H     ; RECEIVE DONE FLAG
                 35
                 36 ; -------------------------------
                 37 ; CONTROL PASSED HERE ON EXT. INT.
                 38 ; -------------------------------
                 39
0003             40         ORG     03H
                 41                         ; CALL SERVICE ROUTINE
0003 1466        42 EIVEC:  CALL    XISR
0005 93          43         RETR
                 44
                 45 ; ---------------------------------------
                 46 ; CONTROL PASSED HERE WHEN TIMER OFLO OCCURS
                 47 ; ---------------------------------------
                 48
                 49                         ; /*ENTER INTERUPT MODE*/
0006 D5          50 TMVEC:  SEL RB1
0007 AF          51         MOV     ATEMP,A
                 52                         ; IF BCOUNT[7]=0 THEN
0008 FE          53         MOV     A,BCOUNT
0009 F236        54         JB7     START
                 55                         ; DO;
                 56                         ;   IF SNAP<LIMIT THEN
000B FD          57         MOV     A,SNAP
000C 0314        58         ADD     A,#LIMIT
000E F217        59         JB7     SLLA
                 60                         ;   DO;
                 61                         ;     TIMER=TMIN;
                 62                         ;     SNAP=LIMIT+1;
                 63                         ;   END;
0010 23D9        64         MOV     A,#TMIN
0012 62          65         MOV     T,A
0013 BD13        66         MOV     SNAP,#LIMIT-1
0015 041C        67         JMP     SLLB
                 68                         ;   ELSE
                 69                         ;   DO;
                 70                         ;     TIMER=TMAX;
                 71                         ;     SNAP=LIMIT-1;
                 72                         ;   END;
0017 23D5        73 SLLA:   MOV     A,#TMAX
```

Figure 27. Hybrid Sampling Program

```
LOC  OBJ       SEQ        SOURCE STATEMENT

0019 62          74        MOV     T,A
001A BD13        75        MOV     SNAP,#LIMIT-1
                 76                        ;       START TIMER;
001C 55          77 SLLB:  STRT    T
                 78                        ;   /*CARRY=RXD*/
                 79                        ;   CARRY=P27 XOR TEST1;
001D 8A          80        IN      A,P2
001E F7          81        RLC     A
001F 4622        82        JNT1    TISRD
0021 A7          83        CPL     C
                 84                        ;   /*SHIFT CARRY INTO BUFFER*/
                 85                        ;   RX0=SERBUF;
                 86                        ;   COUNT=4;
                 87                        ;   DO WHILE COUNT<>0;
                 88                        ;       RSHFT MEM(RX0);
                 89                        ;       RX0=RX0+1;
                 90                        ;       COUNT=COUNT-1;
                 91                        ;   END;
0022 B820        92 TISRD: MOV     RX0,#SERBUF
0024 BA04        93        MOV     COUNT,#4
0026 28          94 SLOOP  XCH     A,RX0
0027 67          95        RRC     A
0028 28          96        XCH     A,@RX0
0029 18          97        INC     RX0
002A EA26        98        DJNZ    COUNT,SLOOP
                 99                        ;   BCOUNT=BCOUNT-1;
                100                        ;   IF BCOUNT=0 THEN
002C EE54       101        DJNZ    BCOUNT,SEXIT
                102                        ;   DO;
                103                        ;       RDF=0;
                104                        ;       DISABLE EX INT;
                105                        ;   END;
002E B824       106        MOV     RX0,#RDF
0030 27         107        CLR     A
0031 A0         108        MOV     @RX0,A
0032 35         109        DIS     TCNTI
0033 15         110        DIS     I
                111                        ; END;
0034 0454       112        JMP     SEXIT
                113                        ; ELSE
                114                        ; DO;
                115                        ;   IF BCOUNT(6)=0 THEN
0036 FE         116 START: MOV     A,BCOUNT
0037 D24C       117        JB6     SLLC
                118                        ;   DO;
                119                        ;       IF TEST1=0 THEN
0039 564A       120        JT1     SLLD
                121                        ;       DO;
                122                        ;           TIMER=TMIN;
                123                        ;           START TIMER;
                124                        ;           SNAP=LIMIT+1;
                125                        ;           P27=0;
                126                        ;           EN I
                127                        ;           BCOUNT(7)=0;
                128                        ;       END;
003B 23D9       129        MOV     A,#TMIN
003D 62         130        MOV     T,A
003E 55         131        STRT    T
003F BD15       132        MOV     SNAP,#LIMIT+1
0041 9A7F       133        ANL     P2,#7FH
0043 05         134        EN      I
0044 FE         135        MOV     A,BCOUNT
0045 537F       136        ANL     A,#7FH
0047 AE         137        MOV     BCOUNT,A
0048 0454       138        JMP     SEXIT
                139                        ;       ELSE
                140                        ;       DO;
                141                        ;           CALL INIT;
                142                        ;       END;
```

```
LOC  OBJ       SEQ        SOURCE STATEMENT

004A 1456       143 SLLD:  CALL INIT
                144                        ;   ELSE
                145                        ;   DO;
                146                        ;       TIMER=(TMIN+TMAX)/2;
                147                        ;       START TIMER;
                148                        ;       BCOUNT(6)=0;
                149                        ;   END;
004C 23EC       150 SLLC:  MOV     A,#HALF
004E 62         151        MOV     T,A
004F 55         152        STRT    T
0050 FE         153        MOV     A,BCOUNT
0051 53BF       154        ANL     A,#0BFH
0053 AE         155        MOV     BCOUNT,A
                156                        ; END;
                157                        ; /*EXIT INTERUPT MODE*/
0054 FF         158 SEXIT: MOV     A,ATEMP
0055 93         159        RETR
                160
                161 ; ---------------------------
                162 ; INTIALIZE ROUTINE-
                163 ;       STARTS RECEIVE PROCESS
                164 ; ---------------------------
                165
                166                        ; INIT:
                167                        ;   PROCEDURE;
                168                        ;       DO;
                169                        ;           DISABLE INTERUPTS;
                170                        ;           P27=1;
                171                        ;           TIMER=-1;
                172                        ;           START EVENT COUNT;
                173                        ;           RDF=1;
                174                        ;           BCOUNT=0C0H OR BITNO
                175                        ;       END;
                176                        ;   END INIT;
0056 15         177 INIT:  DIS     I
0057 35         178        DIS     TCNTI
0058 8A86       179        ORL     P2,#80H
005A 23FF       180        MOV     A,#-1
005C 62         181        MOV     T,A
005D 45         182        STRT    CNT
005E B824       183        MOV     RX0,#RDF
0060 F9         184        MOV     A,@1
0061 A0         185        MOV     @RX0,A
0062 25         186        EN      TCNTI
0063 BEE0       187        MOV     BCOUNT,#0C0H OR BITNO
0065 83         188        RET
                189
                190
                191 ; ------------------------
                192 ; INTERUPT SERVICE ROUTINE
                193 ; ------------------------
                194                        ; XISR:
                195                        ;   PROCEDURE;
                196                        ;   DO;
                197                        ;       /*ENTER INTERUPT MODE*/
                198                        ;       SNAP=TIMER;
                199                        ;       P27=NOT P27;
                200                        ;   END XISR;
0066 D5         201 XISR:  SEL     RB1
0067 AF         202        MOV     ATEMP,A
0068 42         203        MOV     A,T
0069 AD         204        MOV     SNAP,A
006A 0A         205        IN      A,P2
006B D380       206        XRL     A,#80H
006D 3A         207        OUTL    P2,A
006E FF         208        MOV     A,ATEMP
006F 83         209        RET
                210                        ; END OF PROGRAM
                211        END
```

Figure 27. Hybrid Sampling Program

TRANSMITTING SERIAL CODE

Serial transmission is conceptually far simpler than serial reception since no synchronization is required. All that is required is to use the timer to generate interrupts at the bit rate and present the character to be transmitted serially at an I/O pin. A program which does this is shown in Figure 28. The transmission of serial data becomes much more complicated if it must occur simultaneously with reception.

If both reception and transmission are to occur simultaneously then obviously contention will exist for the use of the timer. It is possible to allow the simultaneous reception and transmission of serial data using the timer as a general clock which controls software maintained timers. The attainable baud rates using such techniques are, however, limited and the use of a 8251 USART is probably indicated in all but the most cost sensitive applications. An exception to this rule occurs when the system, although full duplex in nature, actually transmits the same data as it receives. An example of this is a microprocessor driving a terminal such as a Teletype. Although the circuit to the terminal is full duplex, the data that is transmitted is generally the same as that received. A minor modification to the program shown in Figure 26 would implement this mode of operation. The modification would be to the XISR routine and it would add the code necessary to place the TxD I/O pin in the same state as the RxD line. Since any change in RxD results in a call to XISR, this modification would cause the retransmission of any received data. Whenever it becomes necessary to transmit data which is not being received, the program of Figure 28 could be used in a half duplex manner.


```
LOC  OBJ        SEQ        SOURCE STATEMENT

                    0
                    1 ;--------------------------------------
                    2 ; SERIAL TRANSMIT ON THE MCS48
                    3 ;   TO USE PUT A CHAR IN BUFF AND
                    4 ;   SET CHARAV TO 0FFH. WHEN THE
                    5 ;   TRANSMITTER IS READY FOR ANOTHER
                    6 ;   CHAR IT WILL CLEAR CHARAV. THE
                    7 ;   TRANSMISSION IS DOUBLE BUFFERED.
                    8 ;--------------------------------------
                    9
                   10 ; -------
                   11 ; EQUATES
                   12 ; -------
                   13
0007               14 ATEMP   EQU     R7      ; STORAGE FOR A DURING INT.
0006               15 PTOS    EQU     R6      ; PARALLEL TO SERIAL CONVERTER
0005               16 BUFF    EQU     R5      ; CHARACTER BUFFER
0004               17 CHARAV  EQU     R4      ; CHARACTER AVAILABLE FLAG
0003               18 COUNT   EQU     R3      ; BIT COUNTER
00EF               19 CBIT    EQU     0EFH    ; MASK TO CLEAR TXD IN P24
0010               20 SBIT    EQU     10H     ; MASK TO SET TXD IN P24
FFD7               21 P       EQU     -41     ; PERIOD OF TXD
                   22
                   23 ;---------------------------------------
                   24 ; CONTROL PASSED HERE ON TIMER OVERFLOW
                   25 ;---------------------------------------
0007               26         ORG     07H
                   27                         ; ENTER INTERUPT MODE
0007 D5            28 TOFLO:  SEL     RB1
0008 AF            29         MOV     ATEMP,A
                   30                         ; SET TIMER FOR P
0009 23D7          31         MOV     A,#P
000B 62            32         MOV     T,A
000C 55            33         STRT    T
                   34                         ; GET BIT INTO CARRY
000D 141D          35         CALL    BIT
                   36                         ; SET TXD TO CARRY
```

```
LOC  OBJ        SEQ        SOURCE STATEMENT

000F 0A            37         IN      A,P2
0010 D380          38         XRL     A,#80H
0012 3A            39         OUTL    P2,A
0013 F619          40         JC      BITON
0015 9AEF          41         ANL     P2,#CBIT
0017 041B          42         JMP     EXIT
0019 8A10          43 BITON:  ORL     P2,#SBIT
001B FF            44 EXIT:   MOV     A,ATEMP
001C 93            45         RETR
                   46
                   47 ;-------------------------------
                   48 ; BIT ROUTINE
                   49 ; PICKS THE NEXT BIT TO TRANSMIT
                   50 ;-------------------------------
                   51
001D FB            52 BIT:    MOV     A,COUNT
001E C627          53         JZ      IDLE
0020 FE            54         MOV     A,PTOS
0021 67            55         RRC     A
0022 4380          56         ORL     A,#80H
0024 AE            57         MOV     PTOS,A
0025 CB            58         DEC     COUNT
0026 83            59         RET
                   60
0027 97            61 IDLE:   CLR     C
0028 FC            62         MOV     A,CHARAV
0029 962D          63         JNZ     GOTONE
002B A7            64         CPL     C
002C 83            65         RET
                   66
002D FD            67 GOTONE: MOV     A,BUFF
002E AE            68         MOV     PTOS,A
002F BB0A          69         MOV     COUNT,#10
0031 BC00          70         MOV     CHARAV,#0
0033 83            71         RET
                   72                         ; END OF PROGRAM
                   73         END
```

Figure 28. Serial Transmission

GENERATING PARITY

Many communications schemes require the generation and checking of parity. If a USART is used it can be programmed to automatically generate and check parity. If the communications is handled by software within the MCS-48™ then the program must perform parity calculations. Calculating parity is easy if one remembers what parity really means. A character has even parity if the number of one bits in it is even. A character has odd parity if it has an odd number of ones. The program segment shown in Figure 29 can be caused to calculate parity. It starts by setting a loop count to eight and

```
LOC  OBJ       SEQ        SOURCE STATEMENT

                  0
                  1
                  2 ; ************
                  3 ;
                  4 ; PARITY
                  5 ;   THIS PROGRAM GENERATES PARITY
                  6 ;   ON THE ACCUMULATOR
                  7 ;    CARRY WILL BE SET IF A HAS ODD PARITY
                  8 ;
                  9 ; ************
                 10
                 11
                 12 ; -------
                 13 ; EQUATES
                 14 ; -------
                 15
0002             16 COUNT   EQU      R2
                 17
0100             18 PAR:    ORG      100H
0100 BA08        19         MOV      COUNT,#8      ; SET LOOP COUNT
0102 97          20         CLR      C             ; INITIALIZE CARRY
                 21                                 ; FOR EACH ZERO BIT IN A
                 22                                 ; COMPLEMENT THE CARRY FLAG
0103 77          23 LOOP:   RR       A
0104 1207        24         JB0      OVER
0106 A7          25         CPL      C
                 27                                 ; END OF PROGRAM
                 28         END
```

Figure 29. Parity Generation

clearing the CARRY flag. After this initialization a loop is executed eight times. During each execution the accumulator is rotated and the least significant bit is tested. If the bit is a zero the CARRY flag is complemented, if the bit is a one no further action is taken. Since an even number of zeros implies an even number of ones for an eight bit character, after all eight loops have been accomplished the CARRY bit will be set if an odd number of ones were encountered; it will be reset if the number were even. Since the RR instruction does not involve CARRY the net result of executing this program loop is to set CARRY if parity is odd without effecting the character in the accumulator.

CONCLUSION

This Application Note has presented a very small sampling of the application techniques possible with the MCS-48™ family. The application of this new single chip computer system to tasks which have not yet yielded to the power of the microprocessor will present a fascinating challenge to the system designer.

June 1978

Keyboard/Display Scanning With Intel's MCS-48™ Microcomputers

John Wharton
Microcomputer Applications

INTRODUCTION

This application notes presents a software package for interfacing members of Intel's MCS-48™ family of single-chip microcomputers with keyboards and displays using a minimum of external components. Because of the similarity of the architectures of the various members of the family (the 8035, 8048, 8748, 8039, 8049, 8021, and 8022 microcomputers; also the 8041 and 8741 universal peripheral interfaces in the UPI-41® family), the code included here could run with minor modifications on any member of the family.

Since keyboard and display logic can be just one of several functions handled by a microprocessor, the added cost of including these functions in a system is minimal. In fact, considering the extremely low cost of standard X-Y matrix keyboards and integrated displays, their use is often more cost effective than even a handful of discrete switches and indicators. Thus, the additional flexibility of keyboard input and display output can be added to inexpensive consumer products (such as games, clocks, thermostats, tape recorders, etc.), while producing a net savings in system cost.

Since each potential application will have its own unique combination of keys and display characters, the program is written so that very little modification is needed to interface it with a wide variety of hadware configurations. In general, the only changes required are within the set of initial EQUates at the beginning of the program.

Along with the basic software for driving a multiplexed display and/or scanning and debouncing an X-Y matrix of key switches, a collection of utility subroutines is also included for implementing the most commonly used keyboard and display utility functions, such as copying simple messages onto the display or determining the encoded value of each key in the key matrix. As a result of the versatile architecture and applications-oriented instruction set of the MCS-48 family, the entire package fits into about 250 bytes of internal program ROM or EPROM, leaving the rest of the ROM space for the program to cook the perfect piece of toast, or whatever. By tailoring the software to match a known hardware configuration, or by selecting only those functions needed for a given application, the program size could be even further reduced.

Since what is being presented in this application note is a software package, rather than the usual hardware/software system design, the format of this note is somewhat different from most — it consists primarily of a long program listing reproduced in the following pages. For the most part, the listing is self-explanatory, with comments introducing each subroutine and major code segment. Some parts of this introduction are reproduced in the program listing itself, explaining the configuration of the prototype system. However, an additional bit of explanation would make the listing easier to understand, especially for those readers unfamiliar with the concept of multiplexed displays and keyboards.

In traditional digital system design, various hardware registers or counters were used to hold binary or BCD values which had to be conveyed to the user. The standard way of presenting this information was by connecting each register to a seven-segment encoder (such as the 7447) driving a single display character, as represented by Figure 1. Thus, two ICs, seven current limiting resistors, and about 45 solder joints were required for each digit of output. Consider how traditional techniques might be (mis-)applied in designing a microprocessor system: the designer could add a latch, encoder, and resistors for each digit of the display. Still another latch and decoder could be used to turn on one of the decimal points (if used). The characters displayed could only be a sequence of decimal digits. In the same vein, a large matrix of key switches could be read by installing an MSI TTL priority encoder read by an additional input port. Not only would all this use a lot of extra I/O ports and increase the system price and part count drastically, but the flexibility and reliability of the system would be greatly reduced.

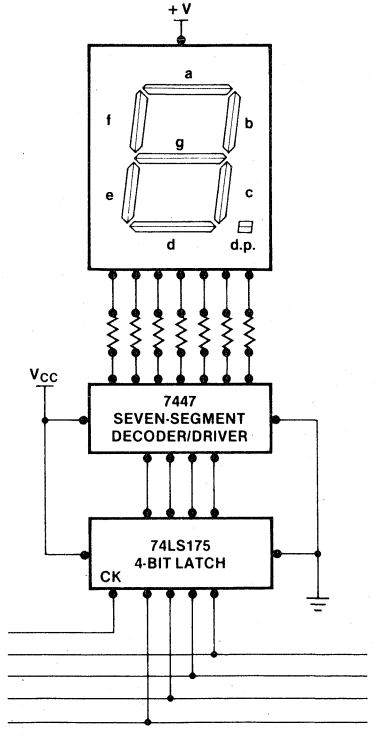


Figure 1. Wrong Way to Design Multiple Digit Displays for Microcomputer Systems

Instead, a scheme of time-multiplexing the display can be used to decrease costs, part count, and interconnections, while allowing a wider range of character types to be used on the display. The techniques used here are fairly typical of today's integrated subsystems designed especially for controlling keyboards and displays (such as in calculators or the Intel® 4269, 8278, and 8279 Keyboard/Display Controller Devices).

In a multiplexed display, all the segments of all the characters are interconnected in a regular two-dimensional array. One terminal of each segment is in common with the other segments of the same character; the other terminal is connected with the same segments of the other characters. This is represented schematically in Figure 2. A digit driver or segment driver is needed for each of these common lines.

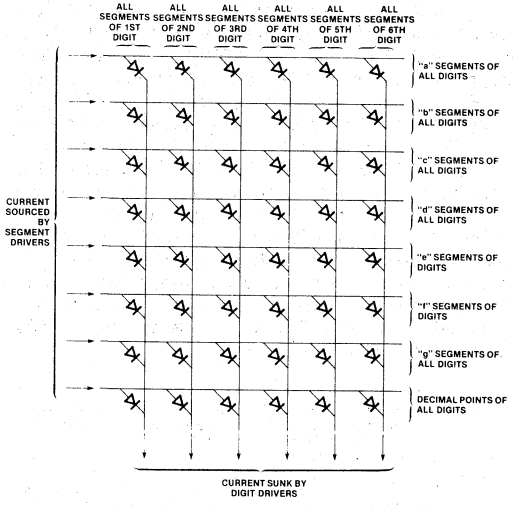


Figure 2. Schematic Representation of 6-Digit, 7-Segment Common-Cathod LED Multiplexed Display

The various characters of the display are not all on at once; rather, only one character at a time is energized. As each character is enabled, some combination of segment drivers is turned on, with the result that a digit appears on the enabled character. (For example, in Figure 3, if segment drivers 'a', 'b', and 'c' were on when character position #6 was enabled, the digit '7' would appear in the left-most place.) Each character is enabled in this way, in sequence, at a rate fast enough to ensure that the display characters seem to be on constantly, with no appearance of flashing or flickering.

In the system presented here, these rapid modifications to the display are all made under the control of the MCS-48™ microcomputer. At periodic intervals the computer quickly turns off all display segments, disables the character now being displayed and enables the next, looks up the pattern of segments for the next character to be displayed, and turns on the appropriate segments. With the next character now turned on, the processor may now resume whatever it had been doing before. The whole display updating task consumes only a small fraction of the processor's time.

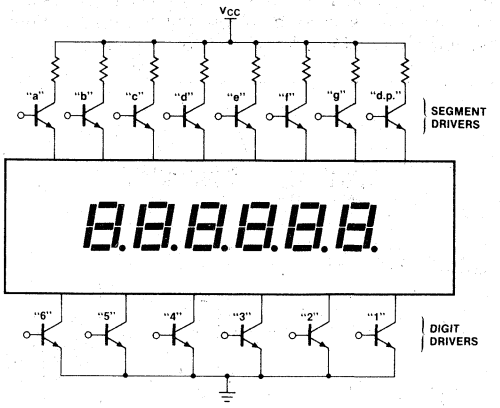


Figure 3. Segment and Digit Drivers used with 6-Position, 7-Segment LED Display

Moreover, since the computer rather than a standard decoder circuit is used to turn the segments off and on, patterns for characters other than decimal digits may be included in the display. Hexadecimal characters, special symbols, and many letters of the alphabet are possible. With sufficient imagination this feature can be exploited for some applications, as suggested by the examples in Figure 4.

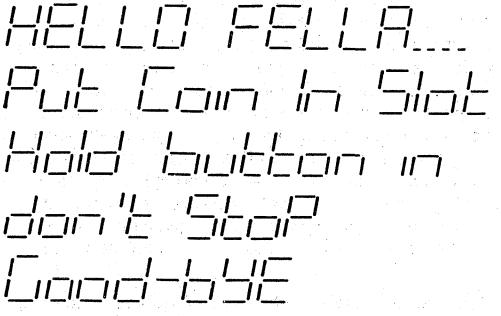


Figure 4. Examples of Typical Messages Possible with Simple 7-Segment Displays

As each character of the display is turned on, the same signal may be used to enable one row of the key matrix. Any keys in that row which are being pressed at the time will then pass the signal on to one of several "return lines", one corresponding to each column of the matrix. (See Figure 5.) By reading the state of these control lines, and knowing which row is enabled, it is possible to compute which (if any) of the keys are down. Note that the keys need not be physically arranged in a rectangular array; Figure 5 is merely a schematic.

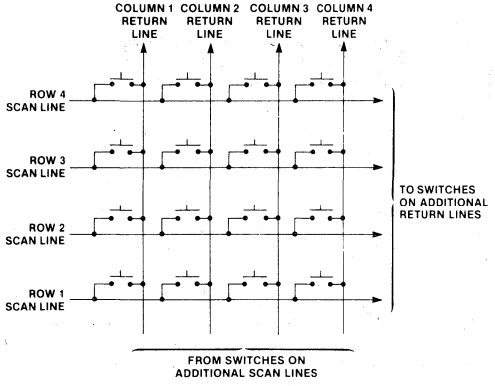


Figure 5. Schematic of X-Y Matrix Multiplexed Keyboard

Since each character is on for only a small fraction of the total display cycle, its segments must be driven with a proportionately higher current so that their brightness averages out over time. This requires character and segment drivers which can handle higher than normal levels of current. Various types of drivers can be used, ranging from specially designed circuits to integrated or discrete transistor arrays. The selection depends on several factors, including the type of display being used (LED, vacuum flourescent, neon, etc.), its size, the number of characters, and the polarity of the individual segments. Some drivers have active high inputs, some active low. Some invert their input logic levels, some do not. Some require insignificant input currents, some present a considerable load. Some systems use external logic to enable one of N characters or to produce the appropriate segment pattern for a given digit, some systems implement these functions through software.

Because of these and the other variables which make each application unique, provisions are made in the first page of symbol EQUates to allow the user to specify such things as the number of characters in the display or the polarity of the drivers used, and the program will be assembled accordingly. The display is refreshed on each timer interrupt, which occurs every 32× (TICK) machine cycles. (One machine cycle occurs every 30 crystal oscillations for the 8021 and 8022, or every 15 oscillations for all other members of the family.) A more detailed explanation of these variables is included in the listing.

Port assignment is also at the discretion of the user — all port references in the listing are "logical" rather than physical port names. The port used to specify which character is enabled is referred to as "PDIGIT". The output segment pattern is written to "PSGMNT" and the keyboard return lines are read by "PINPUT". These logical port names may be assigned to whichever ports the user pleases.

By way of example, the breadboard used to develop and debug this software used a matrix of 16 single-pole pushbuttons and an 8-character common-cathode LED display with right-hand decimal point. No decoders external to the 8748 microcomputer were used; all logic was handled through software. PDIGIT was the 8-bit bus, PSGMNT was port 1, and PINPUT was port 2. The drivers used were 75491 and 75492 logically non-inverting buffers: high level inputs were used to turn a segment or character on. Pull-up resistors were used on the 8748 output lines to source the current levels needed by the buffers. The 8748 was socketed on the breadboard, and was driven with an inexpensive 3.59 MHz television crystal. The short test program included in this listing was used to echo key depressions as they were detected, and to invoke four demonstration subroutines. A summary of the subroutines included in this listing with a short explanation of the function of each is included in Figure 6; Figure 7 shows how the various utilities interact.

KBDIN	**Keyboard Input.** Waits until one keystroke input has been received from the keyboard; determines the meaning or legend of that key, and returns with the encoded value in the accumulator.
CLEAR	Blank out the display.
ENCACC	Encode accumulator with bit pattern corresponding to the segment pattern needed by the display to represent that symbol or character. Uses the value of the accumulator when called to access a table containing the patterns for all legal input values.
WDISP	**Write into Display.** Writes the bit pattern in the accumulator into the next character position of the display. Maintains a character position counter so that repeated calls will automatically write characters into sequential positions.
RENTRY	**Right-hand Entry.** Stores the accumulator segment pattern in the display in the right-most character position. Shifts all other characters to the left one place.
PRINT	Print a string of arbitrary characters onto the display. Useful for prompting messages, warnings, etc. Uses a table of segment patterns in ROM, so that messages will not be restricted to numbers, letters, etc.
FILL	Fill the display with the character pattern in the accumulator. Useful for writing dashes, segment test patterns, etc., into all character positions.
ECHO	Wait for a key to be pressed by the operator and write that key onto the display. Used for providing feedback to the operator when entering numeric data, etc.
RDPADD	Adds or deletes a decimal point to the character at the right-hand side of the display, for entering floating point numbers.
HOLD	Called when a key is known to be down. Does not return until all keys have been released. Used for organ-type keyboards, or when some action should not be initiated until the key invoking that action has been released.
DELAY	Provides a crude real-time delay corresponding to the value of the accumulator when called. Can be used to cause display characters to blink, to momentarily flash information, to enable a buzzer, etc. Could also be used by the program when delays are needed, such as to slow down the computer reaction rate while playing a game against the human operator.

Figure 6. Utility Subroutine Definitions

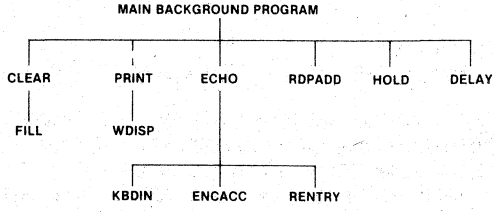


Figure 7. Subroutine Interrelationships

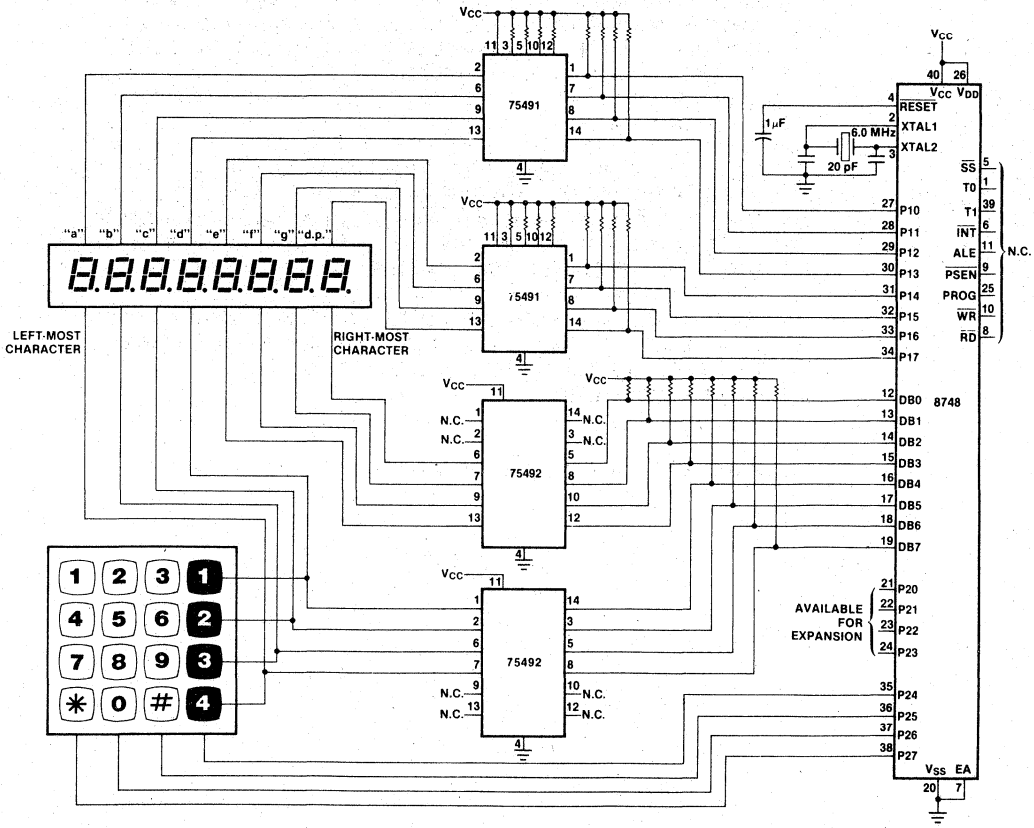


Figure 8 Prototype System Schematic

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0
AP40  INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                   1 $MACROFILE XREF
                   2 $TITLE('AP40, INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX')
                   3 ;
                   4 ;THE FOLLOWING SOFTWARE PACKAGE PROVIDES A SEVEN SEGMENT DISPLAY
                   5 ;INTERFACE FOR MICROCOMPUTERS IN THE INTEL MCS-48 FAMILY.
                   6 ;THE CODE IS WRITTEN SO THAT VARIOUS HARDWARE
                   7 ;CONFIGURATIONS CAN BE ACCOMODATED BY REDEFINING THE INITIAL VARIABLES
                   8 ;IN MOST SITUATIONS, THE KEYBOARD/DISPLAY INTERFACE WILL BE REQUIRED TO
                   9 ;IMPLEMENT MORE SOPHISTICATED SINGLE-CHIP SYSTEMS (CALCULATORS,SCALES,CLOCKS,
                  10 ;ETC.), WITH SECTIONS OF THE FOLLOWING CODE SELECTED AND MODIFIED AS NECESSARY
                  11 ;FOR EACH APPLICATION
                  12 ;
                  13 ;A SINGLE SUBROUTINE (CALLED REFRSH) IS USED TO IMPLEMENT BOTH THE DISPLAY
                  14 ;MULTIPLEXING AND KEYBOARD SCANNING. USING THE SAME SIGNAL BOTH TO ENABLE
                  15 ;ONE CHARACTER OF THE DISPLAY AND TO STROBE ONE ROW OF THE X-Y KEY MATRIX.
                  16 ;THE SUBROUTINE MUST BE CALLED SUFFICIENTLY OFTEN TO ENSURE THE DISPLAY
                  17 ;CHARACTERS DO NOT FLICKER- AT LEAST 5# COMPLETE DISPLAY SCANS PER SECOND.
                  18 ;TO ACCOMODATE SWITCHES OF ARBITRARY CHEAPNESS, THE DEBOUNCE TIME CAN BE
                  19 ;SET TO BE ANY DESIRED NUMBER OF COMPLETE SCANS.
                  20 ;THUS THE DEBOUNCE TIME IS A FUNCTION OF BOTH THE SCAN RATE AND THE VALUE
                  21 ;OF CONSTANT 'DEBNCE'.
                  22 ;
                  23 ;IN THIS LISTING, THE INTERNAL TIMER IS USED TO GENERATE INTERRUPTS THAT
                  24 ;SERVE AS A TIME BASE FOR THE REFRESH SUBROUTINE.
                  25 ;ALTERNATE TIME BASES MIGHT BE AN EXTERNAL OSCILLATOR (DRIVING THE INTERRUPT
                  26 ;PIN OR POLLED BY A TEST OR INPUT PIN), A SOFTWARE DELAY LOOP IN THE BACKGROUND
                  27 ;PROGRAM, OR PERIODIC CALLS TO THE SUBROUTINE FROM THROUGHOUT THE USER'S PROGRAM
                  28 ;AT APPROPRIATE PLACES.
                  29 ;IN THESE CASES, THE CODE STARTING AT LABEL TIINT (TIMER INTERRUPT) AND TIRET
                  30 ;(TIINT RETURN) COULD STILL BE USED TO SAVE AND RESTORE ACCUMULATOR CONTENTS
                  31 ;THE INTERRUPT SERVICING ROUTINE SELECTS REGISTER BANK 1
                  32 ;FOR THE NEEDED REGISTERS.
                  33 ;
                  34 ;
                  35 ;WRITTEN BY JOHN WHARTON, INTEL SINGLE-CHIP COMPUTER APPLICATIONS
                  36 ;
                  37 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0
AP40  INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ          SEQ          SOURCE STATEMENT

                    38 ;IN THIS IMPLEMENTATION OF THE DISPLAY SCAN, IT IS ASSUMED THAT THERE WILL
                    39 ;BE RELATIVELY LITTLE I/O OTHER THAN FOR THE KEYBOARD/DISPLAY
                    40 ;IF THIS IS THE CASE, THEN THERE IS NO NEED FOR FOR ANY ADDITIONAL EXTERNAL
                    41 ;LOGIC (SUCH AS ONE-OF-EIGHT DECODERS OR SEVEN-SEGMENT ENCODERS). THOUGH
                    42 ;THERE WILL STILL BE A NEED FOR CURRENT OR VOLTAGE DRIVERS, ACCORDING TO
                    43 ;THE TYPE OF DISPLAY BEING USED
                    44 ;
                    45 ;IN THIS LISTING, THE PROCESSOR I/O PORTS ARE LOGICALLY DIVIDED AS FOLLOWS
                    46 ;
                    47 ;PDIGIT-EIGHT BIT PORT USED TO ENABLE, ONE AT A TIME, THE INDIVIDUAL
                    48 ;       CHARACTERS OF AN EIGHT DIGIT SEVEN-SEGMENT DISPLAY, WHILE ALSO
                    49 ;       STROBING THE ROWS OF AN X-Y MATRIX KEYBOARD
                    50 ;       BIT7 ENABLES THE LEFTMOST CHARACTER AND THE BOTTOM ROW OF THE KBD.
                    51 ;       BIT4 ENABLES THE TOP ROW OF THE 4X4 KBD AND THE FOURTH CHARACTER.
                    52 ;       BIT0 ENABLES THE RIGHTMOST CHARACTER.
                    53 ;       (A 4X8 KEYBOARD COULD BE STROBED BY ALSO USING BIT3-BIT0
                    54 ;       AND EXTENDING OR ELIMINATING THE TABLE. "LEGNDS".)
                    55 ;       THE ENABLING OF ONE BIT (ACTIVE HIGH OR LOW) IS ACCOMODATED BY
                    56 ;       ACCESSING A LOOK-UP TABLE CALLED CHRSTB.
                    57 ;       THIS TECHNIQUE TAKES ABOUT FOUR BYTES MORE ROM THAN A TECHNIQUE
                    58 ;       OF ROTATING A 'ONE' THROUGH A FIELD OF 'ZEROES' IN THE ACC
                    59 ;       AN APPROPPRIATE NUMBER OF TIMES, BUT IT ALLOWS SOME ADDITIONAL
                    60 ;       FLEXABILITY: IF THE DRIVERS BEING USED HAVE A COMBINATORIAL INPUT
                    61 ;       (AS IN THE 7545X FAMILY OF HIGH-CURRENT, HIGH-VOLTAGE DRIVERS),
                    62 ;       THE CHRSTB TABLE COULD PROVIDE ENCODED OUTPUTS.  NINE DIGITS, FOR
                    63 ;       EXAMPLE, COULD BE ENABLED WITH SIX BITS OF (BUFFERED) OUTPUT:
                    64 ;       (001001,001010,001100,010001,010010,010100,100001,100010,100100)
                    65 ;       IF I/O LINES NEED TO BE CONSERVED, OR IF MANY DIGITS
                    66 ;       MUST BE DISPLAYED, AN EXTERNAL DECODER COULD BE ADDED TO THE SYSTEM.
                    67 ;       DURING CHARACTER TRANSITIONS A 'BLANK' CHARACTER IS
                    68 ;       EXPLICITLY WRITTEN TO THE DISPLAY.  THUS,
                    69 ;       THERE WILL BE NO CHARACTER 'SHADOWING' CAUSED BY THE
                    70 ;       FACT THAT THE HARDWARE OR SOFTWARE DECODER KEEPS ONE
                    71 ;       OUTPUT, AND THUS ONE CHARACTER, ACTIVE AT ALL TIMES
                    72 ;
                    73 ;PSGMNT-EIGHT BIT PORT TO ENABLE THE SEVEN SEGMENTS & D.P. OF A STANDARD
                    74 ;       DISPLAY.
                    75 ;       BIT7-BIT0 CORRESPOND TO THE DP AND SEGMENTS G THROUGH A, RESPECTIVELY.
                    76 ;       IT IS POSSIBLE TO ACCOMODATE
                    77 ;       DRIVERS WHICH ARE EITHER LOGICALLY INVERTING OR NON-INVERTING BY
                    78 ;       SETTING VARIABLE 'SEGPOL' (SEGMENT POLARITY).
                    79 ;       NOTE THAT BY HAVING ARBITRARY CONTROL OVER EACH SEGMENT, NON-NUMERIC
                    80 ;       CHARACTERS CAN BE REPRESENTED ON A SEVEN SEGMENT DISPLAY,
                    81 ;       AS SHOWN IN EXAMPLE SUBROUTINE 'TEST2'.
                    82 ;
                    83 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ          SEQ         SOURCE STATEMENT

                    84 ;PINPUT-FOUR HIGH-ORDER BITS USED AS INPUTS FROM THE KEYBOARD RETURN LINES
                    85 ;       ASSUMES THAT A KEY DOWN IN THE CURRENTLY ENABLED ROW WOULD RETURN
                    86 ;       A LOW LEVEL.
                    87 ;       IN THIS CASE, BIT7 RETURNS THE LEFTMOST COLUMN, BIT4 THE RIGHTMOST.
                    88 ;       THE HIGH-ORDER BITS ARE USED SO THAT IF AN OFF-CHIP DECODER IS USED
                    89 ;       TO ENABLE UP TO 16 CHARACTERS, FOR EXAMPLE, IT COULD BE DRIVEN BY
                    90 ;       THE LOW ORDER BITS OF THE SAME PORT.
                    91 ;       NOTE ALSO THAT IF A SIXTEEN KEY MATRIX WERE ELECTRICALLY ORGANIZED
                    92 ;       IN A 2X8 ARRAY, ONLY TWO RETURN LINES WOULD BE NEEDED.
                    93 ;       (IN THIS CASE, PERHAPS T0 AND T1 COULD BE USED FOR INPUT BITS.)
                    94 ;
                    95 ;PULL-UP RESISTORS ON THE RETURN LINES MIGHT BE IN ORDER IF THERE IS ANY
                    96 ;POSSIBILITY OF A HIGH-IMPEDENCE CONDUCTIVE PATH THROUGH THE SWITCH WHEN
                    97 ;IT IS SUPPOSED TO BE 'OPEN'.
                    98 ;(THIS PHENOMENON HAS ACTUALLY BEEN OBSERVED.)
                    99 ;
                   100 ;THE DRIVERS USED IN THE PROTOTYPE WERE ALL NON-INVERTING IN THAT
                   101 ;A HIGH LEVEL ON AN OUTPUT LINE IS USED TO TURN A CHARACTER OR SEGMENT ON.
                   102 ;THERE ARE A TOTAL OF SEVEN I/O LINES LEFT OVER.
                   103 ;
                   104 ;THE ALGORITHM FOR DRIVING THE DISPLAY USES A BLOCK OF INTERNAL RAM
                   105 ;AS DISPLAY REGISTERS, WITH ONE BYTE CORRESPONDING TO EACH CHARACTER OF THE
                   106 ;DISPLAY.  THE EIGHT BITS OF EACH BYTE CORRESPOND TO THE SEVEN SEGMENTS & DP
                   107 ;OF EACH CHARACTER.  IF AN EXTERNAL ENCODER IS USED (SUCH AS A FOUR-BIT TO
                   108 ;SEVEN-SEGMENT ENCODER OR A ROM FOR TRANSLATING ASCII TO
                   109 ;SIXTEEN-SEGMENT "STARBURST" DISPLAY PATTERNS), THE TABLE ENTRIES WOULD HOLD
                   110 ;THE CHARACTER CODES.  (IN THE FORMER CASE, AN UNUSED BIT COULD BE USED TO
                   111 ;ENABLE THE D.P.)
                   112 ;THUS, WRITING CHARACTERS TO THE DISPLAY FROM THE BACKGROUND PROGRAM
                   113 ;REALLY ENTAILS WRITING THE APPROPRIATE SEGMENT
                   114 ;PATTERNS TO A DISPLAY REGISTER- THE ACTUAL OUTPUTTING IS AUTOMATIC.
                   115 ;THE LEFTMOST CHARACTER CORRESPONDS TO THE LAST BYTE OF THE DISPLAY
                   116 ;REGISTERS, AND IS ACCESSED BY NEXTPL=8 (SEE SOURCE); THE RIGHTMOST
                   117 ;CHARACTER IS THE FIRST DISPLAY BYTE, WHEN NEXTPL=1.
                   118 ;UTILITY SUBROUTINES ARE INCLUDED HERE TO TRANSLATE FOUR BIT NUMBERS TO HEX
                   119 ;DIGIT PATTERNS, AND WRITE THEM INTO THE DISPLAY REGISTERS SEQUENTIALLY
                   120 ;(EITHER FILLING FROM THE LEFT- H.P. CALCULATOR STYLE OR FROM THE
                   121 ;RIGHT- T.I. STYLE, SUBROUTINES WDISP AND RENTRY, RESPECTIVELY).
                   122 ;
                   123 ;THE KEYBOARD SCANNING ALGORITHM SHOWN HERE REQUIRES A KEY BE DOWN FOR
                   124 ;SOME NUMBER OF COMPLETE DISPLAY SCANS TO BE ACKNOWLEGED.  SINCE IT IS
                   125 ;INTENDED FOR 'ONE-FINGER' OPERATION, TWO-KEY ROLLOVER/N-KEY LOCKOUT HAS
                   126 ;BEEN IMPLEMENTED.  HOWEVER, MODIFICATIONS WOULD BE POSSIBLE TO ALLOW, FOR
                   127 ;EXAMPLE, ONE KEY IN THE MATRIX TO BE USED AS A SHIFT KEY OR CONTROL KEY
                   128 ;TO BE HELD DOWN WHILE ANOTHER KEY IN THE MATRIX IS PRESSED.  (SEE NOTE WITHIN
                   129 ;THE BODY OF THE LISTING.)
                   130 ;
                   131 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE    4
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                  132 ;(BE AWARE THAT NO MORE THAN TWO KEYS CAN EVER BE DOWN UNLESS DIODES
                  133 ;ARE PLACED IN SERIES WITH ALL OF THE SWITCHES- CERTAINLY NOT THE CASE FOR EL
                  134 ;CHEAPO KEYBOARDS- BECAUSE SOME COMBINATIONS OF THREE KEYS DOWN WILL RESULT
                  135 ;IN A 'PHANTOM' FOURTH KEY BEING PERCEIVED
                  136 ;THE PHANTOM KEY WOULD BE THE FOURTH 'CORNER' WHEN THREE KEYS FORMING
                  137 ;A RECTANGULAR PATTERN (IN THE X-Y KEY MATRIX) ARE DOWN.)
                  138 ;IF DIODES ARE PLACED IN THE SCANNING ARRAY, CONSIDERATIONS MUST BE MADE
                  139 ;ABOUT HOW THE DIODE VOLTAGE DROP WILL AFFECT INPUT LOGIC LEVELS.
                  140 ;
                  141 ;WHEN A DEBOUNCED KEY IS DETECTED, THE NUMBER OF ITS POSITION IN THE KEY
                  142 ;MATRIX (LEFT-TO-RIGHT, BOTTOM-TO-TOP, STARTING FROM 00) IS PLACED INTO
                  143 ;RAM LOCATION 'KBDBUF'.  AN INPUT SUBROUTINE THEN NEED ONLY READ THIS LOCATION
                  144 ;REPEATEDLY TO DETERMINE WHEN A KEY HAS BEEN PRESSED.  WHEN A KEY IS DETECTED,
                  145 ;A SPECIAL CODE BYTE SHOULD BE WRITTEN BACK TO INTO 'KBDBUF' TO PREVENT
                  146 ;REPEATED DETECTIONS OF THE SAME KEY.
                  147 ;THE ROUTINE 'KBDIN' DEMONSTRATES A TYPICAL INPUT PROTOCOL, ALONG WITH A METHOD
                  148 ;FOR TRANSLATING A KEY POSITION TO ITS ASSOCIATED SIGNIFICANCE BY ACCESSING
                  149 ;TABLE 'LEGNDS' IN ROM.
                  150 ;
                  151 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE    5
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                  152 ;*******************************************************
                  153 ;
                  154 ;       INITIAL EQUATES TO DEFINE SYSTEM CONFIGURATION
                  155 ;
                  156 ;*******************************************************
                  157 ;
0010              158 PDIGIT  EQU     BUS     ;USED TO ENABLE CHARACTERS AND STROBE ROWS OF KEYBOARD
0008              159 PSGMNT  EQU     P1      ;USED TO TURN ON SEGMENTS OF CURRENTLY ENABLED DIGIT
0009              160 PINPUT  EQU     P2      ;PORT USED TO SCAN FOR KEY CLOSURES
                  161                         ;(NOTE THAT THIS PORT ALLOCATION USES THE HIGHER
                  162                         ;CURRENT SOURCING ABILITY OF THE BUS TO SWITCH ON THE
                  163                         ;DIGIT DRIVERS, AND LEAVES P23-P20 FREE FOR USING
                  164                         ;AN 8243 PORT EXPANDER IN THE SYSTEM.)
                  165 ;
0000              166 POSLOG  EQU     00H
00FF              167 NEGLOG  EQU     0FFH
                  168 ;
0000              169 CHRPOL  EQU     POSLOG  ;DEFINES WHETHER OUTPUT LINES ARE ACTIVE HI OR LOW
0000              170 SEGPOL  EQU     POSLOG  ;FOR DRIVING CHARACTERS AND SEGMENT PATTERNS
00F0              171 INPMSK  EQU     0F0H    ;DEFINES BITS USED AS INPUT
                  172 ;
0008              173 CHARNO  EQU     8       ;NUMBER OF DIGITS IN DISPLAY
0004              174 NROWS   EQU     4       ;ROWS OF KEYS (LESS THAN OR EQUAL TO CHARNO)
0004              175 NCOLS   EQU     4       ;LESSER DIMENSION OF KEYBOARD MATRIX
                  176 ;
FFF0              177 TICK    EQU     -10H    ;DETERMINES INTERRUPT INTERVAL
0004              178 DEBNCE  EQU     4       ;NUMBER OF SUCESSIVE SCANS BEFORE KEY CLOSURE ACCEPTED
0000              179 BLANK   EQU     00H     ;CODE TO BLANK DISPLAY CHARACTERS.
                  180                         ;(WOULD BE 20H IF ASCII DECODING ROM USED OR 0FH IF
                  181                         ;7447-TYPE SEVEN-SEGMENT DECODER EXTERNAL TO 8748)
                  182 ;
000F              183 ENCMSK  EQU     0FH     ;SELECTS WHICH BITS ARE RELEVANT TO ENCACC SUBROUTINE
                  184 ;
                  185 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0              PAGE    6
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                  186 ;*********************************************************
                  187 ;
                  188 ;       BANK 0 REGISTERS USED
                  189 ;
                  190 ;POINTERS USED FOR INDIRECT RAM ACCESSING:
 0000             191 PNTR0   EQU     R0
 0001             192 PNTR1   EQU     R1
 0007             193 NEXTPL  EQU     R7      ;USED TO KEEP TRACK OF CHARACTER POSITION BEING
                  194                         ;WRITTEN INTO
                  195 ;
                  196 ;*********************************************************
                  197 ;
                  198 ;       BANK 1 REGISTER ALLOCATION
                  199 ;
                  200 ;PNTR0  EQU     R0      (ALREADY DEFINED)
                  201 ;PNTR1  EQU     R1
 0002             202 ASAVE   EQU     R2      ;HOLDS ACCUMULATOR VALUE DURING SERVICE ROUTINE
 0004             203 ROTPAT  EQU     R4      ;USED TO HOLD INPUT PATTERN BEING ROTATED THROUGH CY
 0005             204 ROTCNT  EQU     R5      ;COUNTS NUMBER OF BITS ROTATED THROUGH CY
 0006             205 LASTKY  EQU     R6      ;HOLDS KEY POSITION OF LAST KEY DEPRESSION DETECTED
 0007             206 CURDIG  EQU     R7      ;HOLDS POSITION OF NEXT CHARACTER TO BE DISPLAYED
                  207 ;
                  208 ;*********************************************************
                  209 ;
                  210 ;       DATA RAM ALLOCATION
                  211 ;
 0020             212 NREPTS  EQU     32      ;KEEPS TRACK OF SUCCESSIVE READS OF SAME KEYSTROKE
 0021             213 KEYLOC  EQU     33      ;INCREMENTED AS SUCCESSIVE KEY LOCATIONS SCANNED
 0022             214 KBDBUF  EQU     34      ;CARRIES POSITION OF DEBOUNCED KEY FROM REFRSH ROUTINE
                  215                         ;\ BACK TO BACKGROUND PROGRAM
 0023             216 RDELAY  EQU     35      ;NON-ZERO WHEN DISPLAY IN PROGRESS
                  217 ;
                  218 ;       THE LAST <CHARNO> REGISTERS HOLD THE DISPLAY SEGMENT PATTERNS
                  219 ;
 0037             220 SEGMAP  EQU     (63-CHARNO)     ;BASE OF REGISTER ARRAY FOR DISPLAY PATTERNS
                  221                                 ;\ (COULD BE ANYWHERE IN INTERNAL RAM)
                  222 ;
                  223 ;*********************************************************
                  224 ;
                  225 ;       NOTE THAT LASTKY, CURDIG, AND F1 RETAIN STATUS INFORMATION FROM
                  226 ;       ONE INTERRUPT TO THE NEXT.  ALL OTHER REGISTERS MAY BE USED IN
                  227 ;       THE USER'S OWN INTERRUPT SERVICING ROUTINE
                  228 ;
                  229 ;*********************************************************
                  230 ;
                  231 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE    7
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                  232 ;
                  233 ;*********************************************************
                  234 ;
 0000             235 ORG     000H
 0000 0460        236         JMP     INIT
                  237 ;
                  238 ;
                  239 ;*********************************************************
                  240 ;
 0007             241 ORG     007H
                  242 ;
                  243 ;TIINT  TIMER INTERRUPT SUBROUTINE
                  244 ;       CALL MADE TO LOC 007H WHEN TIMER TIMES OUT.
                  245 ;       TIMER CAN BE RE-INITIALLIZED AT THIS POINT IF DESIRED.
                  246 ;       USED HERE TO CAUSE THE DISPLAY REFRESH AND KEY SCAN ROUTINES TO
                  247 ;       BE CALLED PERIODICALLY.
 0007 D5          248 TIINT:  SEL     RB1
 0008 AA          249         MOV     ASAVE,A
 0009 23F0        250         MOV     A,#TICK
 000B 62          251         MOV     T,A             ;RELOAD TIMER INTERVAL
                  252 ;
                  253 ;*********************************************************
                  254 ;
                  255 ;       THE USER'S OWN TIMER INTERRUPT ROUTINE (IF IT EXISTS) COULD
                  256 ;       BE PLACED AT THIS POINT
                  257 ;
                  258 ;*********************************************************
                  259 ;
 000C 1410        260         CALL    REFRSH          ;CAUSE DISPLAY TO BE UPDATED
                  261 ;
                  262 ;       THE COMPLETE INTERRUPT ROUTINE SHOULD BE COPIED HERE
                  263 ;       TO SAVE A FULL LEVEL OF SUBROUTINE NESTING.
                  264 ;       IT WAS WRITTEN AS A SUBROUTINE HERE FOR THE SAKE OF CLARITY.
                  265 ;
                  266 ;*********************************************************
                  267 ;
                  268 ;TIRET  TIMER INTERRUPT RETURN CODE- RESTORES ACC VALUE
 000E FA          269 TIRET:  MOV     A,ASAVE
 000F 93          270         RETR
                  271 ;
                  272 $EJECT
```

```
ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE    8
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                  273 ;*********************************************************
                  274 ;REFRSH SUBROUTINE TO MULTIPLEX SEVEN-SEGMENT DISPLAYS
                  275 ;       EACH CALL CAUSES THE NEXT CHARACTER TO BE DISPLAYED,
                  276 ;       ACCORDING TO THE CONTENTS OF THE SEGMAP REGISTER ARRAY.
                  277 ;       REFRSH SHOULD BE CALLED AT LEAST EVERY MSEC OR SO.
                  278 ;*********************************************************
                  279 ;
0010 2300         280 REFRSH: MOV     A,#BLANK XOR SEGPOL
0012 39           281         OUTL    PSGMNT,A        ;WRITE BLANK PATTERN TO SEG DRIVERS
0013 2357         282 REFR1:  MOV     A,#CHRSTB       ;LOOK UP DIGIT ENABLE PATTERN
0015 6F           283         ADD     A,CURDIG        ;ADD CURDIG DISPLACEMENT
0016 A3           284         MOVP    A,@A            ;ENABLE ONE BIT OF ACCUMULATOR
0017 02           285         OUTL    PDIGIT,A        ;ENERGIZE CHARACTER
                  286 ;
                  287                                 ;WRITE NEXT SEGMENT PATTERN
0018 2337         288         MOV     A,#SEGMAP       ;LOAD BASE OF REGISTER ARRAY
001A 6F           289         ADD     A,CURDIG        ;ADD CURDIG DISPLACMENT
001B A9           290         MOV     PNTR1,A
001C F1           291         MOV     A,@PNTR1        ;LOAD ACC W/ NEXT SEGMENT PATTERN
001D 39           292         OUTL    PSGMNT,A        ;ENABLE APPROPRIATE SEGMENTS
                  293 ;
                  294 ;*********************************************************
                  295 ;       THE NEXT CHARACTER IS NOW BEING DISPLAYED.
                  296 ;       THE KEYBOARD SCAN ROUTINE IS INTEGRATED INTO THE DISPLAY SCAN.
                  297 ;       WITH THE CURRENT ROW ENERGIZED, CHECK IF THERE ARE ANY INPUTS.
                  298 ;*********************************************************
                  299 ;
001E B821         300 SCAN:   MOV     PNTR0,#KEYLOC   ;SET POINTER FOR SEVERAL KEYLOC REFERENCES
0020 0A           301         IN      A,PINPUT        ;LOAD ANY SWITCH CLOSURES
                  302 ;
                  303 ;#########################################################################
                  304 ;##     THIS BLOCK OF CODE IS NOT NEEDED BY THE KEYBOARD SCAN LOGIC.    ###
                  305 ;##     HOWEVER, ITS INCLUSION WOULD SPEED THINGS UP A BIT BY          ###
                  306 ;##     SKIPPING OVER ROWS IN WHICH NO KEYS ARE DOWN.                  ###
                  307 ;##     IT WAS OMITTED HERE TO CONSERVE ROM SPACE, BUT MIGHT BE        ###
                  308 ;##     RESTORED IF VERY LARGE KEYBOARDS (ESPECIALLY THOSE WITH EIGHT  ###
                  309 ;##     KEYS PER ROW) ARE TO BE USED WITH THIS ALGORITHM.              ###
                  310 ;#########################################################################
                  311 ;##     CPL     A               ;ANY CLOSURES DETECTED ARE NOW ONE BITS ###
                  312 ;##     ANL     A,#INPMSK                                              ###
                  313 ;##     JNZ     SCAN1   ;-IF A KEY IN THE CURRENTLY ENABLED ROW IS DOWN ###
                  314 ;##;    NO KEY IS NOW DOWN SO THE KEYLOC COUNT MAY BE UPDATED DIRECTLY  ###
                  315 ;##     MOV     A,@PNTR0                                               ###
                  316 ;##     ADD     A,#NCOLS                                               ###
                  317 ;##     MOV     @PNTR0,A                                               ###
                  318 ;##     JMP     SCAN6                                                  ###
                  319 ;#########################################################################
                  320 ;##     IF THIS CODE IS USED, SUBSTITUTE THE 'JC  SCAN5' FOUR LINES    ###
                  321 ;##     HENCE WITH 'JNC  SCAN5' TO ACCOMODATE THE INVERTED POLARITY    ###
                  322 ;#########################################################################
                  323 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE    9
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                 324 ;*********************************************************
                 325 ;       ROTATE BITS THROUGH THE CY WHILE INCREMENTING KEYLOC.
                 326 ;*********************************************************
                 327 ;
 0021 BD04       328 SCAN1:  MOV     ROTCNT,#NCOLS   ;SET UP FOR <NCOLS> LOOPS THROUGH 'NXTLOC'
 0023 F7         329 NXTLOC: RLC     A
 0024 AC         330         MOV     ROTPAT,A        ;SAVE SHIFTED BIT PATTERN
 0025 F63F       331         JC      SCAN5           ;ONE BIT IN CY INDICATES KEY NOT DOWN
                 332 ;
                 333 ;*********************************************************
                 334 ;
                 335 ;       AT THIS POINT IT HAS JUST BEEN DETERMINED THAT THE VALUE
                 336 ;       OF KEYLOC IS THE POSITION OF A KEY WHICH IS NOW DOWN.
                 337 ;       THE FOLLOWING CODE DEBOUNCES THE KEY, ETC.
                 338 ;       IF MODIFICATIONS TO THE KEYBOARD LOGIC, I.E. THE INCLUSION
                 339 ;       OF A SHIFT, CONTROL, OR MODE KEY IN THE KEY MATRIX ITSELF)
                 340 ;       ARE DESIRED, THEY SHOULD BE MADE AT THIS POINT, BEFORE
                 341 ;       THE DEBOUNCE LOGIC BEGINS.  FOR EXAMPLE, AT THIS POINT
                 342 ;       KEYLOC COULD BE COMPARED AGAINST THE POSITION OF THE MODE
                 343 ;       KEY, AND IF THEY MATCH SET SOME FLAG BIT AND JUMP TO
                 344 ;       LABEL 'SCAN5'.  OR, BY COMPARING KEYLOC AGAINST THE LAST
                 345 ;       KEY DEBOUNCED, IMMEDIATE TWO-KEY ROLLOVER COULD BE
                 346 ;       IMPLEMENTED.
                 347 ;
                 348 ;*********************************************************
                 349 ;
 0027 A5         350         CLR     F1              ;MARK THAT AT LEAST ONE KEY WAS DETECTED
 0028 B5         351         CPL     F1              ;\ IN THE CURRENT SCAN
                 352 ;
                 353 ;*********************************************************
                 354 ;       A KEYSTROKE WAS DETECTED FOR THE CURRENT COLUMN.  ITS
                 355 ;       POSITION IS IN REGISTER KEYLOC.  SEE IF SAME KEY SENSED LAST CYCLE.
                 356 ;*********************************************************
                 357 ;
 0029 F0         358         MOV     A,@PNTR0        ;PNTR0 STILL HOLDS #KEYLOC
 002A 2E         359         XCH     A,LASTKY
 002B DE         360         XRL     A,LASTKY
 002C B820       361         MOV     PNTR0,#NREPTS   ;PREPARE TO CHECK AND/OR MODIFY REPEAT COUNT
 002E C634       362         JZ      SCAN3
                 363 ;
                 364 $EJECT
```

```
ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE   10
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ         SEQ         SOURCE STATEMENT

                  365 ;*************************************************************
                  366 ;       A DIFFERENT KEY WAS READ ON THIS CYCLE THAN ON THE PREVIOUS CYCLE.
                  367 ;       SET NREPTS TO THE DEBOUNCE PARAMETER FOR A NEW COUNTDOWN.
                  368 ;*************************************************************
                  369 ;
 0030 B004        370         MOV     @PNTR0,#DEBNCE
 0032 043F        371         JMP     SCAN5
                  372 ;
                  373 ;*************************************************************
                  374 ;       SAME KEY WAS DETECTED AS ON PREVIOUS CYCLE
                  375 ;       LOOK AT NREPTS:  IF ALREADY ZERO, DO NOTHING.
                  376 ;       ELSE DECREMENT NREPTS.
                  377 ;       IF THIS RESULTS IN ZERO, MOVE LASTKY INTO KBDBUF
                  378 ;*************************************************************
                  379 ;
 0034 F0          380 SCAN3:  MOV     A,@PNTR0
 0035 C63F        381         JZ      SCAN5           ;IF ALREADY ZERO
 0037 07          382         DEC     A               ;INDICATE ONE MORE SUCCESIVE KEY DETECTION
 0038 A0          383         MOV     @PNTR0,A
 0039 963F        384         JNZ     SCAN5           ;IF DECREMENT DOES NOT RESULT IN ZERO
 003B FE          385         MOV     A,LASTKY
 003C B822        386         MOV     PNTR0,#KBDBUF
 003E A0          387         MOV     @PNTR0,A        ;TO MARK NEW KEY CLOSURE
                  388 ;
 003F B821        389 SCAN5:  MOV     PNTR0,#KEYLOC
 0041 10          390         INC     @PNTR0
 0042 FC          391         MOV     A,ROTPAT
 0043 ED23        392         DJNZ    ROTCNT,NXTLOC
                  393 ;
                  394 ;
 0045 EF57        395 SCAN6:  DJNZ    CURDIG,SCAN9
                  396 ;
                  397 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE   11
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                  398 ;
                  399 ;*********************************************************
                  400 ;       THE FOLLOWING CODE SEGMENT IS USED BY THE KEYBOARD SCANNING ROUTINE
                  401 ;       IT IS EXECUTED ONLY AFTER A REFRESH SEQUENCE OF ALL
                  402 ;       THE CHARACTERS IN THE DISPLAY IS COMPLETED
                  403 ;*********************************************************
                  404 ;
0047 BF08         405         MOV     CURDIG,#CHARNO
0049 B000         406         MOV     @PNTR0,#0       ;PNTR0 STILL CONTAINS #KEYLOC
004B 764F         407         JF1     SCAN8           ;JUMP IF ANY KEYS WERE DETECTED
004D BEFF         408         MOV     LASTKY,#0FFH    ;CHANGE <LASTKY> WHEN NO KEYS ARE DOWN
004F A5           409 SCAN8:  CLR     F1
                  410 ;
                  411 ;*********************************************************
                  412 ;       THE NEXT CODE SEGMENT IS THE INTERRUPT-DRIVEN PORTION OF THE 'DELAY'
                  413 ;       UTILITY.  IT DECREMENTS RAM LOCATION 'RDELAY' ONCE PER DISPLAY SCAN
                  414 ;       IF 'RDELAY' IS NOT ALREADY ZERO
                  415 ;*********************************************************
                  416 ;
0050 B923         417         MOV     PNTR1,#RDELAY
0052 F1           418         MOV     A,@PNTR1
0053 C657         419         JZ      SCAN9
0055 07           420         DEC     A
0056 A1           421         MOV     @PNTR1,A
                  422 ;
0057 83           423 SCAN9:  RET
                  424 ;
                  425 ;*********************************************************
                  426 ;
                  427 ;CHRSTB IS THE BASE FOR THE PATTERNS TO ENABLE ONE-OF-CHARNO CHARACTERS.
0057              428 CHRSTB  EQU     ($-1) AND 0FFH
0058 01           429         DB      (00000001B XOR CHRPOL)
0059 02           430         DB      (00000010B XOR CHRPOL)
005A 04           431         DB      (00000100B XOR CHRPOL)
005B 08           432         DB      (00001000B XOR CHRPOL)
005C 10           433         DB      (00010000B XOR CHRPOL)
005D 20           434         DB      (00100000B XOR CHRPOL)
005E 40           435         DB      (01000000B XOR CHRPOL)
005F 80           436         DB      (10000000B XOR CHRPOL)
                  437
                  438 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER  V2.0                PAGE   12
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                  439 ;INIT   INITIALIZES PROCESSOR REGISTERS
 0060 D5          440 INIT    SEL     RB1
 0061 BF08        441         MOV     CURDIG,#CHARNO
 0063 B822        442         MOV     PNTR0,#KBDBUF
 0065 B0FF        443         MOV     @PNTR0,#0FFH
 0067 B821        444         MOV     PNTR0,#KEYLOC
 0069 B000        445         MOV     @PNTR0,#0
 006B 23F0        446         MOV     A,#INPMSK
 006D 3A          447         OUTL    PINPUT,A        ;SET BIDIRECTIONAL INPUT LINES
 006E C5          448         SEL     RB0
 006F 149E        449         CALL    CLEAR           ;UTILITY FOR SETTING INITIAL DISPLAY REGISTERS.
 0071 A5          450         CLR     F1
 0072 23F0        451         MOV     A,#TICK         ;LOAD INTERRUPT RATE VALUE
 0074 62          452         MOV     T,A
 0075 55          453         STRT    T
 0076 25          454         EN      TCNTI           ;ENABLE TIMER INTERRUPTS
                  455 ;
                  456 ;
                  457 ;*************************************************************
                  458 ;
                  459 ;ECHO   CHECK FOR ANY NEW KEYSTROKES DETECTED
                  460 ;       TRANSLATE EACH KEYSTROKE INTO A SEGMENT PATTERN
                  461 ;       AND WRITE IT INTO THE APPROPRIATE DISPLAY REGISTER.
                  462 ;
                  463 ;*************************************************************
                  464 ;
 0077 1483        465 ECHO:   CALL    KBDIN           ;GET NEXT KEYSTROKE
 0079 B281        466         JB5     FKEY            ;JUMP IF KEY IN RIGHTHAND COLUMN
                  467 ;       SINCE THE ACC IS USED BY ENCACC AND RENTRY, ITS CONTENTS MUST
                  468 ;       BE PROCESSED OR SAVED BEFORE ENCACC IS CALLED
 007B 14BA        469         CALL    ENCACC          ;FORM APPROPRIATE SEGMENT PATTERN
 007D 14DB        470         CALL    RENTRY          ;WRITE PATTERN INTO DISPLAY REGISTERS
 007F 0477        471         JMP     ECHO            ;LOOP INDEFINITELY
                  472 ;
 0081 2400        473 FKEY:   JMP     FUNCTN          ;JUMP TO OFF-PAGE CODE TO CALL DEMO ROUTINE
                  474 ;
                  475 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0              PAGE   13
AP40, INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ          SEQ         SOURCE STATEMENT

                    476 ;*******************************************************
                    477 ;
                    478 ;       THE FOLLOWING SUBROUTINES IMPLEMENT THE UTILITIES COMMONLY USED FOR
                    479 ;       MOST KEYBOARD/DISPLAY APPLICATIONS.
                    480 ;       THEY COULD BE USED EXACTLY AS SHOWN HERE OR ADAPTED FOR SPECIAL CASES.
                    481 ;
                    482 ;*******************************************************
                    483 ;
                    484 ;KBDIN  KEYBOARD INPUT SUBROUTINE.
                    485 ;       COULD BE USED TO INTERFACE THE USER'S BACKGROUND PROGRAM WITH
                    486 ;       THE INTERRUPT DRIVEN KEYBOARD SCANNER.
                    487 ;       RETURNS ONLY AFTER A NEW KEYSTROKE HAS BEEN DETECTED AND DEBOUNCED.
                    488 ;       ENCODED VALUE OF KEY (RATHER THAN ITS POSITION IN SWITCH MATRIX) IS
                    489 ;       RETURNED IN THE ACCUMULATOR.
0083 B922           490 KBDIN:  MOV     PNTR1,#KBDBUF
0085 2380           491         MOV     A,#80H          ;KBDBUF WILL BE MARKED AS CLEAR
0087 21             492         XCH     A,@PNTR1        ;LOAD BUFFER VALUE
0088 F283           493         JB7     KBDIN
008A 038E           494         ADD     A,#LEGNDS       ;ADD BASE OF KEY ENCODING TABLE
008C A3             495         MOVP    A,@A            ;OBTAIN BYTE REPRESENTING KEY SIGNIFICANCE
008D 83             496         RET
                    497 ;
                    498 ;
                    499 ;LEGNDS IS THE BASE FOR TABLE SHOWING KEY MATRIX SIGNIFICANCE
                    500 ;       FOR THE KEYBOARD USED IN THE PROTOTYPE.
                    501 ;       KEY LAYOUT IS AS SHOWN TO THE RIGHT.
                    502 ;
                    503 ;       NOTE THAT BIT6-BIT4 MAY BE USED TO ENCODE KEY TYPE.  IN THIS CASE:
                    504 ;               BIT4 INDICATES REGULAR DECIMAL DIGITS,
                    505 ;               BIT5 INDICATES RIGHT-COLUMN FUNCTION KEYS,
                    506 ;               BIT6 INDICATES PUNCTUATION MARKS ( * AND # ).
                    507 ;
008E                508 LEGNDS: EQU     ($ AND 0FFH)    ;USE LOW ORDER BITS AS TABLE INDEX
008E 4F             509         DB      4FH
008F 10             510         DB      10H
0090 4E             511         DB      4EH
0091 28             512         DB      28H     ; PDIGIT4==>  1       2       3       <1>
0092 17             513         DB      17H
0093 18             514         DB      18H     ; PDIGIT5==>  4       5       6       <2>
0094 19             515         DB      19H
0095 24             516         DB      24H     ; PDIGIT6==>  7       8       9       <3>
0096 14             517         DB      14H
0097 15             518         DB      15H     ; PDIGIT7==>  *       0       #       <4>
0098 16             519         DB      16H
0099 22             520         DB      22H     ;             !       !       !       !
009A 11             521         DB      11H     ;             !       !       !       !
009B 12             522         DB      12H     ;             V       V       V       V
009C 13             523         DB      13H     ;           PINPUT7 PINPUT6 PINPUT5  PINPUT4
009D 21             524         DB      21H
                    525 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0              PAGE   14
AP40  INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ         SEQ         SOURCE STATEMENT

                  526 ;*********************************************************
                  527 ;
                  528 ;CLEAR  WRITES 'BLANK' CHARACTERS INTO ALL DISPLAY REGISTERS.
                  529 ;       RETURNS WITH NEXTPL SET TO LEFTMOST CHARACTER POSITION
                  530 ;FILL   WRITES SEGMENT PATTERN NOW IN ACC INTO ALL DISPLAY REGISTERS
009E 2300         531 CLEAR  MOV     A,#BLANK XOR SEGPOL
00A0 B938         532 FILL   MOV     PNTR1,#SEGMAP+1
00A2 BF08         533        MOV     NEXTPL,#CHARNO
00A4 A1           534 CLR1:  MOV     @PNTR1,A          ;STORE THE BLANK CODE
00A5 19           535        INC     PNTR1             ;POINT TO NEXT CHARACTER TO THE LEFT
00A6 EFA4         536        DJNZ    NEXTPL,CLR1
00A8 BF08         537        MOV     NEXTPL,#CHARNO
00AA 83           538        RET
                  539 ;
                  540 ;*********************************************************
                  541 ;
                  542 ;PRINT  SUBROUTINE TO COPY A STRING OF BIT PATTERNS FROM ROM TO THE
                  543 ;       DISPLAY REGISTERS.  STRING STARTS AT LOCATION POINTED TO BY PNTR0.
                  544 ;       CONTINUES UNTIL AN ESCAPE CODE (0FFH) IS REACHED.
                  545 ;       NOTE THAT THE CHARACTER STRING PUT OUT MUST BE LOCATED ON THE SAME
                  546 ;       PAGE AS THIS SUBROUTINE, SINCE SAME-PAGE MOVES ARE USED.
                  547 ;       PRINT IN TURN CALLS EITHER SUBROUTINE 'WDISP' OR 'RENTRY'
                  548 ;       TO ACTUALLY EFFECT WRITING INTO THE DISPLAY REGISTERS.
00AB F8           549 PRINT: MOV     A,PNTR0           ;LOAD NEXT CHARACTER LOCATION
00AC A3           550        MOVP    A,@A              ;LOAD BIT PATTERN INDIRECT
00AD C6B4         551        JZ      PRNT1             ;ESCAPE PATTERN
00AF 14D0         552        CALL    WDISP             ;OUTPUT TO NEXT CHARACTER POSITION
                  553 ;##    (CALL   RENTRY            INSTEAD IF MESSAGE IS TO BE RIGHT JUSTIFIED)
00B1 18           554        INC     PNTR0             ;INDEX POINTER
00B2 04AB         555        JMP     PRINT
00B4 83           556 PRNT1: RET                       ;DONE
                  557 ;
                  558 ;*********************************************************
                  559 ;
                  560 ;JOHN   ARRAY HOLDS THE BIT PATTERNS FOR THE LETTERS 'JOHN' (SEE 'TEST2')
                  561 ;       (NOTE THAT 'OHN' IS WRITTEN IN LOWER CASE LETTERS)
00B5              562 JOHN   EQU     $ AND 0FFH
00B5 1E           563        DB      00011110B XOR SEGPOL
00B6 5C           564        DB      01011100B XOR SEGPOL
00B7 74           565        DB      01110100B XOR SEGPOL
00B8 54           566        DB      01010100B XOR SEGPOL
00B9 00           567        DB      00
                  568 ;
                  569 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE   15
AP40  INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                  570 ;*********************************************************
                  571 ;
                  572 ;ENCACC ENCODES LSNIBBLE OF ACC INTO HEX BIT PATTERN INTO ACC
 00BA 530F        573 ENCACC: ANL     A,#ENCMSK
 00BC 03C0        574         ADD     A,#DGPATS
 00BE A3          575         MOVP    A,@A
 00BF 83          576         RET
                  577 ;DGPATS IS THE BASE FOR THE TABLE OF SEGMENT PATTERNS FOR THE BASIC
                  578 ;DIGITS.  HERE THE FULL HEX SET (0-F) IS INCLUDED.
                  579 ;FOR MANY USER APPLICATIONS, THE CHARACTER SET MAY BE AMENDED OR AUGMENTED
                  580 ;TO INCLUDE ADDITIONAL SPECIAL PURPOSE PATTERNS.
                  581 ;FORMAT IS      PGFEDCBA        IN STANDARD SEVEN-SEGMENT ENCODING CONVENTION
                  582 ;                               WHERE P REPRESENTS THE DECIMAL POINT
 00C0             583 DGPATS  EQU     $ AND 0FFH
 00C0 3F          584         DB      00111111B XOR SEGPOL
 00C1 06          585         DB      00000110B XOR SEGPOL
 00C2 5B          586         DB      01011011B XOR SEGPOL
 00C3 4F          587         DB      01001111B XOR SEGPOL
 00C4 66          588         DB      01100110B XOR SEGPOL
 00C5 6D          589         DB      01101101B XOR SEGPOL
 00C6 7D          590         DB      01111101B XOR SEGPOL
 00C7 07          591         DB      00000111B XOR SEGPOL
 00C8 7F          592         DB      01111111B XOR SEGPOL
 00C9 67          593         DB      01100111B XOR SEGPOL
 00CA 77          594         DB      01110111B XOR SEGPOL
 00CB 7C          595         DB      01111100B XOR SEGPOL
 00CC 39          596         DB      00111001B XOR SEGPOL
 00CD 5E          597         DB      01011110B XOR SEGPOL
 00CE 79          598         DB      01111001B XOR SEGPOL
 00CF 71          599         DB      01110001B XOR SEGPOL
                  600 ;
                  601 ;*********************************************************
                  602 ;
                  603 ;WDISP  WRITES BIT PATTERN NOW IN ACC INTO NEXT CHARACTER POSITION
                  604 ;       OF THE DISPLAY (NEXTPL).  ADJUSTS NEXTPL POINTER VALUE.
                  605 ;       RESULTS IN DISPLAY BEING FILLED LEFT TO RIGHT, THEN RESTARTING
 00D0 A9          606 WDISP:  MOV     PNTR1,A
 00D1 FF          607         MOV     A,NEXTPL
 00D2 0337        608         ADD     A,#SEGMAP
 00D4 29          609         XCH     A,PNTR1
 00D5 A1          610         MOV     @PNTR1,A
 00D6 EFDA        611         DJNZ    NEXTPL,WDISP1
 00D8 BF08        612         MOV     NEXTPL,#CHARNO
 00DA 83          613 WDISP1: RET
                  614 ;
                  615 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE   16
AP40  INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

 LOC  OBJ        SEQ        SOURCE STATEMENT

                  616 ;*********************************************************
                  617 ;
                  618 ;RENTRY SUBROUTINE TO ENTER ACC CONTENTS INTO THE RIGHTMOST DIGIT
                  619 ;       AND SHIFT EVERYTHING ELSE ONE PLACE TO THE LEFT
00DB B938         620 RENTRY: MOV     PNTR1,#SEGMAP+1
00DD BF08         621         MOV     NEXTPL,#CHARNO
00DF 21           622 RENTR1: XCH     A,@PNTR1
00E0 19           623         INC     PNTR1
00E1 EFDF         624         DJNZ    NEXTPL,RENTR1
00E3 BF08         625         MOV     NEXTPL,#CHARNO  ;POINT TO LEFTMOST CHARACTER
00E5 83           626         RET
                  627 ;
                  628 ;*********************************************************
                  629 ;
                  630 ;RDPADD TOGGLE DECIMAL POINT IN LAST CHARACTER DISPLAY CHARACTER
                  631 ;DPADD  TOGGLES DECIMAL POINT IN THE CHARACTER POINTED TO BY THE ACC
                  632 ;
00E6 2301         633 RDPADD: MOV     A,#01H          ;SET INDEX TO RIGHTMOST POSITION
00E8 0337         634 DPADD:  ADD     A,#SEGMAP       ;ACCESS DISPLAY REGISTER FOR DESIRED PLACE
00EA A9           635         MOV     PNTR1,A
00EB F1           636         MOV     A,@PNTR1
00EC D380         637         XRL     A,#80H
00EE A1           638         MOV     @PNTR1,A
00EF 83           639         RET
                  640 ;
                  641 ;*********************************************************
                  642 ;
                  643 ;HOLD   SUBROUTINE CALLED WHEN KEY IS KNOWN TO BE DOWN.
                  644 ;       WILL NOT RETURN UNTIL KEY IS RELEASED.
00F0 D5           645 HOLD:   SEL     RB1
00F1 FE           646         MOV     A,LASTKY        ;<LASTKY>=0FFH IFF NO KEYS DOWN
00F2 C5           647         SEL     RB0
00F3 37           648         CPL     A
00F4 96F0         649         JNZ     HOLD
00F6 83           650         RET
                  651 ;
                  652 ;*********************************************************
                  653 ;
                  654 ;DELAY  SUBROUTINE HANGS UP FOR THE NUMBER OF COMPLETE DISPLAY SCANS EQUAL
                  655 ;       TO THE CONTENTS OF THE ACCUMULATOR WHEN CALLED.
00F7 B923         656 DELAY:  MOV     PNTR1,#RDELAY
00F9 A1           657         MOV     @PNTR1,A
00FA F1           658 DELAY1: MOV     A,@PNTR1
00FB 96FA         659         JNZ     DELAY1
00FD 83           660         RET
                  661 $EJECT
```

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ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER V2.0            PAGE   17
AP40: INTEL MCS-48 KEYBOARD/DISPLAY APPLICATION NOTE APPENDIX

  LOC  OBJ        SEQ        SOURCE STATEMENT

  0100             662 ORG    100H
                   663 ;
                   664 ;*************************************************************
                   665 ;
                   666 ;THE CODE ON THIS PAGE IS FOR DEMONSTRATION PURPOSES ONLY-
                   667 ;I TRUELY DOUBT WHETHER ANY END USERS WOULD LIKE TO SEE A NAME
                   668 ;POPPING UP ON THEIR CALCULATOR SCREENS.
                   669 ;HOWEVER, THE CODE SHOWN HERE DOES INDICATE HOW THE UTILITY SUBROUTINES
                   670 ;INCLUDED HERE COULD BE ACCESSED.
                   671 ;THE ROUTINES THEMSELVES ARE CALLED WHEN ONE OF THE FOUR BUTTONS
                   672 ;ON THE RIGHT-HAND SIDE OF THE PROTOTYPE KEYBOARD IS PRESSED.
                   673 ;
                   674 ;*************************************************************
                   675 ;
                   676 ;FUNCTN ROUTINE TO IMPLEMENT ONE OF FOUR DEMO UTILITIES, ACCORDING
                   677 ;       TO WHICH OF THE FOUR FUNCTION KEYS WAS PRESSED
  0100 1212        678 FUNCTN: JB0    FUNCT1
  0102 320E        679         JB1    FUNCT2
  0104 520A        680         JB2    FUNCT3
                   681 ;
  0106 14E6        682 FUNCT4: CALL   RDPADD
  0108 0477        683         JMP    ECHO
                   684 ;
  010A 342E        685 FUNCT3: CALL   TEST3
  010C 0477        686         JMP    ECHO
                   687 ;
  010E 3424        688 FUNCT2: CALL   TEST2
  0110 0477        689         JMP    ECHO
                   690 ;
  0112 3416        691 FUNCT1: CALL   TEST1
  0114 0477        692         JMP    ECHO
                   693 ;
                   694 ;*************************************************************
                   695 ;
                   696 ;TEST1  CODE SEGMENT TO FILL DISPLAY REGISTERS WITH DIGITS DOWN TO '1'
  0116 BF08        697 TEST1:  MOV    NEXTPL,#CHARNO
  0118 B808        698         MOV    PNTR0,#CHARNO   ;SET FOR EIGHT LOOP REPETITIONS
  011A FF          699 TST11:  MOV    A,NEXTPL
  011B 14BA        700         CALL   ENCACC
  011D 14D0        701         CALL   WDISP
  011F E81A        702         DJNZ   PNTR0,TST11     ;COPY NEXT DIGIT INTO DISPLAY REGISTERS
  0121 BF08        703         MOV    NEXTPL,#CHARNO
  0123 83          704         RET
                   705 ;
                   706 $EJECT
```

```
ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0            PAGE   18
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  LOC  OBJ        SEQ        SOURCE STATEMENT

                   707 ;*********************************************************
                   708 ;
                   709 ;TEST2  WRITES THE SEGMENT PATTERN FOR 'JOHN' ONTO THE DISPLAY,
                   710 ;       WAITS FOR A WHILE, AND THEN CLEARS THE DISPLAY
  0124 B8B5        711 TEST2:  MOV     PNTR0,#JOHN
  0126 14AB        712         CALL    PRINT
  0128 2364        713         MOV     A,#100  ;SCAN DISPLAY FOR 100 CYCLES
  012A 14F7        714         CALL    DELAY
  012C 049E        715         JMP     CLEAR
                   716 ;
                   717 ;*********************************************************
                   718 ,
                   719 ;TEST3  SUBROUTINE TO FILL DISPLAY WITH DASHES
                   720 ;       JUMPS INTO SUBROUTINE 'CLEAR'
                   721 ;       AS SOON AS THE KEY IS RELEASED.
  012E 2340        722 TEST3:  MOV     A,#01000000B XOR SEGPOL ;PATTERN FOR '-'
  0130 14A0        723         CALL    FILL
  0132 14F0        724         CALL    HOLD
  0134 049E        725         JMP     CLEAR
                   726 ;
                   727 ;*********************************************************
                   728 ;
                   729 END

USER SYMBOLS
ASAVE  0002   BLANK  0000   CHARNO 0008   CHRPOL 0000   CHRSTB 0057   CLEAR  009E   CLR1   00A4   CURDIG 0007
DEBNCE 0004   DELAY  00F7   DELAY1 00FA   DGPATS 00C0   DPADD  00E8   ECHO   0077   ENCACC 00BA   ENCMSK 000F
FILL   00A0   FKEY   0081   FUNCT1 0112   FUNCT2 010E   FUNCT3 010A   FUNCT4 0106   FUNCTN 0100   HOLD   00F0
INIT   0060   INPMSK 00F0   JOHN   00B5   KBDBUF 0022   KBDIN  0083   KEYLOC 0021   LASTKY 0006   LEGNDS 008E
NCOLS  0004   NEGLOG 00FF   NEXTPL 0007   NPEPTS 0020   NROWS  0004   NXTLOC 0023   PDIGIT 0010   PINPUT 0009
PNTR0  0000   PNTR1  0001   POSLOG 0000   PRINT  00AB   PRNT1  00B4   PSGMNT 0008   RDELAY 0023   RDPADD 00E6
REFR1  0013   REFRSH 0010   RENTR1 00DF   RENTRY 00DB   ROTCNT 0005   ROTPAT 0004   SCAN   001E   SCAN1  0021
SCAN3  0034   SCAN5  003F   SCAN6  0045   SCAN8  004F   SCAN9  0057   SEGMAP 0037   SEGPOL 0000   TEST1  0116
TEST2  0124   TEST3  012E   TICK   FFF0   TIINT  0007   TIRET  000E   TST11  011A   WDISP  00D0   WDISP1 00DA

ASSEMBLY COMPLETE,  NO ERRORS
```

```
ISIS-II ASSEMBLER SYMBOL CROSS REFERENCE, V2.0                PAGE  1

ASAVE   202#  249   269
BLANK   179#  280   531
CHARNO  173#  220   405   441   533   537   612   621   625   697   698   703
CHRPOL  169#  429   430   431   432   433   434   435   436
CHRSTB  282   428#
CLEAR   449   531#  715   725
CLR1    534#  536
CURDIG  206#  283   289   395   405   441
DEBNCE  178#  370
DELAY   656#  714
DELAY1  658#  659
DGPATS  574   583#
DPADD   634#
ECHO    465#  471   683   686   689   692
ENCACC  469   573#  700
ENCMSK  183#  573
FILL    532#  723
FKEY    466   473#
FUNCT1  678   691#
FUNCT2  679   688#
FUNCT3  680   685#
FUNCT4  682#
FUNCTN  473   678#
HOLD    645#  649   724
INIT    236   440#
INPMSK  171#  446
JOHN    562#  711
KBDBUF  214#  386   442   490
KBDIN   465   490#  493
KEYLOC  213#  300   389   444
LASTKY  205#  359   360   385   408   646
LEGNDS  494   508#
NCOLS   175#  328
NEGLOG  167#
NEXTPL  193#  533   536   537   607   611   612   621   624   625   697   699   703
NREPTS  212#  361
NROWS   174#
NXTLOC  329#  392
PDIGIT  158#  285
PINPUT  160#  301   447
PNTR0   191#  300   358   361   370   380   383   386   387   389   390   406   442   443   444   445
        549   554   698   702   711
PNTR1   192#  290   291   417   418   421   490   492   532   534   535   606   609   610   620   622
        623   635   636   638   656   657   658
POSLOG  166#  169   170
PRINT   549#  555   712
PRNT1   551   556#
PSGMNT  159#  281   292
RDELAY  216#  417   656
RDPADD  633#  682
REFR1   282#
REFRSH  260   280#
RENTR1  622#  624
RENTRY  470   620#
```

```
ISIS-II ASSEMBLER SYMBOL CROSS REFERENCE, V2 0                PAGE  2

ROTCNT  204#  328   392
ROTPAT  203#  330   391
SCAN    300#
SCAN1   328#
SCAN3   362   380#
SCAN5   331   371   381   384   389#
SCAN6   395#
SCAN8   407   409#
SCAN9   395   419   423#
SEGMAP  220#  288   532   608   620   634
SEGPOL  170#  280   531   563   564   565   566   584   585   586   587   588   589   590   591   592
        593   594   595   596   597   598   599   722
TEST1   691   697#
TEST2   686   711#
TEST3   685   722#
TICK    177#  250   451
TIINT   248#
TIRET   269#
TST11   699#  702
WDISP   552   606#  701
WDISP1  611   613#

CROSS REFERENCE COMPLETE
```

intel

APPLICATION NOTE

AP-49

January 1979

Serial I/O and Math Utilities for the 8049 Microcomputer

Lionel Smith and Cecil Moore
Microcomputer Applications

INTRODUCTION

The Intel® MCS-48 family of microcomputers marked the first time an eight bit computer with program storage, data storage, and I/O facilities was available on a single LSI chip. The performance of the initial processors in the family (the 8748 and the 8048) has been shown to meet or exceed the requirements of most current applications of microcomputers. A new member of the family, however, has been recently introduced which promises to allow the use of the single chip microcomputer in many application areas which have previously required a multichip solution. The Intel® 8049 virtually doubles processing power available to the systems designer. Program storage has been increased from 1K bytes to 2K bytes, data storage has been increased from 64 bytes to 128 bytes, and processing speed has been increased by over 80%. (The 2.5 microsecond instruction cycle of the first members of the family has been reduced to 1.36 microseconds.)

It is obvious that this increase in performance is going to result in far more ambitious programs being written for execution in a single chip microcomputer. This article will show how several program modules can be designed using the 8049. These modules were chosen to illustrate the capability of the 8049 in frequently encountered design situations. The modules included are full duplex serial I/O, binary multiply and divide routines, binary to BCD conversions, and BCD to binary conversion. It should be noted that since the 8049 is totally software compatible with the 8748 and 8048 these routines will also be useful directly on these processors. In addition the algorithms for these programs are expressed in a program design language format which should allow them to be easily understood and extended to suit individual applications with minimal problems.

FULL DUPLEX SERIAL COMMUNICATIONS

Serial communications have always been an important facet in the application of microprocessors. Although this has been partially due to the necessity of connecting a terminal to the microprocessor based system for program generation and debug, the main impetus has been the simple fact that a large share of microprocessors find their way into end products (such as intelligent terminals) which themselves depend on serial communication. When it is necessary to add a serial link to a microprocessor such as the Intel® MCS-85 or 86 the solution is easy; the Intel® 8251A USART or 8273 SDLC chip can easily be added to provide the necessary protocol. When it is necessary to do the same thing to a single chip microcomputer, however, the situation becomes more difficult.

Some microcomputers, such as the Intel 8048 and 8049 have a complete bus interface built into them which allows the simple connection of a USART to the processor chip. Most other single chip microcomputers, although lacking such a bus, can be connected to a USART with various artificial hardware and software constructs. The difficulty with using these chips, however, is more economic than technical; these same peripheral chips which are such a bargain when coupled to a microprocessor such as the MCS-85 or 86, have a significant cost impact on a single chip microcomputer based system. The high speed of the 8049, however, makes it feasible to implement a serial link under software control with no hardware requirements beyond two of the I/O pins already resident on the microcomputer.

There are many techniques for implementing serial I/O under software control. The application note "Application Techniques for the MCS-48 Family" describes several alternatives suitable for half duplex operation. Full duplex operation is more difficult, however, since it requires the receive and transmit processes to operate concurrently. This difficulty is made more severe if it is necessary for some other process to also operate while serial communication is occurring. Scanning a keyboard and display, for example, is a common operation of single chip microcomputer based system which might have to occur concurrently with the serial receive/transmit process. The next section will describe an algorithm which implements full duplex serial communication to occur concurrently with other tasks. The design goal was to allow 2400 baud, full duplex, serial communication while utilizing no more than 50% of the available processing power of the high speed 8049 microcomputer.

The format used for most asynchronous communication is shown in Figure 1. It consists of eight data bits with a leading 'START' bit and one or more trailing 'STOP' bits. The START bit is used to establish synchronization between the receiver and transmitter. The STOP bits ensure that the receiver will be ready to synchronize itself when the next start bit occurs. Two stop bits are normally used for 110 baud communication and one stop bit for higher rates.

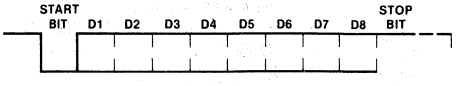


Figure 1.

The algorithm used for reception of the serial data is shown in Figure 2. It uses the on board timer of the 8049 to establish a sampling period of four times the desired baud rates. For 2400 baud operation a crystal frequency of 9.216 MHz was chosen after the following calculation:

$f = 480N(2400)(4)$

where 480 is the factor by which the crystal frequency is divided within the processor to get the basic interrupt rate
2400 is the desired baud rate
4 is the required number of samples per bit time
N is the value loaded into the MCS-48 timer when it overflows

The value N was chosen to be two (resulting in f = 9.216 MHz) so that the operating frequency of the 8049 could be as high as possible without exceeding the maximum frequency specification of the 8049 (11 MHz).

```
;
;
;START OF RECEIVE ROUTINE
;=======================
;
;1 IF RECEIVE FLAG=0 THEN
;2    IF SERIAL INPUT=SPACE THEN
;3       RECEIVE FLAG:=1
;3       BYTE FINISHED FLAG:=0
;2    ENDIF
;1 ELSE    SINCE RECEIVE FLAG=1 THEN
;2    IF SYNC FLAG=0 THEN
;3       IF SERIAL INPUT=SPACE THEN
;4          SYNC FLAG:=1
;4          DATA:=80H
;4          SAMPLE CNTR:=4
;3       ELSE    SINCE SERIAL INPUT=MARK THEN
;4          RECEIVE FLAG:=0
;3       ENDIF
;2    ELSE    SINCE SYNC FLAG=1 THEN
;3       SAMPLE COUNTER:=SAMPLE COUNTER-1
;3       IF SAMPLE COUNTER=0 THEN
;4          SAMPLE COUNTER:=4
;4          IF BYTE FINISHED FLAG=0 THEN
;5             CARRY:=SERIAL INPUT
;5             SHIFT DATA RIGHT WITH CARRY
;5             IF CARRY=1 THEN
;6                OKDATA:=DATA
;6                IF DATA READY FLAG=0 THEN
;7                   BYTE FINISHED FLAG=1
;6                ELSE
;7                   BYTE FINISHED FLAG:=1
;7                   OVERRUN FLAG:=1
;6                ENDIF
;5             ENDIF
;4          ELSE    SINCE BYTE FINISHED FLAG=1 THEN
;5             IF SERIAL INPUT=MARK THEN
;6                DATA READY FLAG:=1
;5             ELSE    SINCE SERIAL INPUT=SPACE THEN
;6                ERROR FLAG:=1
;5             ENDIF
;5             RECEIVE FLAG:=0
;5             SYNC FLAG:=0
;4          ENDIF
;3       ENDIF
;2    ENDIF
;1 ENDIF
```

Figure 2

The timer interrupt service routine always loads the timer with a constant value. In effect the timer is used to generate an independent time base of four times the required baud rate. This time base is free running and is never modified by either the receive or transmit programs, thus allowing both of them to use the same timer. Routines which do other time dependent tasks (such as scanning keyboards) can also be called periodically at some fixed multiple of this basic time unit.

The algorithm shown in Figure 2 uses this basic clock plus a handful of flags to process the serial input data. Once the meaning of these flags are understood the operation of the algorithm should be clear. The ***Receive Flag*** is set whenever the program is in the process of receiving a character. The ***Synch Flag*** is set when the center of the start bit has been checked and found to be a SPACE (if a MARK is detected at this point the receiver process has been triggered by a noise pulse so the program clears the ***Receive Flag*** and returns to the idle state). When the program detects synchronization it loads the variable ***DATA*** with 80H and starts sampling the serial line every four counts. As the data is received it is right shifted into variable ***DATA***; after eight bits have been received the initial one set into ***DATA*** will result in a carry out and the program knows that it has received all eight bits. At this point it will transfer all eight bits to the variable ***OKDATA*** and set the ***Byte Finished Flag*** so that on the next sample it will test for a valid stop bit instead of shifting in data. If this test is successful the ***Data Ready Flag*** will be set to indicate that the data is available to the main process. If the test is unsuccessful the ***Error Flag*** will be set.

The transmit algorithm is shown in Figure 3. It is executed immediately following the receive process. It is a simple program which divides the free running clock down and transmits a bit every fourth clock. The variable ***TICK COUNTER*** is used to do the division. The ***Transmitting Flag*** indicates when a character transmission is in progress and is also used to determine when the START bit should be sent. The ***TICK COUNTER*** is used to determine when to send the next bit (TICK COUNTER MODULO 4 = 0) and also when the STOP bits should be sent (TICK COUNTER = 9 4). After the transmit routine completes any other timer based routines, such as a keyboard/display scanner or a real time clock, can be executed.

```
;
;START OF TRANSMIT ROUTINE
;========================
;
;1
;1 TICK COUNTER:=TICK COUNTER+1
;1 IF TICK COUNTER MOD 4=0 THEN
;2    IF TRANSMITTING FLAG=1 THEN
;3       IF TICK COUNTER=00 1010 00 BINARY THEN
;4          TRANSMITTING FLAG:=0
;3       ELSE    IF TICK COUNTER=00 1001 00 BINARY THEN
;4          SEND END MARK
;4          TRANSMITTING FLAG:=0
;3       ELSE    SINCE TICK COUNTER<>THE ABOVE COUNT THEN
;4          SEND NEXT BIT
;3       ENDIF
;2    ELSE    SINCE TRANSMITTING FLAG=0 THEN
;3       IF TRANSMIT REQUEST FLAG=1 THEN
;4          XMTBYT:=NXTBYT
;4          TRANSMIT REQUEST FLAG:=0
;4          TRANSMITTING FLAG:=1
;4          TICK COUNTER:=0
;4          SEND SYNC BIT (SPACE)
;3       ENDIF
;2    ENDIF
;1 ENDIF
```

Figure 3

Figure 4 shows the complete receive and transmit programs as they are implemented in the instruction set of the 8049. Also included in Fig. 4 is a short routine which was used to test the algorithm.

```
ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0

LOC  OBJ        SEQ        SOURCE STATEMENT

                  1 ;*******************************************************************************
                  2 ;*                                                                             *
                  3 ;*      THIS PROGRAM TESTS THE FULL DUPLEX COMMUNICATION SOFTWARE              *
                  4 ;*                                                                             *
                  5 ;*******************************************************************************
                  6 ;
                  7 $INCLUDE(:F1:UPTEST.PDL)
                =  8 ;
                =  9 ;       START OF TEST ROUTINE
                = 10 ;       =====================
                = 11 ;
                = 12 ;
                = 13 ;
                = 14 ;
                = 15 ;
                = 16 ;1 ERROR COUNT:=0
                = 17 ;1 REPEAT
                = 18 ;2    PATTERN:=0
                = 19 ;2    INITIALIZE TIMER
                = 20 ;2    CLEAR FLAGBYTE
                = 21 ;2    FLAG1=MARK
                = 22 ;2    REPEAT
                = 23 ;3       IF TRANSMIT REQUEST FLAG=0 THEN
                = 24 ;4          NXTBYTE:=PATTERN
                = 25 ;4          TRANSMIT REQUEST FLAG=1
                = 26 ;3       ENDIF
                = 27 ;3       IF DATA READY FLAG=1 THEN
                = 28 ;4          PATTERN:=OKDATA
                = 29 ;4          DATA READY FLAG:=0
                = 30 ;3       ENDIF
                = 31 ;2    UNTIL ERROR FLAG OR OVERRUN FLAG
                = 32 ;2    INCREMENT ERROR COUNT
                = 33 ;1 UNTIL FOREVER
                = 34 ;EOF
                  35 $EJECT
0000              36         ORG     0
                  37 ;1 SELECT REGISTER BANK 0
0000 C5           38         SEL     RB0
                  39 ;1 GOTO TEST
0001 2400         40         JMP     TEST
                  41 $       INCLUDE(.F1:UART)
                =  42 ;
                =  43 ;
                =  44 ;       ASYNCHRONOUS RECEIVE/TRANSMIT ROUTINE
                =  45 ;       ====================================
                =  46 ;       THIS ROUTINE RECEIVES SERIAL CODE USING PIN T0 AS RXD
                =  47 ;       AND CONCURRENTLY TRANSMITS USING PIN P27
                =  48 ;       NOTE.
                =  49 ;           THIS ROUTINE USES FLAG 1 TO BUFFER THE TRANSMITTED
```

Figure 4

```
LOC  OBJ          SEQ        SOURCE STATEMENT

                =  50 ;1 DATA LINE.  THIS ELIMINATES THE JITTER THAT
                =  51 ;1 WOULD BE CAUSED BY VARIATIONS IN THE RECEIVE
                =  52 ;1 TIMING.  NO OTHER PROGRAM MAY USE FLAG 1 WHILE
                =  53 ;1 THE TIMER INTERRUPT IS ENABLED
                =  54 ;
                =  55 ;
                =  56 ;
                =  57 ;
                =  58 ;
                =  59 ;       REGISTER ASSIGNMENTS-BANK1
                =  60 ;       ==========================
                =  61 ;
                =  62 ;
0007            =  63 ATEMP   EQU     R7      ; USED TO SAVE ACCUMULATOR CONTENTS DURING INTERRUPT
0006            =  64 FLGBYT  EQU     R6      ; CONTAINS VARIOUS FLAGS USED TO CONTROL THE RECEIVE
                =  65                         ; AND TRANSMIT PROCESS.  SEE CONSTANT DEFINITIONS FOR
                =  66                         ; THE MEANING OF EACH BIT
0005            =  67 SAMCTR  EQU     R5      ; SAMPLE COUNTER FOR THE RECIEVE PROCESS
0004            =  68 TCKCTR  EQU     R4      ; SAMPLE COUNTER FOR THE TRANSMIT PROCESS
0000            =  69 REG0    EQU     R0      ; USED AS POINTER REGISTER
                =  70 ;
                =  71 ;       RAM ASSIGNMENTS
                =  72 ;       ===============
                =  73 ;
0020            =  74 MOKDAT  EQU     20H     ; RECEIVE RETURNS VALID DATA IN THIS BYTE
0021            =  75 MDATA   EQU     21H     ; RECEIVE ACCUMULATES DATA IN THIS BYTE
0022            =  76 MXMTBY  EQU     22H     ; CONTAINS BYTE BEING TRANSMITTED
0023            =  77 MNXTBY  EQU     23H     ; CONTAINS THE NEXT BYTE TO BE TRANSMITTED
                =  78 $EJECT
                =  79 ;
                =  80 ;
                =  81 ;       CONSTANTS
                =  82 ;       =========
                =  83 ;
                =  84 ;       THE FOLLOWING CONSTANTS ARE USED TO ACCESS THE FLAG BITS CONTAINED
                =  85 ;       IN REGISTER FLGBYT
                =  86 ;
0001            =  87 RCVFLG  EQU     01H     ; SET WHEN START BIT IS FIRST DETECTED
                =  88                         ; RESET WHEN RECEIVE PROCESS IS COMPLETE
0002            =  89 SYNFLG  EQU     02H     ; SET WHEN START BIT IS VERIFIED
                =  90                         ; RESET WHEN RECEIVE PROCESS IS COMPLETE
0004            =  91 BYFNFL  EQU     04H     ; RESET WHEN START BIT IS FIRST DETECTED
                =  92                         ; SET WHEN THE EIGHT DATA BITS HAVE ALL BEEN RECEIVED
0008            =  93 DRDYFL  EQU     08H     ; SHOULD BE RESET BY MAIN PROGRAM WHEN DATA IS ACCEPTED
                =  94                         ; SET BY RECEIVE PROCESS WHEN STOP BIT(S) ARE VERIFIED
0010            =  95 ERRFLG  EQU     10H     ; SHOULD BE RESET BY MAIN PROGRAM WHEN SAMPLED
                =  96                         ; SET BY RECEIVE PROCESS IF A FRAMING ERROR IS DETECTED
0020            =  97 TRRQFL  EQU     20H     ; TESTED BY MAIN PROGRAM TO DETERMINE IF READY TO
                =  98                         ; TRANSMIT A NEW BYTE-SET TO INDICATE THAT NXTBYT
                =  99                         ; HAS BEEN LOADED
                = 100                         ; RESET BY TRANSMIT PROCESS WHEN BYTE IS ACCEPTED
0040            = 101 TRNGFL  EQU     40H     ; SET WHEN TRANSMISSION OF A BYTE STARTS
                = 102                         ; RESET WHEN STOP BIT IS TRANSMITTED
0080            = 103 OVRUN   EQU     80H     ; SET BY RECEIVE PROCESS WHEN OVERUN OCCURRS
                = 104                         ; SHOULD BE RESET BY MAIN PROGRAM WHEN SAMPLED
```

Figure 4 (continued)

```
LOC  OBJ        SEQ         SOURCE STATEMENT

                = 105 ;
                = 106 ;       GENERAL CONSTANTS
                = 107 ;       ================
                = 108 ;
0080            = 109 MARK    EQU     80H     ; USED TO GENERATED A MARK
FF7F            = 110 SPACE   EQU     NOT 80H ; USED TO GENERATE A SPACE
0000            = 111 STPBTS  EQU     0       ; CONTROLS THE NUMBER OF STOP BITS
                = 112                         ;   0 GENERATES ONE STOP BIT
                = 113                         ;   1 GENERATES TWO STOP BITS
                = 114 ;
                = 115 $EJECT
                = 116 ;
                = 117 ;       START OF RECEIVE/TRANSMIT INTERRUPT SERVICE ROUTINE
                = 118 ;       ==================================================
                = 119 ;
0007            = 120         ORG     0007H
                = 121
                = 122 ;1 ENTER INTERRUPT MODE
0007 160A       = 123 TISR:   JTF     UART
0009 93         = 124         RETR
000A D5         = 125 UART:   SEL     RB1
                = 126 ;1 SAVE ACCUMULATOR CONTENTS
000B AF         = 127         MOV     ATEMP,A
                = 128 ;1 RELOAD TIMER
000C 23FE       = 129         MOV     A,#TIMCNT
000E 62         = 130         MOV     T,A
                = 131 ;
                = 132 ;       OUTPUT TXD BUFFER (F1) TO TXD I/O LINE (P27)
                = 133 ;       ============================================
                = 134 ;
000F 7615       = 135         JF1     OMARK
0011 9A7F       = 136 OSPACE: ANL     P2,#SPACE
0013 0417       = 137         JMP     RCV000
0015 8A80       = 138 OMARK:  ORL     P2,#MARK
                = 139 ;
                = 140 ;       START OF RECEIVE ROUTINE
                = 141 ;       ========================
                = 142 ;
                = 143 ;1 IF RECEIVE FLAG=0 THEN
0017 FE         = 144 RCV000: MOV     A,FLGBYT
0018 1224       = 145         JB0     RCV010
                = 146 ;2    IF SERIAL INPUT=SPACE THEN
001A 3664       = 147         JT0     XMIT
                = 148 ;3      RECEIVE FLAG:=1
001C FE         = 149         MOV     A,FLGBYT
001D 4301       = 150         ORL     A,#RCVFLG
                = 151 ;3      BYTE FINISHED FLAG:=0
001F 53FB       = 152         ANL     A,#NOT BYFNFL
                = 153 ;2    ENDIF
0021 AE         = 154         MOV     FLGBYT,A
0022 0464       = 155         JMP     XMIT
                = 156 ;1 ELSE    SINCE RECEIVE FLAG=1 THEN
                = 157 ;2    IF SYNC FLAG=0 THEN
0024 2238       = 158 RCV010: JB1     RCV030
                = 159 ;3      IF SERIAL INPUT=SPACE THEN
```

Figure 4 (continued)

```
LOC  OBJ        SEQ         SOURCE STATEMENT

0026 3633       = 160          JT0     RCV020
                = 161 ;4           SYNC FLAG:=1
0028 4302       = 162          ORL     A,#SYNFLG
002A AE         = 163          MOV     FLGBYT,A
                = 164 ;4           DATA:=80H
002B B821       = 165          MOV     R0,#MDATA
002D B080       = 166          MOV     @R0,#80H
                = 167 ;4           SAMPLE CNTR:=4
002F BD04       = 168          MOV     SAMCTR,#4
0031 0464       = 169          JMP     XMIT
                = 170 ;3       ELSE    SINCE SERIAL INPUT=MARK THEN
                = 171 ;4           RECEIVE FLAG:=0
0033 53FE       = 172 RCV020:  ANL     A,#NOT RCVFLG
                = 173 ;3       ENDIF
0035 AE         = 174          MOV     FLGBYT,A
0036 0464       = 175          JMP     XMIT
                = 176 ;2     ELSE    SINCE SYNC FLAG=1 THEN
                = 177 ;3       SAMPLE COUNTER:=SAMPLE COUNTER-1
0038 ED64       = 178 RCV030:  DJNZ    SAMCTR,XMIT
                = 179 ;3       IF SAMPLE COUNTER=0 THEN
                = 180 ;4           SAMPLE COUNTER:=4
003A BD04       = 181          MOV     SAMCTR,#4
                = 182 ;4           IF BYTE FINISHED FLAG=0 THEN
003C 5259       = 183          JB2     RCV050
003E 97         = 184          CLR     C
                = 185 ;5               CARRY:=SERIAL INPUT
003F 2642       = 186          JNT0    RCV040
0041 A7         = 187          CPL     C
0042 B821       = 188 RCV040:  MOV     R0,#MDATA
0044 F0         = 189          MOV     A,@R0
                = 190 ;5               SHIFT DATA RIGHT WITH CARRY
0045 67         = 191          RRC     A
0046 A0         = 192          MOV     @R0,A
                = 193 ;5               IF CARRY=1 THEN
0047 E664       = 194          JNC     XMIT
                = 195 ;6                   OKDATA:=DATA
0049 B820       = 196          MOV     R0,#MOKDAT
004B A0         = 197          MOV     @R0,A
                = 198 ;6                   IF DATA READY FLAG=0 THEN
004C FE         = 199          MOV     A,FLGBYT
004D 7254       = 200          JB3     RCV045
                = 201 ;7                       BYTE FINISHED FLAG=1
004F 4304       = 202          ORL     A,#BYFNFL
0051 AE         = 203          MOV     FLGBYT,A
0052 0464       = 204          JMP     XMIT
                = 205 ;6                   ELSE
                = 206 ;7                       BYTE FINISHED FLAG:=1
                = 207 ;7                       OVERRUN FLAG:=1
                = 208 RCV045:
                = 209          ;MOV    A,FLGBYT
0054 4384       = 210          ORL     A,#(BYFNFL OR OVRUN)
0056 AE         = 211          MOV     FLGBYT,A
                = 212 ;6               ENDIF
                = 213 ;5           ENDIF
0057 0464       = 214          JMP     XMIT
```

Figure 4 (continued)

```
LOC  OBJ        SEQ         SOURCE STATEMENT

                = 215 ;4          ELSE    SINCE BYTE FINISHED FLAG=1 THEN
                = 216 ;5             IF SERIAL INPUT=MARK THEN
0059 265F       = 217 RCV050: JNT0    RCV060
                = 218 ;6                 DATA READY FLAG:=1
005B 4308       = 219         ORL     A,#DRDYFL
005D 0461       = 220         JMP     RCV070
                = 221 ;5             ELSE    SINCE SERIAL INPUT=SPACE THEN
                = 222 ;6                 ERROR FLAG:=1
005F 4310       = 223 RCV060: ORL     A,#ERRFLG
                = 224 ;5             ENDIF
                = 225 ;5             RECEIVE FLAG:=0
                = 226 ;5             SYNC FLAG:=0
0061 53FC       = 227 RCV070: ANL     A,#NOT(SYNFLG OR RCVFLG)
0063 AE         = 228         MOV     FLGBYT,A
                = 229 ;4          ENDIF
                = 230 ;3       ENDIF
                = 231 ;2    ENDIF
                = 232 ;1 ENDIF
                = 233 $EJECT
                = 234 ;
                = 235 ;       START OF TRANSMIT ROUTINE
                = 236 ;       ========================
                = 237 ;
                = 238 ;1
                = 239         ;TRANSMITTER OUTPUT BIT IS P2-7
                = 240 ;1 TICK COUNTER:=TICK COUNTER+1
0064 1C         = 241 XMIT:   INC     TCKCTR
                = 242 ;1 IF TICK COUNTER MOD 4=0 THEN
0065 2303       = 243         MOV     A,#03H
0067 5C         = 244         ANL     A,TCKCTR
0068 9697       = 245         JNZ     RETURN
                = 246 ;2    IF TRANSMITTING FLAG=1 THEN
006A FE         = 247         MOV     A,FLGBYT
006B 37         = 248         CPL     A
006C D286       = 249         JB6     XMT040
                = 250         IF STPBTS EQ 1
                = 251 ;3       IF TICK COUNTER=00 1010 00 BINARY THEN
                = 252         MOV     A,#28H                  ; CONDITIONAL ASSEMBLY
                = 253         XRL     A,TCKCTR                ;
                = 254         JNZ     XMT010                  ;
                = 255 ;4          TRANSMITTING FLAG:=0
                = 256         MOV     A,FLGBYT                ;
                = 257         ANL     A,#NOT TRNGFL           ;
                = 258         MOV     FLGBYT,A                ;
                = 259         JMP     RETURN                  ;
                = 260         ENDIF
                = 261 ;3       ELSE    IF TICK COUNTER=00 1001 00 BINARY THEN
006E 2324       = 262 XMT010: MOV     A,#24H
0070 DC         = 263         XRL     A,TCKCTR
0071 967B       = 264         JNZ     XMT020
                = 265 ;4          SEND END MARK
0073 A5         = 266         CLR     F1      ; SET FLAG1 TO MARK
0074 B5         = 267         CPL     F1
                = 268         IF STPBTS EQ 0
                = 269 ;4          TRANSMITTING FLAG:=0
```

Figure 4 (continued)

```
LOC  OBJ        SEQ         SOURCE STATEMENT

0075 FE         = 270         MOV     A,FLGBYT                ; CONDITIONAL ASSEMBLY
0076 53BF       = 271         ANL     A,#NOT TRNGFL           ;
0078 AE         = 272         MOV     FLGBYT,A                ;
0079 0497       = 273         JMP     RETURN                  ;
                = 274         ENDIF
                = 275 ;3       ELSE    SINCE TICK COUNTER<>THE ABOVE COUNT THEN
                = 276 ;4          SEND NEXT BIT
007B B822       = 277 XMT020: MOV     R0,#MXMTBY
007D F0         = 278         MOV     A,@R0
007E 67         = 279         RRC     A
007F A0         = 280         MOV     @R0,A
0080 A5         = 281         CLR     F1      ; FLAG 1 WILL BE USED TO BUFFER TXD
0081 E697       = 282         JNC     RETURN  ; GO TO RETURN POINT IF TXD=SPACE (0)
0083 B5         = 283         CPL     F1      ; ELSE COMPLEMENT FLAG 1 TO A MARK
0084 0497       = 284         JMP     RETURN
                = 285 ;3       ENDIF
                = 286 ;2    ELSE    SINCE TRANSMITTING FLAG=0 THEN
                = 287 ;3       IF TRANSMIT REQUEST FLAG=1 THEN
0086 B297       = 288 XMT040: JB5     RETURN                  ;FLAG BYTE THERE
                = 289 ;4          XMTBYT:=NXTBYT
0088 B823       = 290         MOV     R0,#MNXTBY
008A F0         = 291         MOV     A,@R0
008B B822       = 292         MOV     R0,#MXMTBY
008D A0         = 293         MOV     @R0,A
                = 294 ;4          TRANSMIT REQUEST FLAG:=0
008E FE         = 295         MOV     A,FLGBYT
008F 53DF       = 296         ANL     A,#NOT TRRQFL
                = 297 ;4          TRANSMITTING FLAG:=1
0091 4340       = 298         ORL     A,#TRNGFL
0093 AE         = 299         MOV     FLGBYT,A
                = 300 ;4          TICK COUNTER:=0
0094 BC00       = 301         MOV     TCKCTR,#0
                = 302 ;4          SEND SYNC BIT (SPACE)
0096 A5         = 303         CLR     F1      ; SET FLAG 1 TO CAUSE A SPACE
                = 304 ;3       ENDIF
                = 305 ;2    ENDIF
                = 306 ;1 ENDIF
                = 307 RETURN:
                = 308 ;1 RESTORE ACCUMULATOR
0097 FF         = 309         MOV     A,ATEMP
0098 93         = 310         RETR
                  311 $EJECT
                  312 ;
                  313 ;       START OF TEST ROUTINE
                  314 ;       ====================
                  315 ;
0100              316         ORG     0100H
FFFE              317 TIMCNT  EQU     -2
001E              318 MFLGBY  EQU     1EH
001D              319 MSAMCT  EQU     1DH
001C              320 MTCKCT  EQU     1CH
                  321 ;
0007              322 ERRCNT  EQU     R7
0006              323 PATT    EQU     R6
                  324 ;
```

Figure 4 (continued)

```
LOC  OBJ        SEQ        SOURCE STATEMENT

                 325 ;
                 326 ;
                 327 ;1 ERROR COUNT:=0
0100 BF00        328 TEST:   MOV     ERRCNT,#0
                 329 ;1 REPEAT
                 330 TLOP:
                 331 ;2    PATTERN:=0
0102 BE00        332         MOV     PATT,#00
                 333 ;2    INITIALIZE TIMER
0104 23FE        334         MOV     A,#TIMCNT
0106 62          335         MOV     T,A
0107 55          336         STRT    T
0108 25          337         EN      TCNTI
                 338 ;2    CLEAR FLAGBYTE
0109 B81E        339         MOV     R0,#MFLGBY
010B B000        340         MOV     @R0,#0
                 341 ;2    FLAG1=MARK
010D A5          342         CLR     F1
010E B5          343         CPL     F1
                 344 ;2    REPEAT
                 345 TILOP:
                 346 ;3       IF TRANSMIT REQUEST FLAG=0 THEN
010F B81E        347         MOV     R0,#MFLGBY
0111 F0          348         MOV     A,@R0
0112 B224        349         JB5     TREC
                 350 ;4          NXTBYTE:=PATTERN
0114 B923        351         MOV     R1,#MNXTBY
0116 FE          352         MOV     A,PATT
0117 A1          353         MOV     @R1,A
                 354 ;4          TRANSMIT REQUEST FLAG=1
0118 35          355         DIS     TCNTI   ; LOCK OUT TIMER INTERRUPT
                 356                         ; SO THAT MUTUAL EXCLUSION IS MAINTHINED WHILE
                 357                         ; THE FLAG BYTE IS BEING MODIFIED
0119 F0          358         MOV     A,@R0
011A 4320        359         ORL     A,#TRR0FL
011C A0          360         MOV     @R0,A
011D 25          361         EN      TCNTI
011E 1622        362         JTF     TESTA
0120 2424        363         JMP     TREC
0122 140A        364 TESTA:  CALL    UART    ; CALL UART BECAUSE TIMER OVERFLOWED DURING LOCKOUT
                 365 ;3       ENDIF
                 366 ;3       IF DATA READY FLAG=1 THEN
                 367 TREC:
0124 F0          368         MOV     A,@R0
0125 37          369         CPL     A
0126 7238        370         JB3     TRECE
                 371 ;4          PATTERN:=OKDATA
0128 B920        372         MOV     R1,#MOKDAT
012A F1          373         MOV     A,@R1
012B AE          374         MOV     PATT,A
                 375 ;4          DATA READY FLAG:=0
012C 35          376         DIS     TCNTI   ; LOCK OUT TIMER INTERRUPT
                 377                         ; SO THAT MUTUAL EXCLUSION IS MAINTIANED WHILE
                 378                         ; THE FLAG BYTE IS BEING MODIFIED
012D F0          379         MOV     A,@R0
```

Figure 4 (continued)

```
LOC  OBJ        SEQ        SOURCE STATEMENT

012E 53F7         380          ANL     A,#NOT DRDYFL
0130 A0           381          MOV     @R0,A
0131 25           382          EN      TCNTI
0132 1636         383          JTF     TESTB
0134 2438         384          JMP     TRECE
0136 140A         385 TESTB:   CALL    UART    ; CALL UART IF TIMER OVERFLOWED DURING LOCKOUT
                  386 TRECE:
                  387 ;3        ENDIF
                  388 ;2    UNTIL ERROR FLAG OR OVERRUN FLAG
0138 F0           389          MOV     A,@R0
0139 5390         390          ANL     A,#(OVRUN OR ERRFLG)
013B C60F         391          JZ      TILOP
                  392 ;2    INCREMENT ERROR COUNT
013D 1F           393          INC     ERRCNT
                  394 ;1 UNTIL FOREVER
013E 2402         395          JMP     TLOP
                  396 ;EOF
                  397          END


USER SYMBOLS
ATEMP  0007   BYFNFL 0004   DRDYFL 0008   ERRCNT 0007   ERRFLG 0010   FLGBYT 0006   MARK   0080   MDATA  0021
MFLGBY 001E   MNXTBY 0023   MOKDAT 0020   MSAMCT 001D   MTCKCT 001C   MXMTBY 0022   OMARK  0015   OSPACE 0011
OVRUN  0080   PATT   0006   RCV000 0017   RCV010 0024   RCV020 0033   RCV030 0038   RCV040 0042   RCV045 0054
RCV050 0059   RCV060 005F   RCV070 0061   RCVFLG 0001   REG0   0000   RETURN 0097   SAMCTR 0005   SPACE  FF7F
STPBTS 0000   SYNFLG 0002   TCKCTR 0004   TEST   0100   TESTA  0122   TESTB  0136   TILOP  010F   TIMCNT FFFE
TISR   0007   TLOP   0102   TREC   0124   TRECE  0138   TRNGFL 0040   TRRQFL 0020   UART   000A   XMIT   0064
XMT010 006E   XMT020 007B   XMT040 0086


ASSEMBLY COMPLETE,  NO ERRORS
```

Figure 4 (continued)

MULTIPLY ALGORITHMS

Most microcomputer programmers have at one time or another implemented a multiply routine as part of a larger program. The usual procedure is to find an algorithm that works and modify it to work on the machine being used. There is nothing wrong with this approach. If engineers felt that they had to reinvent the wheel every time a new design is undertaken, that's probably what most of us would be doing—designing wheels. If the efficiency of the multiply algorithm, either in terms of code size or execution time is important, however, it is necessary to be reasonably familiar with the multiplication process so that appropriate optimizations for the machine being used can be made.

To understand how multiplication operates in the binary number system, consider the multiplication of two four bit operands A and B. The "ones and zeros" in A and B represent the coefficients of two polynomials. The operation A × B can be represented as the following multiplication of polynomials:

$$\begin{array}{rl} & A3*2^3 + A2*2^2 + A1*2^1 + A0*2^0 \\ X & B3*2^3 + B2*2^2 + B1*2^1 + B0*2^0 \end{array}$$

$$\begin{array}{l} + B0A3*2^3 + B0A2*2^2 + B0A1*2^1 + B0A0*2^0 \\ + B1A3*2^4 + B1A2*2^3 + B1A1*2^2 + B1A0*2^1 \\ + B2A3*2^5 + B2A2*2^4 + B2A1*2^3 + B2A0*2^2 \\ + B3A3*2^6 + B3A2*2^5 + B3A1*2^4 + B3A0*2^3 \end{array}$$

The sum of all these terms represents the product of A and B. The simplest multiply algorithm factors the above terms as follows:

$$A*B = B0*(A)*2^0 + B1*(A)*2^1 + B2*(A)*2^2 + B3*(A)*2^3$$

Since the coefficients of B (i.e., B0, B1, B2, and B3) can only take on the binary values of 1 or 0, the sum of the products can be formed by a series of simple adds and multiplications by two. The simplest implementation of this would be:

```
MULTIPLY:
  PRODUCT = 0
  IF B0 = 1 THEN PRODUCT: = PRODUCT + A
  IF B1 = 1 THEN PRODUCT: = PRODUCT + 2*A
  IF B2 = 1 THEN PRODUCT: = PRODUCT + 4*A
  IF B3 = 1 THEN PRODUCT: = PRODUCT + 8*A
END MULTIPLY
```

In order to conserve memory, the above straight line code is normally converted to the following loop:

```
MULTIPLY:
 PRODUCT: = 0
 COUNT: = 4
 REPEAT
  IF B[0] = 1 THEN PRODUCT: = PRODUCT + A ENDIF
  A: = 2*A
  B: = B/2
  COUNT: = COUNT - 1
 UNTIL COUNT: = 0
END MULTIPLY
```

The repeated multiplication of A by two (which can be performed by a simple left shift) forms the terms 2*A, 4*A, and 8*A. The variable B is divided by two (performed by a simple right shift) so that the least significant bit can always be used to determine whether the addition should be executed during each pass through the loop. It is from these shifting and addition operations that the "shift and add" algorithm takes its common name.

The "shift and add" algorithm shown above has two areas where efficiency will be lost if implemented in the manner shown. The first problem is that the addition to the partial product is double precision relative to the two operands. The other problem, which is also related to double precision operations, is that the A operand is double precision and that it must be left shifted and then the B operand must be right shifted. An examination of the "longhand" polynomial multiplication will reveal that, although the partial product is indeed double precision, each addition performed is only single precision. It would be desirable to be able to shift the partial product as it is formed so that only single precision additions are performed. This would be especially true if the partial product could be shifted into the "B" operand since one bit of the partial product is formed during each pass through the loop and (happily) one bit of the "B" operand is vacated. To do this, however, it is necessary to modify the algorithm so that both of the shifts that occur are of the same type.

To see how this can be done one can take the basic multiplication equation already presented:

$$A*B = B0*(A*2^0) + B1*(A*2^1) + B2*(A*2^2) + B3*(A*2^3)$$

and factoring 2^4 from the right side:

$$A*B = 2^4[B0*(A*2^{-4}) + B1*(A*2^{-3}) + B2*(A*2^{-2}) + B3*(A*2^{-1})]$$

This operation has resulted in a term (within the brackets) which can be formed by right shifts and adds and then multiplied by 2^4 to get the final result. The resulting algorithm, expanded to form an eight by eight multiplication, is shown in figure 5. Note that although the result is a full sixteen bits, the algorithm only performs eight bit additions and that only a single sixteen bit shift operation is involved. This has the effect of reducing both the code space and the execution time for the routine.

```
ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0

 LOC  OBJ        SEQ        SOURCE STATEMENT

                   1 $MACROFILE
                   2 $INCLUDE(:F1:MPY8.HED)
                =  3 ;*****************************************************************************
                =  4 ;*                                                                           *
                =  5 ;*      MPY8X8                                                               *
                =  6 ;*                                                                           *
                =  7 ;*===========================================================================*
                =  8 ;*                                                                           *
                =  9 ;*      THIS UTILITY PROVIDES AN 8 BY 8 UNSIGNED MULTIPLY                    *
                =  10 ;*     AT ENTRY:                                                            *
                =  11 ;*       A = LOWER EIGHT BITS OF DESTINATION OPERAND                        *
                =  12 ;*       XA= DON'T CARE                                                     *
                =  13 ;*       R1= POINTER TO SOURCE OPERAND (MULTIPLIER) IN INTERNAL MEMEORY      *
```

Figure 5

```
LOC  OBJ        SEQ        SOURCE STATEMENT


                =  14 ;*                                                              *
                =  15 ;*     AT EXIT:                                                 *
                =  16 ;*       A = LOWER EIGHT BITS OF RESULT                         *
                =  17 ;*       XA= UPPER EIGHT BITS OF RESULT                         *
                =  18 ;*       C = SET IF OVERFLOW ELSE CLEARED                       *
                =  19 ;*                                                              *
                =  20 ;*******************************************************************************
                   21 ;
                   22 ;
                   23 $INCLUDE(:F1:MPY8.PDL)
                =  24 ;1 MPY8X8:
                =  25 ;1 MULTIPLICAND[15-8]:=0
                =  26 ;1 COUNT:=8
                =  27 ;1 REPEAT
                =  28 ;2    IF MULTIPLICAND[0]=0 THEN BEGIN
                =  29 ;3       MULTIPLICAND:=MULTIPLICAND/2
                =  30 ;2    ELSE
                =  31 ;3       MULTIPLICAND[15-8]:=MULTIPLICAND[15-8]+MULTIPLIER
                =  32 ;2       MULTIPLICAND:=MULTIPLICAND/2
                =  33 ;2    ENDIF
                =  34 ;2    COUNT:=COUNT-1
                =  35 ;1 UNTIL COUNT=0
                =  36 ;1 END MPY8X8
                   37 ;
                   38 ; EQUATES
                   39 ; =======
                   40 ;
0002               41 XA      EQU     R2
0003               42 COUNT   EQU     R3
0004               43 ICNT    EQU     R4
                   44 ;
0003               45 DIGPR   EQU     3
                   46 ;
                   47 $EJECT
                   48 $INCLUDE(:F1:MPY8)
                =  49 ;1 MPY8X8:
                =  50 MPY8X8:
                =  51 ;1 MULTIPLICAND[15-8]:=0
0000 BA00       =  52          MOV     XA,#00
                =  53 ;1 COUNT:=8
0002 BB08       =  54          MOV     COUNT,#8
                =  55 ;1 REPEAT
                =  56 MPY8LP
                =  57 ;2    IF MULTIPLICAND[0]=0 THEN BEGIN
0004 120E       =  58          JB0     MPY8A
                =  59 ;3       MULTIPLICAND:=MULTIPLICAND/2
0006 2A         =  60          XCH     A,XA
0007 97         =  61          CLR     C
0008 67         =  62          RRC     A
0009 2A         =  63          XCH     A,XA
000A 67         =  64          RRC     A
000B EB04       =  65          DJNZ    COUNT,MPY8LP
000D 83         =  66          RET
                =  67 ;2    ELSE
```

Figure 5 (continued)

```
LOC  OBJ        SEQ        SOURCE STATEMENT

                =  68 MPY8A:
                =  69 ;3      MULTIPLICAND[15-8]:=MULTIPLICAND[15-8]+MULTIPLIER
000E 2A         =  70         XCH     A,XA
000F 61         =  71         ADD     A,@R1
0010 67         =  72         RRC     A
0011 2A         =  73         XCH     A,XA
0012 67         =  74         RRC     A
0013 EB04       =  75         DJNZ    COUNT,MPY8LP
0015 83         =  76         RET
                =  77 ;3      MULTIPLICAND:=MULTIPLICAND/2
                =  78 ;2    ENDIF
                =  79 ;2    COUNT:=COUNT-1
                =  80 ;1 UNTIL COUNT=0
                =  81 ;1 END MPY8X8
                   82  END

USER SYMBOLS
COUNT  0003    DIGPR  0003    ICNT   0004    MPY8A  000E    MPY8LP 0004    MPY8X8 0000    XA     0002

ASSEMBLY COMPLETE.  NO ERRORS
```


DIVIDE ALGORITHMS

In order to understand binary division a four bit operation will again be used as an example. The following algorithm will perform a four by four division:

```
DIVIDE:
  IF 16*DIVISOR> = DIVIDEND THEN
    SET OVERFLOW ERROR FLAG
  ELSE
    IF 8*DIVISOR> = DIVIDEND THEN
      QUOTIENT[3]: = 1
      DIVIDEND: = DIVIDEND – 8*DIVISOR
    ELSE
      QUOTIENT[3]: = 0
    ENDIF
    IF 4*DIVISOR> = DIVIDEND THEN
      QUOTIENT[2]: = 1
      DIVIDEND: = DIVIDEND – 4*DIVISOR
    ELSE
      QUOTIENT[2]: = 0
    ENDIF
    IF 2*DIVISOR> = DIVIDEND THEN
      QUOTIENT[1]: = 1
      DIVIDEND: = DIVIDEND – 2*DIVISOR
    ELSE
      QUOTIENT[1]: = 0
    ENDIF
    IF 1*DIVISOR> = DIVIDEND THEN
      QUOTIENT[0]: = 1
      DIVIDEND: = DIVIDEND – 1*DIVISOR
    ELSE
      QUOTIENT[0]: = 0
    ENDIF
  ENDIF
END DIVIDE
```

The algorithm is easy to understand. The first test asks if the division will fit into the dividend sixteen times. If it will, the quotient cannot be expressed in only four bits so an overflow error flag is set and the divide algorithm ends. The algorithm then proceeds to determine if eight times the divisor fits, four times, etc. After each test it either sets or clears the appropriate quotient bit and modifies the dividend. To see this algorithm in action, consider the division of 15 by 5:

```
  00001111     (15)
– 01010000     (16*5)
---------------------
               Doesn't fit—no overflow

  00001111     (15)
– 00101000     (8*5)
---------------------
               Doesn't fit—Q[3] = 0

  00001111     (15)
– 00010100     (4*5)
---------------------
               Doesn't fit—Q[2] = 0

  00001111     (15)
– 00001010     (2*5)
---------------------
  00000101       Fits—Q[1] = 1

  00000101     (15-2*5)
– 00000101     (1*5)
---------------------
  00000000     Fits—Q[0] = 1
```

The result is Q = 0011 which is the binary equivalent of 3—the correct answer. Clearly this algorithm can (and has been) converted to a loop and used to perform divisions. An examination of the procedure, however, will show that it has the same problems as the original multiply algorithm.

The first problem is that double precision operations are involved with both the comparison of the division with the dividend and the conditional subtraction. The second problem is that as the quotient bits are derived they must be shifted into a register. In order to reduce the register requirements, it would be desirable to shift them into the divisor register as they are generated since the divisor register gets shifted anyway. Unfortunately the quotient bits are derived most significant bits first so doing this will form a mirror image of the quotient—not very useful.

Both of these problems can be solved by observing that the algorithm presented for divide will still work if both sides of all the "equations" involving the dividend are divided by sixteen. The looping algorithm then would proceed as follows:

```
DIVIDE:
 QUOTIENT:=0
 COUNT:=4
 DIVIDEND:=DIVIDEND/16
 IF DIVISOR>=DIVIDEND THEN
  OVERFLOW FLAG:=1
 ELSE
  REPEAT
   DIVIDEND:=DIVIDEND*2
   QUOTIENT:=QUOTIENT*2
   IF DIVISOR>=DIVIDEND THEN
    QUOTIENT:=QUOTIENT+1/*SET QUOTIENT[0]*/
    DIVIDEND:=DIVIDEND-DIVISOR
   ENDIF
   COUNT:=COUNT-1
  UNTIL COUNT=0
 ENDIF
END DIVIDE
```

When this algorithm is implemented on a computer which does not have a direct compare instruction the comparison is done by subtraction and the inner loop of the algorithm is modified as follows:

```
*
*
REPEAT
  DIVIDEND:=DIVIDEND*2
  QUOTIENT:=QUOTIENT*2
  DIVIDEND:=DIVIDEND-DIVISOR
  IF BORROW=0 THEN
    QUOTIENT:=QUOTIENT+1
  ELSE
    DIVIDEND:=DIVIDEND+DIVISOR
  ENDIF
  COUNT:=COUNT-1
UNTIL COUNT=0
*
*
```

An implementation of this algorithm using the 8049 instruction set is shown in figure 6. This routine does an unsigned divide of a 16 bit quantity by an eight bit quantity. Since the multiply algorithm of figure 5 generates a 16 bit result from the multiplication of two eight bit operands, these two routines complement each other and can be used as part of more complex computations.

```
ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0

 LOC  OBJ        SEQ        SOURCE STATEMENT

                   1 $MACROFILE
                   2 $INCLUDE(:F1:DIV16.HED)
                 = 3 ;*************************************************************************
                 = 4 ;*                                                                       *
                 = 5 ;*      DIV16                                                            *
                 = 6 ;*                                                                       *
                 = 7 ;*=======================================================================*
                 = 8 ;*                                                                       *
                 = 9 ;*      THIS UTILITY PROVIDES AN 16 BY 8 UNSIGNED DIVIDE                 *
                 = 10 ;*     AT ENTRY:                                                        *
                 = 11 ;*       A = LOWER EIGHT BITS OF DESTINATION OPERAND                    *
                 = 12 ;*       XA= UPPER EIGHT BITS OF DIVIDEND                               *
                 = 13 ;*       R1= POINTER TO DIVISOR IN INTERNAL MEMORY                      *
                 = 14 ;*                                                                      *
                 = 15 ;*     AT EXIT:                                                         *
                 = 16 ;*       A = LOWER EIGHT BITS OF RESULT                                 *
                 = 17 ;*       XA= REMAINDER                                                  *
```

Figure 6

```
LOC  OBJ          SEQ         SOURCE STATEMENT

                  =  18 ;*        C = SET IF OVERFLOW ELSE CLEARED                                *
                  =  19 ;*                                                                        *
                  =  20 ;*********************************************************************************
                     21 ;
                     22 ;
                     23 $INCLUDE(:F1:DIV16.PDL)
                  =  24 ;1 DIV16
                  =  25 ;1 COUNT:=8
                  =  26 ;1 DIVIDEND[15-8]:=DIVIDEND[15-8]-DIVISOR
                  =  27 ;1 IF BORROW=0 THEN /* IT FITS*/
                  =  28 ;2    SET OVERFLOW FLAG
                  =  29 ;1 ELSE
                  =  30 ;2    RESTORE DIVIDEND
                  =  31 ;2    REPEAT
                  =  32 ;3       DIVIDEND:=DIVIDEND*2
                  =  33 ;3       QUOTIENT:=QUOTIENT*2
                  =  34 ;3       DIVIDEND[15-8]:=DIVIDEND[15-8]-DIVISOR
                  =  35 ;3       IF BORROW=1 THEN
                  =  36 ;4          RESTORE DIVIDEND
                  =  37 ;3       ELSE
                  =  38 ;4          QUOTIENT[0]:=1
                  =  39 ;3       ENDIF
                  =  40 ;3       COUNT:=COUNT-1
                  =  41 ;2    UNTIL COUNT=0
                  =  42 ;2    CLEAR OVERFLOW FLAG
                  =  43 ;1 ENDIF
                  =  44 ;1 ENDDIVIDE
                     45 ;
                     46 ; EQUATES
                     47 ; =======
                     48 ;
0002                 49 XA      EQU     R2
0003                 50 COUNT   EQU     R3
                     51 ;
                     52 $EJECT
                     53 $INCLUDE(:F1:DIV16)
                  =  54 ;1 DIV16:
0000 2A           =  55 DIV16:  XCH     A,XA    ; ROUTINE WORKS MOSTLY WITH BITS 15-8
                  =  56 ;1 COUNT:=8
0001 BB08         =  57         MOV     COUNT,#8
                  =  58 ;1 DIVIDEND[15-8]:=DIVIDEND[15-8]-DIVISOR
0003 37           =  59         CPL     A
0004 61           =  60         ADD     A,@R1
0005 37           =  61         CPL     A
                  =  62 ;1 IF BORROW=0 THEN /* IT FITS*/
0006 F60B         =  63         JC      DIVIA
                  =  64 ;2    SET OVERFLOW FLAG
0008 A7           =  65         CPL     C
0009 0424         =  66         JMP     DIVIB
                  =  67 ;1 ELSE
                  =  68 DIVIA:
                  =  69 ;2    RESTORE DIVIDEND
000B 61           =  70         ADD     A,@R1
                  =  71 ;2    REPEAT
                  =  72 DIVILP:
                  =  73 ;3       DIVIDEND:=DIVIDEND*2
```

Figure 6 (continued)

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                  =  74 ;3       QUOTIENT =QUOTIENT*2
000C 97           =  75          CLR     C
000D 2A           =  76          XCH     A,XA
000E F7           =  77          RLC     A
000F 2A           =  78          XCH     A,XA
0010 F7           =  79          RLC     A
0011 E618         =  80          JNC     DIVIE
0013 37           =  81          CPL     A
0014 61           =  82          ADD     A,@R1
0015 37           =  83          CPL     A
0016 0420         =  84          JMP     DIVIC
                  =  85 ;2       DIVIDEND[15-8]:=DIVIDEND[15-8]-DIVISOR
0018 37           =  86 DIVIE:   CPL     A
0019 61           =  87          ADD     A,@R1
001A 37           =  88          CPL     A
                  =  89 ;3       IF BORROW=1 THEN
001B E620         =  90          JNC     DIVIC
                  =  91 ;4         RESTORE DIVIDEND
001D 61           =  92          ADD     A,@R1
001E 0421         =  93          JMP     DIVID
                  =  94 ;3       ELSE
                  =  95 DIVIC:
                  =  96 ;4         QUOTIENT[0].=1
0020 1A           =  97          INC     XA
                  =  98 ;3       ENDIF
                  =  99 ;3       COUNT =COUNT-1
                  = 100 ;2     UNTIL COUNT=0
0021 EB0C         = 101 DIVID:   DJNZ    COUNT,DIVILP
                  = 102 ;2     CLEAR OVERFLOW FLAG
0023 97           = 103          CLR     C
                  = 104 ;1 ENDIF
                  = 105 ;1 ENDDIVIDE
0024 2A           = 106 DIVIB:   XCH     A,XA
0025 83           = 107          RET
                    108  END

USER SYMBOLS
COUNT  0003    DIV16  0000    DIVIA  0008    DIVIB  0024    DIVIC  0020    DIVID  0021    DIVIE  0018    DIVILP 000C
XA     0002

ASSEMBLY COMPLETE,  NO ERRORS
```

Figure 6 (continued)

BINARY AND BCD CONVERSIONS

The conversion of a binary value to a BCD (binary coded decimal) number can be done with a very straightforward algorithm:

```
CONVERT_TO_BCD:
  BCDACCUM: = 0
  COUNT: = PRECISION
  REPEAT
    BIN: = BIN * 2
    BCD: = BCD * 2 + CARRY
    COUNT: = COUNT - 1
  UNTIL COUNT = 0
END CONVERT_TO_BCD
```

The variable ***BCDACCUM*** is a BCD string used to accumulate the result; the variable ***BIN*** is the binary number to be converted. ***PRECISION*** is a constant which gives the length, in binary bits of BIN. To see how this works, assume that BIN is a sixteen bit value with the most significant bit set. On the first pass through the loop the multiplication of ***BIN*** will result in a carry and this carry will be added to BCD. On the remaining passes through the loop BCD will be multiplied by two 15 times. The initial carry into BCD will be multiplied by 2^{15} or 32678, which is the "value" of the most significant bit of ***BIN***. The process repeats with each bit of ***BIN*** being introduced to ***BCDACCUM*** and then being scaled up on successive passes through the loop. Figure 7 shows the implementation of this algorithm for the 8049.

```
ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0


 LOC  OBJ        SEQ        SOURCE STATEMENT

                    1 $MACROFILE
                    2 $INCLUDE(:F1:CONBCD.HED)
                =   3 ;*******************************************************************************
                =   4 ;*                                                                             *
                =   5 ;*      CONBCD                                                                 *
                =   6 ;*                                                                             *
                =   7 ;*=============================================================================*
                =   8 ;*                                                                             *
                =   9 ;*      THIS UTILITY CONVERTS A 16 BIT BINARY VALUE TO BCD                      *
                =  10 ;*      AT ENTRY                                                               *
                =  11 ;*        A = LOWER EIGHT BITS OF BINARY VALUE                                 *
                =  12 ;*        XA= UPPER EIGHT BITS OF BINARY VALUE                                 *
                =  13 ;*        R0= POINTER TO A PACKED BCD STRING                                   *
                =  14 ;*                                                                             *
                =  15 ;*      AT EXIT                                                                *
                =  16 ;*        A = UNDEFINED                                                        *
                =  17 ;*        XA= UNDEFINED                                                        *
                =  18 ;*        C = SET IF OVERFLOW ELSE CLEARED                                     *
                =  19 ;*                                                                             *
                =  20 ;*******************************************************************************
                   21 ;
                   22 ;
                   23 $INCLUDE(:F1:CONBCD.PDL)
                =  24 ;1 CONVERT_TO_BCD
                =  25 ;1 BCDACC:=0
                =  26 ;1 COUNT:=16
                =  27  1 REPEAT
                =  28 ;2    BIN:=BIN*2
                =  29 ;2    BCD:=BCD*2+CARRY
                =  30 ;2    IF CARRY FROM BCDACC GOTO ERROR EXIT
                =  31 ;2    COUNT:=COUNT-1
                =  32 ;1 UNTIL COUNT=0
                =  33 ;1 END CONVERT_TO_BCD
                   34 ;
                   35 ; EQUATES
                   36 ; =======
                   37 ;
0002               38 XA      EQU     R2
0003               39 COUNT   EQU     R3
0004               40 ICNT    EQU     R4
                   41 ;
0003               42 DIGPR   EQU     3
                   43 ;
                   44 $EJECT
                   45 $INCLUDE(:F1:CONBCD)
                =  46 ;
0005            =  47 TEMP1   SET     R5
                =  48 ;
                =  49 ;1 CONVERT_TO_BCD
                =  50 CNBCD
                =  51 ;1 BCDACC:=0
0000 28         =  52         XCH     A,R0
```

Figure 7

```
LOC  OBJ        SEQ        SOURCE STATEMENT

0001 A9         =  53          MOV     R1,A
0002 28         =  54          XCH     A,R0
0003 BC03       =  55          MOV     ICNT,#DIGPR
0005 B100       =  56 BCDCOA:  MOV     @R1,#00
0007 19         =  57          INC     R1
0008 EC05       =  58          DJNZ    ICNT,BCDCOA
                =  59 ;1 COUNT:=16
000A BB10       =  60          MOV     COUNT,#16
                =  61 ;1 REPEAT
                =  62 BCDCOB:
                =  63 ;2    BIN:=BIN*2
000C 97         =  64          CLR     C
000D F7         =  65          RLC     A
000E 2A         =  66          XCH     A,XA
000F F7         =  67          RLC     A
0010 2A         =  68          XCH     A,XA
                =  69 ;2    BCD:=BCD*2+CARRY
0011 28         =  70          XCH     A,R0
0012 A9         =  71          MOV     R1,A
0013 28         =  72          XCH     A,R0
0014 BC03       =  73          MOV     ICNT,#DIGPR
0016 AD         =  74          MOV     TEMP1,A
0017 F1         =  75 BCDOC:   MOV     A,@R1
0018 71         =  76          ADDC    A,@R1
0019 57         =  77          DA      A
001A A1         =  78          MOV     @R1,A
001B 19         =  79          INC     R1
001C EC17       =  80          DJNZ    ICNT,BCDOC
001E FD         =  81          MOV     A,TEMP1
                =  82 ;2    IF CARRY FROM BCDACC GOTO ERROR EXIT
001F F624       =  83          JC      BCDCOD
                =  84 ;2    COUNT:=COUNT-1
                =  85 ;1 UNTIL COUNT=0
0021 EB0C       =  86          DJNZ    COUNT,BCDCOB
0023 97         =  87          CLR     C       ; CLEAR CARRY TO INDICATE NORMAL TERMINATION
                =  88 ;1 END CONVERT_TO_BCD
0024 83         =  89 BCDCOD:  RET
                   90  END

USER SYMBOLS
BCDCOA 0005    BCDCOB 000C    BCDCOD 0024    BCDOC  0017    CNBCD  0000    COUNT  0003    DIGPR  0003    ICNT   0004
TEMP1  0005    XA     0002

ASSEMBLY COMPLETE,  NO ERRORS
```

Figure 7 (continued)

The conversion of a BCD value to binary is essentially the same process as converting a binary value to BCD.

```
CONVERT_TO_BINARY
  BIN:=0
  COUNT:=DIGNO
  REPEAT
    BCDACCUM:=BCDACCUM * 10
    BIN:=10 * BIN+CARRY DIGIT
    COUNT:=COUNT-1
  UNTIL COUNT=0
END CONVERT_TO_BINARY
```

The only complexity is the two multiplications by ten. The BCDACCUM can be multiplied by ten by shifting it left four places (one digit). The variable BIN could be multiplied using the multiply algorithm already discussed, but it is usually more efficient to do this by making the following substitution:

$$BIN = 10 * BIN = (2) * (5) * (BIN) = 2 * (2 * 2 + 1) * BIN$$

This implies that the value 10 * BIN can be generated by saving the value of BIN and then shifting BIN two places left. After this the original value of BIN can be added to the new value of BIN (forming 5 * BIN) and then BIN can be multiplied by two. It is often possible to implement the multiplication of a value by a constant by using such techniques. Figure 8 shows an 8049 routine which converts BCD values to binary. This routine differs slightly from the algorithm above in that the BCD digits are read, and converted to binary, two digits at a time. Protection has also been added to detect BCD operands which, if converted, would yield binary values beyond the range of the result.

1

```
ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V2.0

 LOC  OBJ        SEQ        SOURCE STATEMENT

                    1 $MACROFILE
                    2 $INCLUDE( F1:CONBIN.HED)
                =   3 ;*******************************************************************************
                =   4 ;*                                                                             *
                =   5 ;*      CONBIN                                                                 *
                =   6 ;*                                                                             *
                =   7 ;*=============================================================================*
                =   8 ;*                                                                             *
                =   9 ;*      THIS UTILITY CONVERTS A 6 DIGIT BCD VALUE TO BINARY                    *
                =  10 ;*      AT ENTRY:                                                              *
                =  11 ;*        R0= POINTER TO A PACKED BCD STRING                                   *
                =  12 ;*                                                                             *
                =  13 ;*      AT EXIT:                                                               *
                =  14 ;*        A = LOWER EIGHT BITS OF THE BINARY RESULT                            *
                =  15 ;*        XA= UPPER EIGHT BITS OF THE BINARY RESULT                            *
                =  16 ;*        C = SET IF OVERFLOW ELSE CLEARED                                     *
                =  17 ;*                                                                             *
                =  18 ;*******************************************************************************
                   19 ;
                   20 ;
                   21 $INCLUDE( F1:CONBIN.PDL)
                =  22 ;
                =  23 ;
                =  24 ;1 CONVERT_TO_BINARY
                =  25 ;1 POINTER0:=POINTER0+DIGITPAIR-1
                =  26 ;1 COUNT:=DIGITPAIR
                =  27 ;1 BIN:=0
                =  28 ;1 REPEAT
                =  29 ;2    BIN:=BIN*10
                =  30 ;2    BIN:=BIN+MEM(R0)[7-4]
                =  31 ;2    BIN:=BIN*10
                =  32 ;2    BIN:=BIN+MEM(R0)[3-0]
```

```
LOC  OBJ        SEQ        SOURCE STATEMENT

                =  33 ;2    POINTER0:=POINTER0-1
                =  34 ;2    COUNT:=COUNT-1
                =  35 ;1 UNTIL COUNT=0
                =  36 ;1 END CONVERT_TO_BINARY
                   37 ;
                   38 ; EQUATES
                   39 ; =======
                   40 ;
0002               41 XA      EQU     R2
0003               42 COUNT   EQU     R3
0004               43 ICNT    EQU     R4
                   44 ;
0003               45 DIGPR   EQU     3
                   46 ;
                   47 $EJECT
                   48 $INCLUDE( F1:CONBIN)
                =  49 ;
0005            =  50 TEMP1   SET     R5
0006            =  51 TEMP2   SET     R6
                =  52 ;
                =  53 ;1 CONVERT_TO_BINARY
                =  54 CONBIN:
                =  55 ;1 POINTER0:=POINTER0+DIGITPAIR-1
0000 F8         =  56          MOV     A,R0
0001 0302       =  57          ADD     A,#DIGPR-1
0003 A8         =  58          MOV     R0,A
                =  59 ;1 COUNT:=DIGITPAIR
0004 BB03       =  60          MOV     COUNT,#DIGPR
                =  61 ;1 BIN =0
0006 27         =  62          CLR     A
0007 AA         =  63          MOV     XA,A
                =  64 ;1 REPEAT
                =  65 CONBLP:
                =  66 ;2    BIN:=BIN*10
0008 142B       =  67          CALL    CONB10
000A F62A       =  68          JC      CONBER
                =  69 ;2    BIN.=BIN+MEM(R0)[7-4]
000C AD         =  70          MOV     TEMP1,A
000D F0         =  71          MOV     A,@R0
000E 47         =  72          SWAP    A
000F 530F       =  73          ANL     A,#0FH
0011 6D         =  74          ADD     A,TEMP1
0012 2A         =  75          XCH     A,XA
0013 1300       =  76          ADDC    A,#00
0015 2A         =  77          XCH     A,XA
0016 F62A       =  78          JC      CONBER
                =  79 ;2    BIN.=BIN*10
0018 142B       =  80          CALL    CONB10
001A F62A       =  81          JC      CONBER
                =  82 ;2    BIN.=BIN+MEM(R0)[3-0]
001C AD         =  83          MOV     TEMP1,A
001D F0         =  84          MOV     A,@R0
001E 530F       =  85          ANL     A,#0FH
0020 6D         =  86          ADD     A,TEMP1
0021 2A         =  87          XCH     A,XA
```

```
LOC  OBJ        SEQ        SOURCE STATEMENT

 0022 1300      =  88          ADDC    A,#00
 0024 2A        =  89          XCH     A,XA
 0025 F62A      =  90          JC      CONBER
                =  91 ;2    POINTER0:=POINTER0-1
 0027 C8        =  92          DEC     R0
                =  93 ;2    COUNT:=COUNT-1
                =  94 ;1 UNTIL COUNT=0
 0028 EB08      =  95          DJNZ    COUNT,CONBLP
                =  96 ;1 END CONVERT_TO_BINARY
 002A 83        =  97 CONBER:  RET
                =  98 $EJECT
                =  99  ;
                = 100  ;
                = 101  ;       UTILITY TO MULTIPLY BIN BY 10
                = 102  ;       CARRY WILL BE SET IF OVERFLOW OCCURS
                = 103  ;
 002B AD        = 104 CONB10:  MOV     TEMP1,A ; SAVE A
 002C 2A        = 105          XCH     A,XA    ; SAVE XA
 002D AE        = 106          MOV     TEMP2,A
 002E 2A        = 107          XCH     A,XA
                = 108  ;
 002F 97        = 109          CLR     C
 0030 F7        = 110          RLC     A       ; BIN:=BIN*2
 0031 2A        = 111          XCH     A,XA
 0032 F7        = 112          RLC     A
 0033 2A        = 113          XCH     A,XA
 0034 F646      = 114          JC      CONB1E  ; ERROR ON OVERFLOW
                = 115  ;
 0036 F7        = 116          RLC     A       ; BIN:=BIN*4
 0037 2A        = 117          XCH     A,XA
 0038 F7        = 118          RLC     A
 0039 2A        = 119          XCH     A,XA
 003A F646      = 120          JC      CONB1E  ; ERROR ON OVERFLOW
                = 121  ;
 003C 6D        = 122          ADD     A,TEMP1 ; BIN:=BIN*5
 003D 2A        = 123          XCH     A,XA
 003E 7E        = 124          ADDC    A,TEMP2
 003F 2A        = 125          XCH     A,XA
 0040 F646      = 126          JC      CONB1E  ; ERROR ON OVERFLOW
                = 127  ;
 0042 F7        = 128          RLC     A       ; BIN:=BIN*10
 0043 2A        = 129          XCH     A,XA
 0044 F7        = 130          RLC     A
 0045 2A        = 131          XCH     A,XA
                = 132  ;
 0046 83        = 133 CONB1E:  RET
                = 134
                = 135  ;
                  136  END

USER SYMBOLS
CONB10 002B    CONB1E 0046    CONBER 002A    CONBIN 0000    CONBLP 0008    COUNT  0003    DIGPR  0003    ICNT   0004
TEMP1  0005    TEMP2  0006    XA     0002

ASSEMBLY COMPLETE,  NO ERRORS
```

CONCLUSION

The design goals of the full duplex serial communications software were realized; if transmission and reception are occurring concurrently, only 42 percent of the real time available to the 8049 will be consumed by the serial link. This implies that an 8049 running full duplex serial I/O will still outperform earlier members of the family running without the serial I/O requirement. It is also possible to run this program in an 8048 or 8748 at 1200 baud with the same 42 percent CPU utilization.

The execution times for the other routines that have been discussed have been summarized in Table 1. All of these routines were written to maintain maximum useability rather than minimum code size or execution time. The resulting execution times and code size are therefore what the user can expect to see in a real application. The results that were obtained clearly show the efficiency and speed of the 8049. The equivalent times for the 8048 are also shown. It is clear that the 8049 represents a substantial performance advantage over the 8048. Considering, in most applications, that the 8048 is the highest performance microcomputer available to date, the performance advantage of the 8049 should allow the cost benefits of a single chip microcomputer to be realized in many applications which up until now have required too much "computer power" for a single chip approach.

	BYTES	EXECUTION TIME (MICROSECONDS) 8049	8048
MPY8	21	109	200
DIV 16	37	183 MIN 204 MAX	335 MIN 375 MAX
CONBCD	36	733	1348
CONBIN	70	388	713

Table 1. Program Performance

intel

APPLICATION NOTE

AP-55A

1

August 1979

A High-Speed Emulator for Intel MCS-48™ Microcomputers

Applications Staff
Microcontroller Operation

9801007-01

I. PURPOSE AND SCOPE

This Application Note presents a description of the design and operation of a high-speed emulator for the Intel® MCS-48™ family of single chip microcomputers. The HSE-49™ emulator provides a simple and inexpensive means for executing and debugging 8049 programs which require the full 11-MHz operating speed of the part.

Section II of this Application Note describes some of the features of this development tool and how it may be used. Section III briefly discusses the hardware used to implement these features, while Section IV describes the manner in which program execution status is made available to the operator.

A detailed description of all of the operator commands is presented in Section V of this note, along with the modifiers and options which may be specified for each command. Known restrictions and limitations of the HSE-49 system are listed and explained in Section VI. Section VII shows how the basic circuit may be modified to provide options on memory organization, I/O configurations, etc.

Full schematics of the system hardware, as well as monitor software listings, are presented in Appendices A and B, respectively. A short summary of the command syntax is presented in Appendix C,. Appendix D explains the error message codes which may appear during use.

It is assumed that the reader is already familiar with the operation of the 8048 or 8049 microcomputers. Some knowledge of the 8048 architecture is needed to understand sections of the command and modifier descriptions. Most users will already have this background. Other readers are referred to the *MCS-48 Microcomputer User's Manual,* Intel publication number 9800270.

II. THE HSE-49 DEVELOPMENT TOOL

In essence, the HSE-49 emulator provides the user a means for executing an MCS-48 program located in external RAM rather than internal ROM or EPROM. This allows programs being debugged to be modified easily and quickly during the debug cycle. A user's program may be entered into system RAM either manually or via a serial link from a host computer such as an Intellec® Microcomputer Development System. Once loaded, the program can be modified using an on-board keyboard and display, and executed in real-time in a number of breakpoint modes. The internal state of the processor, including RAM, accumulator, timer/counter, and status register contents, can also be read and modified through the keyboard.

Breakpoint and debug facilities are extremely flexible. The following execution modes are provided.

- Programs may be run in full (11 MHz) real time;
- Programs may be single-stepped;
- In break mode, programs run in full real time until break occurs;
- Breaks may be triggered by either program or external data RAM accesses;
- Any number of breakpoints may be used in any combination;
- "Auto-Step" operation causes the current program counter and Accumulator contents to be printed on the display for a short time on every instruction cycle;
- "Auto-Break" provides the above display only when a break flag is encountered, with real time operation otherwise;
- While running in non-break mode, a TTL-level pulse is generated whenever a break flag is encountered. This signal may be used to trigger an oscilloscope or Logic Analyzer to assist in hardware and software debug.
- While running in any mode, the keyboard and display are "alive". Execution may be suspended or terminated by commands from the keyboard.

Intent of this Note

While the HSE-49 emulator can assist a new microcomputer user in becoming familiar with the 8048 and 8049 microcomputers, its inherent debug capabilities will also prove helpful to design engineers. The design could be used for new system development and verification or adapted for prototype production.

The main concern in designing the HSE-49 emulator was to keep the basic design simple, while maximizing the system's flexibility. The design allows the use of jumpers, hardware and software switches, etc. to allow the user to reconfigure the system according to the way he dedicates chip-select pins, I/O, etc. The emulator can be changed to fit each user's unique needs, rather than forcing the user to alter his needs to what is provided.

The primary intent of note is to provide the reader with the information needed to reconstruct and make full use of the HSE-49 emulator. Less emphasis is placed on describing how the hardware operates or how the commands are implemented. This information may be found in the schematic diagrams and software listings included in the Appendices.

III. GENERAL HARDWARE OVERVIEW

User Program Emulation

The actual emulation of the user's program is done using an 8039 microcomputer (IC29 on the schematics in Appendix A) executing a program stored in external RAM. The basic minimum configuration includes the 8039 microcomputer, an 8282 address latch (IC19), and 2K bytes of 2114 RAM to use for program development and real-time execution (ICs B1, C1, B2, and C2). Additional RAM may be added to allow the user to expand his program and data memory to 4K each. (If an 11-MHz crystal is used with the microcomputer, type 2114-3 RAMs must be used.)

System Supervision

A second microcomputer — another 8039 (IC25) with an 8282 address latch (IC16) and off-chip program memory in a 2716 EPROM (IC15) — is used to scan the on-board keyboard and display, interpret and implement commands, drive serial interfaces, etc. In general, the master processor is used to interface the execution processor's memory spaces with the outside world and control the operation of the execution processor. In this note the two processors will be abbreviated "MP" and "EP", respectively. Figure 1 shows how the two processors interrelate with the rest of the system.
system.

Keyboard/Display

The 33-key keyboard shown in Figure 2 includes a 16-key hexidecimal keypad and 17 special function keys for specifying commands and modifiers. Readers already familiar with the PROMPT-48™ debug tool for the 8048 will find that 25 of the HSE-49 emulator keys are identical in function and layout to the PROMPT-48 keyboard, and use the PROMPT-48 command syntax. The eight additional keys are used to generalize and augment the PROMPT-48 capabilities, as described in Section V.

The eight-character seven-segment display (DS1-DS8) is used for displaying addresses, data, and pseudo-alphanumeric messages. The display responses printed in Section V and throughout this note use a mix of upper and lower case letters to indicate what seven-segment patterns appear. An 8243 (IC9) and eight DIP packages (resistor packs, current buffers, etc.) are used for multiplexing the display and scanning the keyboard.

Breakpoint Detection

Breakpoints are specified and detected using a 2102A 1K x 8 RAM corresponding to each pair of 2114s (ICs A1

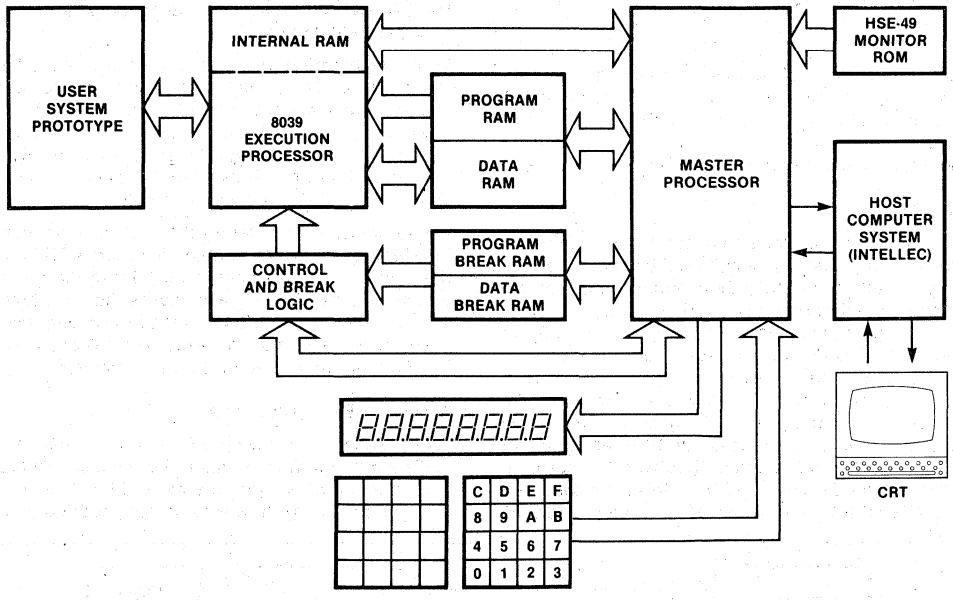


Figure 1. HSE-49™ Emulator Signal Flow Diagram

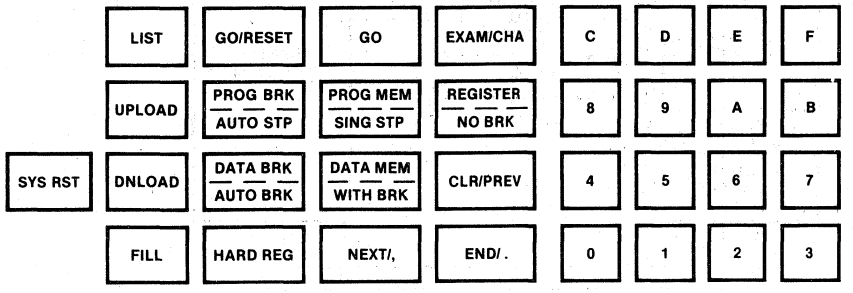


Figure 2. HSE-49™ Emulator Command Keyboard Organization

and A2). In effect, each program or data address accesses a 9-bit word. Eight bits are used normally for code or data storage. The ninth bit, accessed in parallel with the other eight, is used to indicate if a breakpoint has been set for that address. This output, when asserted, is latched (IC27 and IC36) and used to halt the execution processor via the single-step input. (In other modes, the break logic can be reconfigured to set the break requested flip-flop on any EP machine cycle or any EP "MOVX" instruction.)

Link Register

An 8212 8-bit latch (IC18) is used to communicate data and commands between the master and control processors. Under control of the MP, this register, called the "Link" register, may be logically mapped into either the program or data RAM address spaces. When this is done, the 2114s in the respective memory space are disabled and the link responds to all accesses, regardless of address. The link will be discussed in greater detail in Section IV.

Control Logic

In addition to the devices mentioned above, the minimum configuration requires about 10 additional ICs for bus arbitration, system control, and breakpoint and single-step logic. Additional parts may be optionally added for serial port interfacing, I/O reconstruction, etc.

MP Monitor

The monitor program executed by the MP includes commands for filling, reading, or writing the various memory spaces, including the execution processor's program RAM, external ("MOVX") data RAM, accumulator, PSW, PC, timer/counter, working registers, and internal RAM; to execute the user's program from arbitrary addresses in various debugging modes; and to upload or download object or data files from diskettes using an Intellec® development system. No special software is needed for the Intellec® other than ISIS Version 3.4 or later. The data format is compatible with the standard Intel hex file format produced by ASM-4; the baud rate may be altered from 110 baud (default state) up to 2400 baud from the on-board keybad. Blocks of data may be transmitted to a CRT or printer and displayed in a tabular format.

IV. INTERPROCESSOR COMMUNICATION

Program Break Sequence

When the MP detects that the EP has been halted by the breakpoint hardware, or when the operator presses a key while the program is executing, the program break sequence is initiated. The low-order 23 bytes of user program memory is read into a buffer within the internal RAM of the MP. A short program for reading and transmitting internal EP status is written over the low-order program memory. (This is one of several "mini-monitors" overlayed over the user program area.) The link register is mapped logically over the user program memory, and loaded with the 8049 machine code for a "CALL" instruction to the mini-monitor program area. The EP is then allowed to fetch a single instruction from the link, i.e., the "CALL" to the mini-monitor is forced onto the EP data bus.

From this point on, the EP executes code contained in the mini-monitor. The link is logically mapped over the data RAM address space (whether or not any 2114 data RAMs are present). A block diagram of the system at this point is shown in Figure 3. The break logic is reconfigured so that any "MOVX" (RD or WR) operation executed by the EP will cause it to halt.

For example, after entering the first mini-monitor, the EP executes a "MOVX @R0,A" instruction. This writes the contents of the accumulator prior to the execution termination into the link, and causes the EP to halt. The MP may then read and retain the link contents to determine the EP accumulator value. The EP timer/counter and PSW are preserved in the same manner.

Accessing EP Internal RAM

After reading and saving EP internal status, the MP loads a different mini-monitor into the same RAM area. This monitor allows the internal RAM of the EP to be read and written by the MP by passing address and data

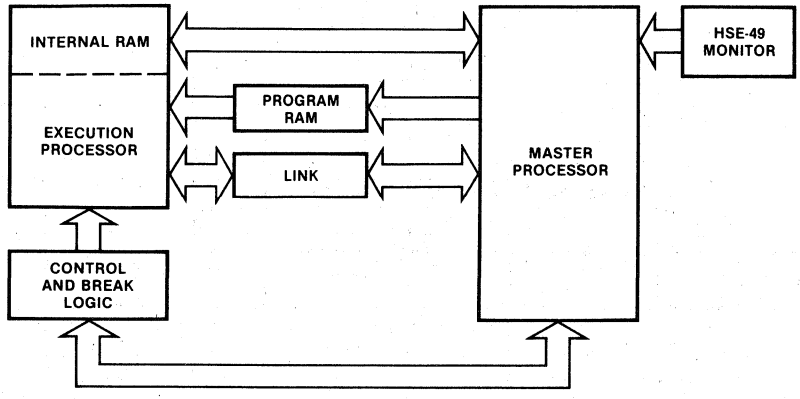


Figure 3. Communication between EP & MP

values between the two processors using the link register.

This is needed for two reasons. First, the EP program counter prior to the forced "CALL" instruction may be derived from the EP stack contents, and may be modified to cause the EP to resume execution at any desired address. Secondly, the internal RAM of the EP may then be accessed and modified in the process of executing a number of the monitor commands.

Resuming User Program Execution

In order to resume user program execution, a status-restoration mini-monitor is overlayed. This restores the EP internal status using a scheme analogous to the one in which the status was originally saved. The final step of the last mini-monitor is an "RETR" instruction, after which the EP is again halted. The low-order program memory saved earlier is rewritten into the appropriate area, the break logic is reconfigured for the desired execution mode, and the EP is released to run at full speed until the next break situation is encountered.

Note that all commands are implemented using "logical" rather than "physical" addressing. Thus the operator need not be concerned with the intricacies of the system design. For example, when any monitor command refers to low-order user program memory, the appropriate byte of storage within the MP internal RAM is accessed instead. If the location is altered, the internal RAM is modified appropriately. When program memory is reloaded prior to resuming user program execution, the modified version of the user program will be the one loaded.

Baud	HR06	HR07
110	93H	04H
150	96H	03H
300	45H	02H
600	9DH	01H
1200	44H	01H
2400	1AH	01H

Table 1. Serial Interface Data Rate Parameters

V. HSE-49 COMMAND DESCRIPTION

Whenever the characters "HSE-49" are present on the system display, a command string may be entered by the operator. In general, all command strings consist of a basic command initiator, an optional command modifier or type-designator, and a number of parameters or delimiters entered as hexidecimal digits. A command is executed, or a command in progress terminated, by pressing the [END/.] key. Logical default values are assumed for the modifier and parameters if either (or both) are omitted. A defualt parameter assumed for the command modifier will be presented on the display when the first parameter is entered.

Each parameter is a string of up to three hexidecimal digits. If more than three digits are entered, only the most recent three are considered. This allows an erroneous digit to be corrected without respecifying the entire command. A parameter is completed by pressing the [NEXT/,] key. Some commands may only need the low order part of a parameter; i.e., a command incorporating a data byte (such as [FILL]) will use only the low-order 8 bits of the corresponding parameter; Internal RAM and hardware register addressing uses only seven. In each case, higher order bits are ignored.

A command string is terminated and the command invoked by pressing the [END/.] key. The command will also be invoked by pressing the [NEXT/,] key when no additional parameters are allowed. A command string may be aborted at any point before the command is invoked by pressing the [CLEAR/PREV] key, and the sign-on message will appear.

Errors

An illegal command string, command terminator, or hardware failure will cause an error message and error code number to appear on the display (e.g., "Error-.3"). When this occurs, the monitor can be returned to command mode by pressing the [CLEAR] or [END/.] keys. An explanation of the various error codes is given in Appendix D.

Command Classes

Commands for the HSE-49 emulator are divided into general classes, where all commands in each class have the same choice of options or modifiers. A brief description of each command, followed by a description of the allowed options, is presented below by class.

Data Manipulation/Control Command Group

Commands:

[EXAM/CHA]

Display Response — "ECh."

Function — Examine/change memory location.

Causes the memory address specified to be read and presented on the display. New data may be entered (if desired) from the hexidecimal keypad. New data is verified before appearing on the display. Subsequent or previous locations may be read by pressing the [NEXT/,] or [PREV] keys, respectively. Command terminated with [END/.] key.

[FILL]

Display Response — "FIL."

Function — Fill range of memory addresses with a single data value.

Fill the appropriate memory space between the addresses specified by the first two parameters with the low-order byte of the third parameter. If second parameter less than first, only the location specified by the first is affected. If third parameter omitted, zero is assumed. If second and third parameters omitted, individual address specified is cleared. Command is useful for setting a large range of breakpoints; e.g., all of page 3 may be enabled for break with the command:

[FILL][PROG BRK]<300>[,]<3FF>[,]<1>[.]

[LIST]

Display Response — "LSt."

Function — List memory to output device through HSE-49 serial port.

Display the contents of a range of addresses given by two parameters to a teletype or CRT screen. Data is formatted, 16 separated bytes per line, with the starting address of each line printed. If used with an Intellec® system, the operator first uses ISIS-II to transfer the TTY input to the CRT output ("COPY :TI: TO :CO:") then invokes this command from the keypad. Alternatively, any ISIS device or disk file name(:TO:, :LP:, :F1:HRDREG.SAV, etc.) may be used as the destination.

[DNLOAD]

Display Response — "dnL."

Function — Download memory through HSE-49 serial port

Load data in hex file format through the serial input port. If used with Intellec® system, the operator first invokes this command from the keypad, then uses ISIS-II to transfer a disk file to the teletype port ("COPY : Fn:file.HEX TO :TO:").

The use of the checksum field for the download command is expanded slightly over the Intel hex file format standard. If the first character of the checksum field is a question mark ("?"), the checksum for that record will not be verified. This allows large object files produced by the assembler to be patched using the ISIS text editor without the necessity of manually recomputing the checksum value.

[UPLOAD]

Display Response — "UPL."

Function — Upload memory through HSE-49 serial port.

Output the contents of a range of addresses specified by the two parameters through the HSE-49 serial port in standard Intel hex file format. If used with Intellec® system, the operator first uses ISIS-II to transfer the TTY input to a disk file ("COPY :TI: TO :Fn:file.HEX"), then invokes this command from the keypad.

Data types allowed:

[PROG MEM]

Display Response — "Pr."

Function — User program memory.

Memory used to develop and execute user program. Addresses 000 through 7FF are the execution processor's memory bank 0; 800 through FFF are memory bank 1.

[REGISTER]

Display Response — "rG."

Function — Register memory and RAM.

Internal RAM of execution processor. Locations 0-7 are working register bank 0; 18-1F are working register bank 1. Only the low-order 7 bits of an address are considered.

[DATA MEM]

Display Response — "dA."

Function — External data memory (if installed).

Memory accessed by execution processor "MOVX A,@Rr" or "MOVX @Rr,A" instructions. High-order 4 bits may or may not be relevant, depending on jumpering option selected (explained in Section VII of this note).

[HARD REG]

Display Response — "Hr."

Function — Hardware registers.

The execution processor (EP) hardware registers (accumulator, timer/counter, etc.), as well as several parameters for controlling HSE-49 system status, are accessible through this catch-all memory space. Addresses are as follows:

00 — EP accumulator.

01 — EP PSW.
Bits correspond to 8049 PSW except that bit 3 (unused in the 8049) is used to monitor and alter the state of F1. Bits 2-0 correspond to the stack pointer value after the EP executes a CALL to the mini-monitor; i.e., one greater than when EP was running the user's program.

02 — EP timer/counter.

03 — EP internal RAM location 00.
(This value is also accessible through [REGISTER] space.)

04 — EP program counter (low byte).

05 — EP program counter (high nibble).

06-07 — HSE-49 serial interface baud rate parameters. Defaults to 110 baud; other rates may be selected by loading the values listed in Table 1.

08 — HSE-49 automatic sequencing rate parameter. Used in [GO][AUTO STP] and [GO][AUTO BRK] execution commands. 00 → fastest; FF → slowest. Defaults to 20H; approximately two steps per second.

09 — Monitor version/release number (packed BCD).

0A-0F — Currently unused by the monitor program.

10-7F — Variables used by master processor (MP) monitor. Should not be altered by operator.

[PROG BRK]

Display Response — "Pb."

Function — User program breakpoint memory.

Memory space used to indicate points where program execution should halt when running in a mode with breakpoints enabled ([GO][W/ BRK] and [GO][AUTOBRK]). Break will occur if enabled byte is read as the first or last byte of a 2-byte instruction, or read in executing a MOVP, MOVP3, or JMPP instruction. Memory is only 1 bit per location; 00 indicates continue, 01 causes a halt. Addresses 000 through 7FF are the execution processor's memory bank 0; 800 through FFF are memory bank 1.

[DATA BRK]

Display Response — "db."

Function — External data RAM breakpoint memory.

Memory space used to indicate points where data accesses should halt when running in a mode with breakpoints enabled ([GO][W/ BRK] and [GO][AUTOBRK]). Memory is only 1 bit per location; 00 indicates continue, 01 causes a halt. High-order 4 bits of breakpoint address may or may not be relevant, dependent on jumpering option selected for the corresponding data RAM (explained in Section VII of this note).

User Program Execution Control Group

Commands:

[GO]

Display Response — "Go."

Function — Begin execution.

If a parameter is given as part of the command string, execution will begin at that address. Otherwise, the EP program counter (hardware registers 04 and 05) will be used. These will contain the program counter from an earlier program execution break unless they have since been explicitly modified by the operator.

If command is terminated by [END/.], the EP's F1, PSW and stack pointer will be cleared. If command string is terminated by [NEXT/,], PSW will be taken from the EP PSW contents (hardware register 01).

While running the user's program, the characters "-run-." are written on the display. Execution may be halted and another command initiated by pressing the appropriate command key. Execution may be suspended at any time in any mode by pressing the [END/.] key. This will cause the current value of the execution processor program counter and accumulator to appear on the display in the form "PC.234-56". System status is saved in the appropriate hardware registers. At this point, or when an enabled breakpoint is encountered, pressing the [NEXT/,] key will cause the program to continue in the same mode as before. Any other command may be invoked by pressing the appropriate command string.

[GO/RESET]

Display Response — "Gr."

Function — Go from reset state.

EP is hardware-reset and released to execute the user's program from location 000H. No parameters are allowed. F0, F1, PSW, stack printer, memory bank flip-flop, etc., are cleared.

Note that this command does not require the use of mini-monitors to initiate program execution. As the last phase of the program development cycle, the 2114 program RAMs and address decoder may be removed and replaced by a ROM or EPROM part (not shown in schematics). This command may be used to start execution when the program RAM has been removed. No interrogation of EP status or internal RAM may be done, nor are break or single-step modes allowed in this case, though the 2102A breakpoint RAM outputs may still be used to trigger a logic analyzer.

Execution modes allowed:

[NO BRK]

Display Response — "nb."

Function — Without breakpoints.

Full-speed execution without breakpoints enabled. Does not affect the state of the breakpoint memories.

[SING STP]

Display Response — "SSt."

Function — Single Step.

Step through program one instruction at a time. After each instruction is executed, execution halts with the current value of the Execution Processor Program Counter and Accumulator appearing on the display in the form "PC.234-56". System status is saved in the appropriate Hardware Registers. At the point, [NEXT/,] will cause the program to execute one more instruction, or any other command may be invoked by pressing the appropriate command string. Does not affect the state of the Breakpoint Memories.

[W/ BRK]

Display Response — "br."

Function — With breakpoints.

Full-speed execution with breakpoints enabled. When a breakpoint is encountered, execution halts with the current value of the execution processor program counter and accumulator appearing on the display in the form "PC.234-56". System status is saved in the appropriate hardware registers. At this point, [NEXT.,] will cause the program to continue until the next breakpoint is reached, or any other command may be invoked by pressing the appropriate command string.

[AUTO STP]

Display Response — "ASt."

Function — Automatically sequence through a series of instructions.

Step through program one instruction at a time. After each instruction is executed, execution halts with the current value of the execution processor program counter and accumulator appearing on the display in the form "PC.234-56". System status is saved in the appropriate hardware registers. Execution resumes after a time determined by contents of hardware register 08. Does not affect the state of the breakpoint memories.

[AUTO BRK]

Display Response — "Abr."

Function — Automatically sequence between breakpoints.

Execute a series of instructions in real time between breakpoints. When breakpoint is encountered, halt EP temporarily while program counter and accumulator contents are displayed, then continue. Display is sustained after execution resumes. Does not affect the state of the breakpoint memories.

Breakpoint Control Command Group

Commands:

[B]

Display Response — "Stb."

Function — Breakpoint set.

Set breakpoint for the address given. Multiple breakpoints may be set by entering additional addresses, separated by the [NEXT/,] key. Command terminated by pressing [END/.]. Action taken is to fill the appropriate breakpoint memory locations with logical ones.

[C]

Display Response — "CLb."

Function — Clear breakpoint.

Clear breakpoint for the address given. Multiple breakpoints may be cleared by entering additional addresses, separated by the [NEXT/,] key. Command terminated by pressing [END/.]. Action taken is to fill the appropriate breakpoint memory locations with logical zeroes.

Data types allowed:

[PROG MEM]

Display Response — "Pr."

Function — Break on program memory fetch.

Applies command to the program breakpoint memory space.

[DATA MEM]

Display Response — "dA."

Function — Break on data memory access.

Applies command to the external data breakpoint memory space.

System Control Command Group

Command:

[SYS RST]

Display Response — "HSE-49."

Function — System reset.

Reset both the MP and EP and clear all breakpoints (requires approximately one second). CAUTION — If reset while EP is executing the user's program, the low order section of program memory (about 23 bytes) will be altered.

VI. SYSTEM LIMITATIONS

In designing the HSE-49 emulator, certain compromises were made in an attempt to maximize the usefulness of the emulator while keeping the circuitry simple and inexpensive. As a result, the following limitations exist and must be taken into account when using the system.

1. As explained in Section IV, user program execution is terminated (by single-stepping, breakpoints, pressing the [END/.] key, etc.) by forcing the execution processor to execute a "CALL" instruction to the mini-monitor. This uses one level of the EP subroutine stack. The EP PSW reflects the value of the stack pointer *after* processing this CALL. As a result, the value indicated for stack depth by examining the EP PSW (hardware register 01) is one greater than the depth when the break was initiated. The user program must not be using all eight levels of stack when a break is initiated or the bottom level will be destroyed.
2. User program is initiated (by the [GO] command or when resuming execution after a breakpoint, single-stepping, etc.) by forcing the EP to execute an "RETR" instruction. This will clear the EP interrupt-in-progress flip-flop. If the user program allows both external and timer interrupts to be enabled at the same time, care must be taken to avoid causing a break while the EP is within an interrupt servicing routine. No limitation is placed on breakpoints or single-stepping in the background program because of this.
3. When the user program execution is terminated (by a break, single-stepping, etc.) and later resumed, the EP timer/counter is restored to its value when the break occurred (unless modified by the user). The prescaler, however, will have changed. Thus, up to 31 machine cycles may be "lost" or "gained" if a break occurs while the timer is running.
4. Timer interrupts occurring at the same time as an EP break may be ignored if the timer overflow occurs after breaking user program execution before the timer value is saved.
5. The 8049 "RET" and "RETR" instructions are each 1-byte, 2-cycle instructions. During the second cycle the byte following the return instruction is fetched and ignored. If a program breakpoint is set for a location following a "RET" or "RETR" instruction, a break will be initiated when the return is executed.

6. Breakpoints should not be placed in the last 3 bytes of an EP memory bank (locations 7FDH-7FFH and 0FFDH-0FFFH). User program should not be single-stepped or auto-stepped through these locations.
7. Since I/O configuration is determined by external hardware rather than software, I/O modes may not be altered while a program is executing. (See Section VII for further details.)
8. The "ANL BUS,#nn" and "ORL BUS,#nn" instructions may not be used in the user program, as external hardware cannot properly restore these functions.
9. The memory bank select flag is not affected by the user program break sequence. Upon resuming execution with the [GO] command this flag will remain in the same state as before the preceding break. The flag may be cleared only by executing the [GO/RESET] or [SYS RST] commands.

VII. HARDWARE CONFIGURATIONS

A number of control and status lines are available to the user. All are low-power Schottky TTL-compatible signals.

TP1 — Unused MP input.

TP2 — Unused MP output.

TP3 — User program suspended. Low when EP running user code. High when halted or running mini-monitors.

TP4 — Breakpoint encountered. Normally low. High-level pulse generated when breakpoint passed. Useful for triggering logic analyzers, oscilloscopes, etc.

TP5 & TP6 — Memory matrix mode control. Select program vs. data RAM, link mapping configuration, etc. (See Appendix B for details.)

TP7 — Bus control. Low when MP controls common memory buses. High when EP controls memory buses.

The HSE-49 emulator hardware is designed to allow the user to reconfigure the system for a wide variety of different applications by installing or removing jumper wires or additional components. The schematics in Appendix A show the components needed for a variety of different configurations. In general, not all of the devices are required (or allowed) for any one configuration. The devices which are required are included in the following description.

The types of options allowed are divided below into several general classes and subdivided into mutually-independent features. Within some of these features there are numbered, mutually exclusive configurations; i.e., the serial interface (if desired) may use either current-loop or RS-232C current buffers, but not both at one time.

Standard Operating Configuration

(Minimum system configurations — up to 4K program RAM; no data RAM; no serial interfaces; no execution processor I/O reconstruction.)

A. Basic 2K monitor from Appendix B:

Install resistors R4-R6
Install transistor Q1
Install crystals Y1-Y2
Install capacitors C5-C38
Install switches S1-S33
Install displays DS1-DS8
Install IC1-IC2
Install RP3-RP5
Install IC6-IC7
Install RP8
Install IC9
Install IC15-IC20
Install IC25-IC30
Install IC34
Install IC36-IC38
Install A1-A2
Install B1-B2
Install C1-C3
Install jumpers 13-15
Install jumpers 17-18
Install jumper 20

B. Expansion 2K monitor:

Install IC14
Remove jumper 17

Serial Interface Buffer Selection

A. Current loop serial interfaces (4N46s) installed for use with full Intellec® Model 800 development system TTY port.

Install IC21-IC22
Install resistor R1-R3
Install jumpers 4-9
(Remove RS-232 jumpers)

B. RS-232C serial interfaces (MC1488 and MC1489) installed for use with CRT as output device for data dumps:

Install IC23-IC24
Install jumpers 1-3
Install jumpers 10-11
(Remove current-loop jumpers)

External Data RAM Address Decoding Scheme for Execution Processor

A. Up to 16 pages of on-board external data RAM installed for execution processor (addresses 0 through

0FFFH = 4K bytes); port 2 used for addressing pages 0 through 15:

Install jumpers 21-25
Install jumper 27
Install A5-A8
Install B5-B8
Install C5-C8

B. One page of on-board external data RAM installed for execution processor (addresses 0 through 0FFH); port 2 not used for data addressing:

Install jumper 26
Install jumper 28
Install A5
Install B5
Install C5

Connect the outputs of IC20, pins 7, 9, 10, & 11 to the inputs of a 74LS21 AND gate (not shown). Connect the output to CE and CS inputs of A5-C5. (Note: these signals are all present at jumpers 21-24 on the schematics.)

Reconstructing I/O for Execution Processor

A. Application of port 2, pins P23-P20:

(1) Using P23-P20 for latched output data (used with "OUTL P2,A", "ANL P2,#data", and "ORL P2,#data" instructions):

Install IC31

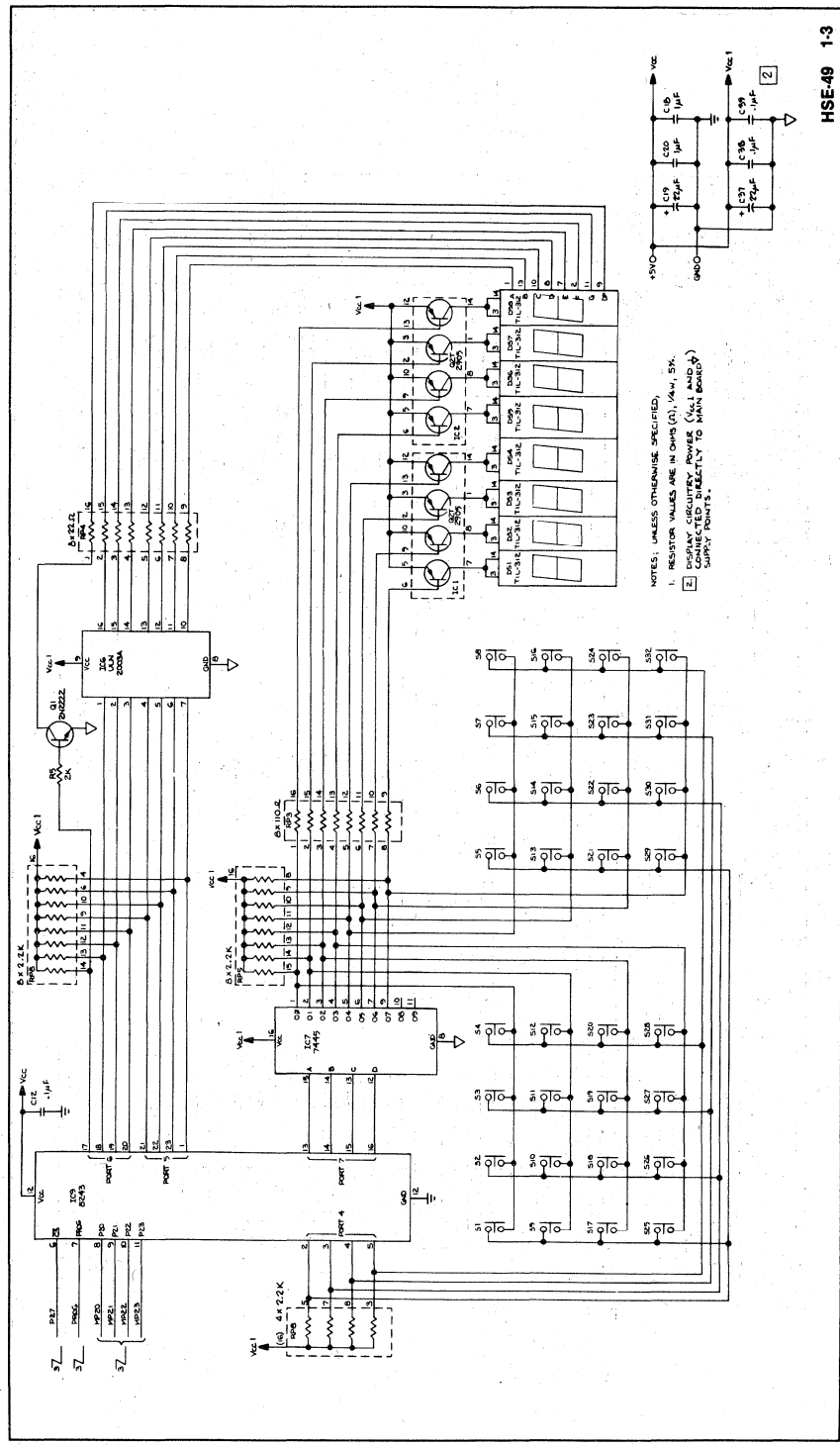
(2) Using P23-P20 for interfacing to an 8243 in user's prototype:

Connect D3-D0 pins on IC31 socket to corresponding Q3-Q0 pins.

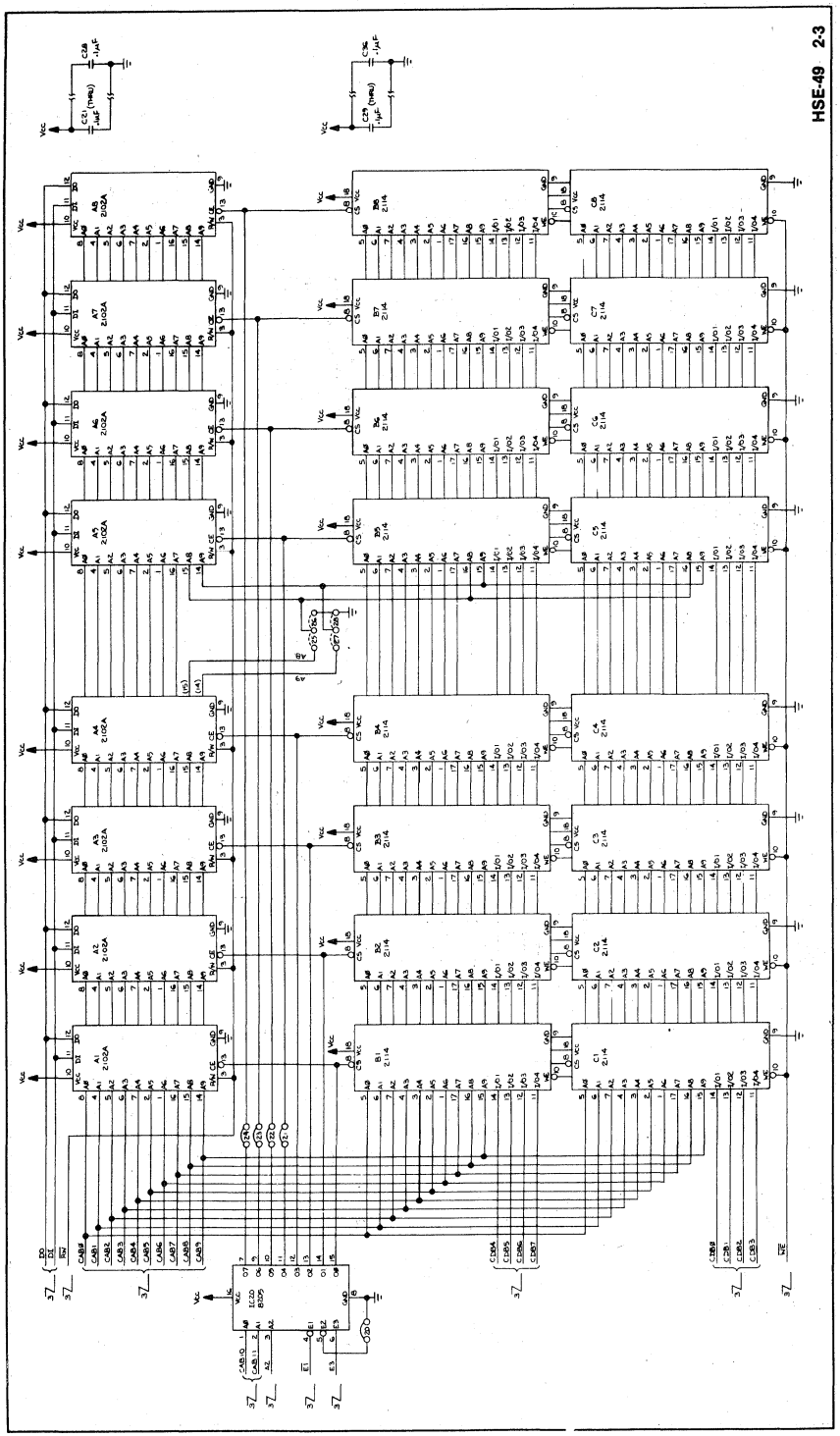
B. Application of execution processor BUS:

(1) Use of BUS as latched output port ("OUTL BUS,A"):

Install IC32

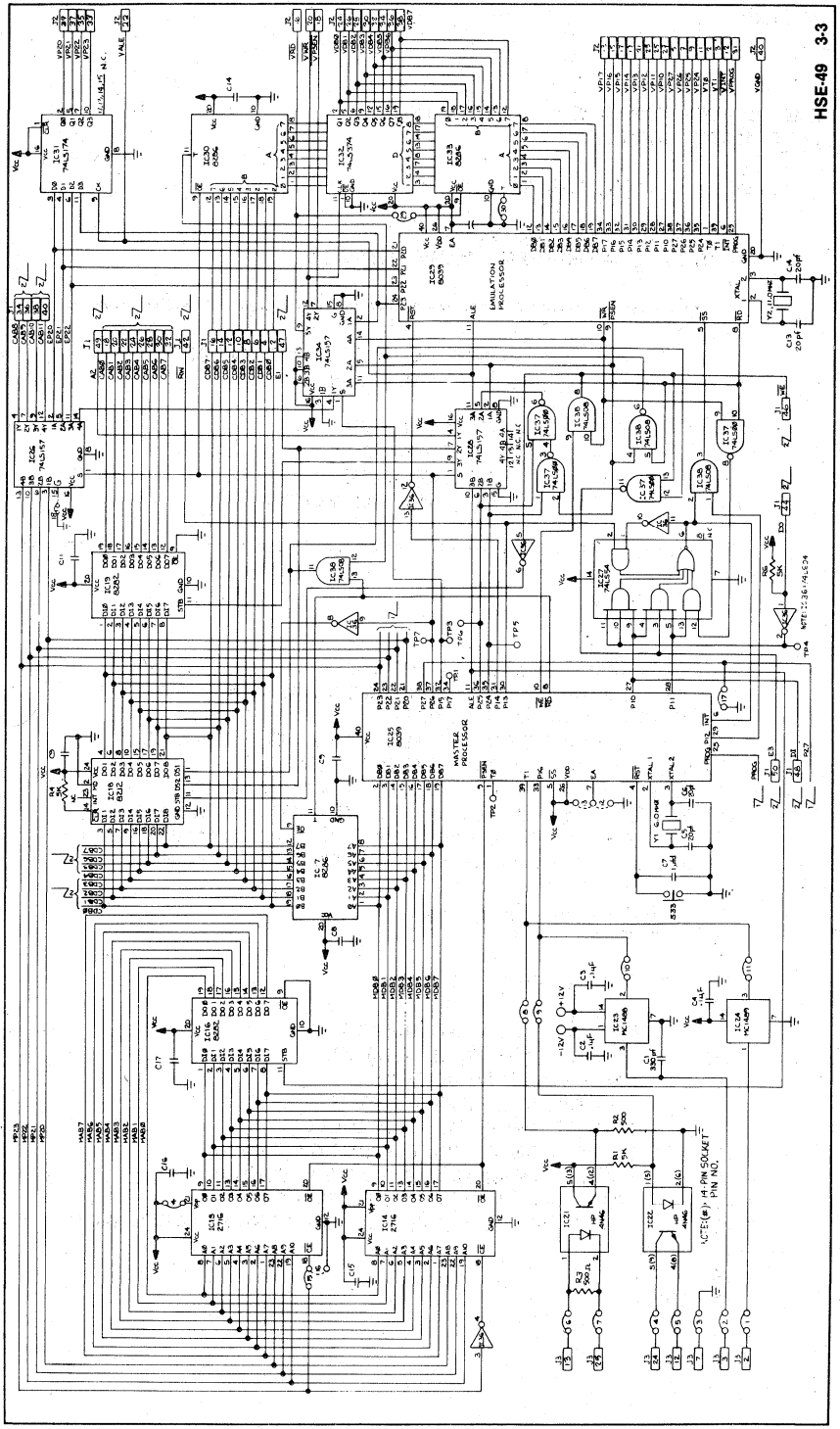


Key Board Display



HSE-49 2-3

Ram Memory


HSE-49 3-3
Central Processor
EMULATION PROCESSOR
MASTER PROCESSOR
NOTE: (#) 14 PIN SOCKET PIN NO.

1

```
ASM48 HSE49 LNK PRINT(:LP:)


ISIS-II MCS-48/UPI-41 MACRO ASSEMBLER, V3.0            PAGE    1
HSE-49(TM) EMULATOR MONITOR VERSION 2.5

 LOC  OBJ        LINE       SOURCE STATEMENT

                    1 $MACROFILE NOGEN NOCOND XREF
                    2 $TITLE('HSE-49(TM) EMULATOR MONITOR VERSION 2.5')
                    3 ;
                    4 ;*******************************************************************************
                    5 ;
                    6 ;                       PROGRAM: HSE-49(TM) EMULATOR MONITOR
                    7 ;                                VERS 2.5/709
                    8 ;
                    9 ;                       COPYRIGHT (C) 1979
                   10 ;                       INTEL CORPORATION
                   11 ;                       3065 BOWERS AVENUE
                   12 ;                       SANTA CLARA, CALIFORNIA 95051
                   13 ;
                   14 ;*******************************************************************************
                   15 ;
                   16 ;  ABSTRACT
                   17 ;  ========
                   18 ;
                   19 ; THIS PROGRAM CONTAINS THE SOFTWARE NECESSARY TO RUN THE HSE-49(TM)
                   20 ; HIGH-SPEED EMULATOR FOR INTEL'S MCS-48(TM) FAMILY FAMILY OF MICROCOMPUTERS.
                   21 ; THE EMULATOR PROVIDES AN ASSORTMENT OF UTILITY FUNCTIONS FOR
                   22 ; DEVELOPING AND DEBUGGING 8049-BASED APPLICATIONS, INCLUDING THE
                   23 ; ABILITY TO ENTER AND MODIFY PROGRAMS IN PROGRAM RAM,
                   24 ; ALTER DATA, SINGLE-STEP SECTIONS OF A PROGRAM, AND EXECUTE PROGRAMS
                   25 ; AT SPEEDS OF UP TO 11 MHZ. WITH OR WITHOUT BREAKPOINTS ENABLED.
                   26 ; THE EMULATOR IS DESCRIBED IN GREATER DEPTH IN INTEL'S APPLICATION NOTE
                   27 ; AP-55  "A HIGH-SPEED EMULATOR FOR INTEL MCS-48(TM) MICROCOMPUTERS."
                   28 ;
                   29 ;  PROGRAM ORGANIZATION
                   30 ;  ======= ============
                   31 ;
                   32 ; THIS LISTING IS ORGANIZED AS FOLLOWS:
                   33 ;
                   34 ;       INTRODUCTION AND HARDWARE OVERVIEW;
                   35 ;       VARIABLE DECLARATION AND DEFINITION;
                   36 ;       POWER-ON SYSTEM INITIALIZATION;
                   37 ;       KEYBOARD COMMAND PARSER AND ASSOCIATED TABLES;
                   38 ;       IMPLEMENTATIONS OF THE PRIMARY COMMANDS;
                   39 ;       DATA ACCESSING UTILITY SUBROUTINES USED THROUGHOUT;
                   40 ;       KEYBOARD SCANNING AND DISPLAY DRIVING SUBROUTINE;
                   41 ;       KEYBOARD AND DISPLAY INTERFACING UTILITIES;
                   42 ;       ROUTINES AND UTILITY SUBROUTINES WHICH INTERACT BETWEEN MP AND EP.
                   43 ;
                   44 ;
                   45 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                    46 ;
                    47 ;  INTRODUCTION AND HARDWARE OVERVIEW
                    48 ;  ============ === ======== ========
                    49 ;
                    50 ; THE EMULATOR DESIGN USES TWO MICROPROCESSORS.  ONE PROCESSOR CONTROLS
                    51 ; SYSTEM STATUS, INTERPRETS MONITOR COMMANDS, AND COMMUNICATES
                    52 ; WITH THE OUTSIDE WORLD THROUGH THE ON-BOARD KEYBOARD, DISPLAY, SERIAL
                    53 ; INTERFACES, CONTROL SIGNALS, ETC.
                    54 ; A SECOND PROCESSOR IS USED TO ACTUALLY
                    55 ; EXECUTE THE USER'S PROGRAM UNDER THE CONTROL OF THE FIRST.
                    56 ; THESE PROCESSORS ARE REFERRED TO
                    57 ; THROUGHOUT THIS PROGRAM AS THE MASTER PROCESSOR (MP) AND EXECUTION
                    58 ; PROCESSOR (EP) RESPECTIVELY.
                    59 ;
                    60 ; THE PROGRAM IN THIS LISTING IS EXECUTED BY THE MASTER PROCESSOR.
                    61 ; AT THE END OF THIS LISTING ARE SEVERAL SHORT "MINI-MONITOR OVERLAYS"
                    62 ; WHICH THE EXECUTION PROCESSOR EXECUTES WHEN INTERACTION BETWEEN THE
                    63 ; TWO PROCESSORS IS NECESSARY.
                    64 ;
                    65 ; THIS PROGRAM WAS WRITTEN USING A NUMBER OF MACROS TO HANDLE THE ALLOCATION
                    66 ; OF MPU RESOURCES (WORKING REGISTERS, INTERNAL RAM, AND MP MONITOR ROM
                    67 ; FOR CODE AND DATA STORAGE).  THESE MACRO DEFINITIONS ARE INCLUDED IN A FILE
                    68 ; NAMED "ALLOC.MAC," AND ARE PRINTED IN THIS LISTING FOR REFERENCE.
                    69 ; ANOTHER SET OF MACROS IS USED TO SIMPLIFY THE ACCESSING OF VARIABLES
                    70 ; STORED IN INTERNAL RAM (AS OPPOSED TO WORKING REGISTERS) BY USING R1 TO
                    71 ; INDIRECTLY ADDRESS THE APPROPRIATE RAM LOCATION WHEN NECESSARY.
                    72 ; THESE MACROS ARE INCLUDED IN "MOMCOD.MAC", AND ARE ALSO PRINTED HERE.
                    73 ; COMPLETE UNDERSTANDING OF THESE MACROS IS NOT REQUIRED TO UNDERSTAND THE
                    74 ; MONITOR PROPER.  ALL LINES WHICH ACTUALLY PRODUCE OBJECT CODE APPEAR IN
                    75 ; THE LISTING ITSELF, INDENTED TWO SPACES FROM THE NORMAL TABULATION COLUMNS.
                    76 ; THE ACTUAL MONITOR PROGRAM FOR THE EMULATOR BEGINS AT APPROXIMATELY
                    77 ; SOURCE LINE NUMBER 500.
                    78 ;
                    79 ; LINES GENERATED BY MACRO EXPANSION ARE FLAGGED BY A PLUS SIGN ("+")
                    80 ; IMMEDIATELY FOLLOWING THE SOURCE LINE NUMBER.
                    81 ; A NUMBER OF LINES FROM THE VARIOUS MACRO DEFINITIONS WHICH DO NOT
                    82 ; PRODUCE ANY OBJECT CODE ARE PROCESSED BY THE ASSEMBLER
                    83 ; AS THESE MACROS ARE EXPANDED.  WHEN THIS IS THE CASE, THESE LINES ARE
                    84 ; SUPPRESSED FROM THE LIST FILE.  AS A RESULT, THE LINE NUMBERS ARE
                    85 ; NOT ALWAYS CONSECUTIVE WHERE A MACRO IS BEING INVOKED.
                    86 ;
                    87 ; NOTE:
                    88 ; ====
                    89 ; "SOURCE-LINE" REFERS TO THE DECIMAL NUMBERS LEFT OF EACH INSTRUCTION.
                    90 ; AT THE END OF THE LISTING IS AN ASSEMBLY CROSS-REFERENCE TABLE INDICATING
                    91 ; THE SEQUENTIAL SOURCE-LINE NUMBER OF ALL INSTANCES WHERE ANY VARIABLE
                    92 ; IS DEFINED OR REFERENCED.  THIS WILL BE OF GREAT ASSISTANCE IN
                    93 ; LOCATING SPECIFIC SUBROUTINES, ETC. IN THE LISTING.
                    94 ;
                    95 ; MNEMONICS COPYRIGHT (C) 1976 INTEL CORPORATION
                    96 ;
                    97 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                  98 $       INCLUDE(:F0:ALLOC.MAC)
0000            =  99 ?R1     SET     0
                = 100 ;
0000            = 101 ?RB0    EQU     0
0001            = 102 ?RB1    EQU     1
0002            = 103 ?RAM    EQU     2
0003            = 104 ?CONST  EQU     3
0004            = 105 ?A      EQU     4       ;ACCUMULATOR VARIABLE TYPE
                = 106 ;
                = 107 ;THE FOLLOWING INITIALIZES THE LINKED LIST POINTERS FOR
                = 108 ;THE REGISTER ALLOCATION AND DEALLOCATION ROUTINES.
                = 109 ;
0003            = 110 ?B0R2   SET     3
0004            = 111 ?B0R3   SET     4
0005            = 112 ?B0R4   SET     5
0006            = 113 ?B0R5   SET     6
0007            = 114 ?B0R6   SET     7
0008            = 115 ?B0R7   SET     8
                = 116 ;
0002            = 117 ?B0PNT  SET     2
                = 118 ;
0003            = 119 ?B1R2   SET     3
0004            = 120 ?B1R3   SET     4
0005            = 121 ?B1R4   SET     5
0006            = 122 ?B1R5   SET     6
0007            = 123 ?B1R6   SET     7
0008            = 124 ?B1R7   SET     8
                = 125 ;
0002            = 126 ?B1PNT  SET     2
                = 127 ;
0000            = 128 ORGPG0  SET     000H
0100            = 129 ORGPG1  SET     100H
0200            = 130 ORGPG2  SET     200H
0300            = 131 ORGPG3  SET     300H
0400            = 132 ORGPG4  SET     400H
0500            = 133 ORGPG5  SET     500H
0600            = 134 ORGPG6  SET     600H
0700            = 135 ORGPG7  SET     700H
                = 136 ;
                = 137 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                = 138 ;*****************************************************************
                = 139 ;
                = 140 ;         START OF ALLOCATION MACROS
                = 141 ;
                = 142 ;*****************************************************************
                = 143 ;
                = 144 ?RSAVE    MACRO   SYMBOL,BANK,PNTVAL
-               = 145 IF        PNTVAL EQ 8
--              = 146           ERROR   2
--              = 147           EXITM
-               = 148 ENDIF
--              = 149 $         SAVE GEN
-               = 150           SYMBOL  SET  R&PNTVAL
--              = 151 $         RESTORE
-               = 152 ?B&BANK&PNT       SET     ?B&BANK&R&PNTVAL
                = 153           ENDM
                = 154 ;
                = 155 ;
0020            = 156 ?MINDX    SET     20H
                = 157 ;
                = 158 ?MSAVE    MACRO   SYMBOL,LENGTH,ADDR
                = 159 $         SAVE GEN
--              = 160           SYMBOL  EQU  ADDR
-               = 161 $         RESTORE
.               = 162 ?MINDX    SET     ?MINDX+LENGTH
                = 163 ENDM
                = 164 ;
                = 165 MBLOCK    MACRO   SYMBOL,LENGTH
-               = 166 ?&SYMBOL          EQU   3
--              = 167           ?MSAVE  SYMBOL,LENGTH,%?MINDX
                = 168 ENDM
                = 169 ;
                = 170 DECLARE MACRO   SYMBOL,TYPE
-               = 171 ?&SYMBOL          SET     ?&TYPE
-               = 172 IF        ?&TYPE EQ 2
--              = 173           ?MSAVE  SYMBOL,1,%?MINDX
---             = 174           EXITM
--              = 175 ENDIF
--              = 176 IF        ?&TYPE EQ 0
-               = 177           ?RSAVE  SYMBOL,0,%?B0PNT
.               = 178           EXITM
-               = 179 ENDIF
.               = 180 IF        ?&TYPE EQ 1
--              = 181           ?RSAVE  SYMBOL,1,%?B1PNT
--              = 182           EXITM
--              = 183 ENDIF
                = 184           ENDM
                = 185 ;
                = 186 $         EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                = 187 ;
                = 188 ;REORG  MACRO TO RESET THE INSTRUCTION LOCATION COUNTER
                = 189 ;       TO THE FIRST FREE LOCATION ON THE FIRST PAGE MODULE WILL
                = 190 ;       FIT WITHIN.
                = 191 REORG   MACRO LOCATION
                = 192 $SAVE GEN
                = 193           ORG     LOCATION
                = 194 $RESTORE
                = 195         ENDM
                = 196 ;
                = 197 ;CODEBLK        MACRO TO FIND A PAGE OF ROM
                = 198 ;       WHICH THIS BLOCK OF CODE WILL FIT WITHIN
                = 199 CODEBLK MACRO   LENGTH
                = 200 ?LENGTH SET     LENGTH
                = 201 IF      HIGH(ORGPG0+LENGTH-1) EQ 0
                = 202         REORG   %ORGPG0
                = 203 ?START  SET     $
                = 204 EXITM
                = 205 ENDIF
                = 206 IF      HIGH(ORGPG1+LENGTH-1) EQ 1
                = 207         REORG   %ORGPG1
                = 208 ?START  SET     $
                = 209 EXITM
                = 210 ENDIF
                = 211 IF      HIGH(ORGPG2+LENGTH-1) EQ 2
                = 212         REORG   %ORGPG2
                = 213 ?START  SET     $
                = 214 EXITM
                = 215 ENDIF
                = 216 IF      HIGH(ORGPG4+LENGTH-1) EQ 4
                = 217         REORG   %ORGPG4
                = 218 ?START  SET     $
                = 219 EXITM
                = 220 ENDIF
                = 221 IF      HIGH(ORGPG5+LENGTH-1) EQ 5
                = 222         REORG   %ORGPG5
                = 223 ?START  SET     $
                = 224 EXITM
                = 225 ENDIF
                = 226 IF      HIGH(ORGPG6+LENGTH-1) EQ 6
                = 227         REORG   %ORGPG6
                = 228 ?START  SET     $
                = 229 EXITM
                = 230 ENDIF
                = 231 IF      HIGH(ORGPG7+LENGTH-1) EQ 7
                = 232         REORG   %ORGPG7
                = 233 ?START  SET     $
                = 234 EXITM
                = 235 ENDIF
                = 236 IF      HIGH(ORGPG3+LENGTH-1) EQ 3
                = 237         REORG   %ORGPG3
                = 238 ?START  SET     $
                = 239 EXITM
                = 240 ENDIF
                = 241         ERROR   0       ;*** INSUFFICIENT SPACE FOR CODE ON ANY PAGE ***
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                = 242          ENDM
                = 243 ;DATABLK        INSERTS ONTO PAGE 3
                = 244 DATABLK MACRO   LENGTH
-               = 245 ?LENGTH SET     LENGTH
--              = 246 IF      HIGH(ORGPG3+LENGTH-1) EQ 3
--              = 247         REORG   %ORGPG3
-               = 248 ?START  SET     $
--              = 249 EXITM
-               = 250 ENDIF
--              = 251         ERROR   0       ;*** INSUFFICIENT SPACE FOR DATA BLOCK ON PAGE 3 ***
                = 252         ENDM
                = 253 ;?SIZE  PRINTS A LINE TO THE SOURCE FILE GIVING BLOCK SIZE.
                = 254 ;       AND UPDATES APPROPRIATE ORGPG#
                = 255 ?SIZE   MACRO   BLK,PGE
                = 256 $SAVE GEN
-               = 257   SIZE  SET   BLK
-               = 258 ;
-               = 259 ;*******************************************************
                = 260 IF ?LENGTH LT SIZE
-               = 261         ERROR   0       ;*** SIZE EXCEEDS SPACE CHECKED FOR BY CODEBLK MACRO
-               = 262 ENDIF
-               = 263 IF      HIGH($-1) NE HIGH(?START)
-               = 264         ERROR   0       ;*** CODE OR DATA BLOCK ROLLED OVER PAGE BOUNDARY ***
--              = 265 ENDIF
-               = 266 $RESTORE
--              = 267 ORGPG&PGE       SET     $
                = 268         ENDM
                = 269 ;SIZECHK        CHECKS SIZE OF PRECEDING BLOCK, PRINTS SIZE TO .LST FILE.
                = 270 SIZECHK MACRO
-               = 271         ?SIZE   %($-?START),%HIGH(?START)
                = 272         ENDM
                = 273 ;
                = 274 ;
                = 275 ;RSOURCE        CODE SPACE  ALLOCATION SUMMARY STATEMENT
                = 276 RSOURCE MACRO
                = 277 $SAVE LIST GEN
--              = 278           PGSIZE  SET   ORGPG0-000H     ;BYTES USED ON PAGE 0
-               = 279           PGSIZE  SET   ORGPG1-100H     ;BYTES USED ON PAGE 1
--              = 280           PGSIZE  SET   ORGPG2-200H     ;BYTES USED ON PAGE 2
-               = 281           PGSIZE  SET   ORGPG3-300H     ;BYTES USED ON PAGE 3
--              = 282           PGSIZE  SET   ORGPG4-400H     ;BYTES USED ON PAGE 4
-               = 283           PGSIZE  SET   ORGPG5-500H     ;BYTES USED ON PAGE 5
--              = 284           PGSIZE  SET   ORGPG6-600H     ;BYTES USED ON PAGE 6
-               = 285           PGSIZE  SET   ORGPG7-700H     ;BYTES USED ON PAGE 7
-               = 286 $EJECT
-               = 287 $RESTORE
                = 288         ENDM
                = 289 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                  290 ;
                  291 $       INCLUDE(:F0:MOPCOD.MAC)
                = 292 ;
                = 293 ;?FORM1 MACRO   FOR GENERALIZING OPCODE INSTRUCTION
                = 294 ;
                = 295 ?FORM1  MACRO   OPCODE,SRC
-               = 296 IF      ?&SRC EQ 2
--              = 297 $       SAVE GEN
-               = 298           MOV     R1,#SRC
-               = 299           OPCODE          A,@R1
-               = 300 $       RESTORE
-               = 301         EXITM
--              = 302 ENDIF
--              = 303 IF      ?&SRC EQ 0 OR ?&SRC EQ 1
-               = 304 $       SAVE GEN
--              = 305           OPCODE          A,SRC
--              = 306 $       RESTORE
--              = 307         EXITM
-               = 308 ENDIF
--              = 309 IF      ?&SRC EQ 3
--              = 310 $       SAVE GEN
-               = 311           OPCODE          A,#SRC
--              = 312 $       RESTORE
--              = 313         EXITM
--              = 314 ENDIF
--              = 315         ERROR   1
                = 316 ENDM
                = 317 ;
                = 318 ;?FORM2 MACRO   FOR GENERALIZING MOVES FROM THE ACC TO A VARIABLE
                = 319 ?FORM2  MACRO   DEST
-               = 320 IF      ?&DEST EQ 2
-               = 321 $       SAVE GEN
-               = 322           MOV     R1,#DEST
-               = 323           MOV     @R1,A
--              = 324 $       RESTORE
--              = 325         EXITM
-               = 326 ENDIF
--              = 327 IF      ?&DEST EQ 0 OR ?&DEST EQ 1
--              = 328 $       SAVE GEN
-               = 329           MOV     DEST,A
-               = 330 $       RESTORE
-               = 331         EXITM
--              = 332 ENDIF
-               = 333         ERROR   1
                = 334 ENDM
                = 335 ;
                = 336 ;?FORM3 MACRO   FOR GENERALIZING MOVES FROM THE ACC TO A VARIABLE
                = 337 ;               WHEN IT IS KNOWN THAT R1 (IF NEEDED FOR INDIRECT ADDRESSING)
                = 338 ;               IS ALREADY PRESET.
                = 339 ?FORM3  MACRO   DEST
-               = 340 IF      ?&DEST EQ 2
-               = 341 $       SAVE GEN
-               = 342           MOV     @R1,A
-               = 343 $       RESTORE
-               = 344         EXITM
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                = 345 ENDIF
                = 346 IF      ?&DEST EQ 0 OR ?&DEST EQ 1
                = 347 $       SAVE GEN
                = 348           MOV     DEST,A
                = 349 $       RESTORE
                = 350         EXITM
                = 351 ENDIF
                = 352         ERROR   1
                = 353 ENDM
                = 354 ;
                = 355 ;?FORM4 MACRO   FOR GENERALIZING 'MOV   A,SRC' INSTRUCTION
                = 356 ?FORM4  MACRO   SRC
                = 357 IF      ?&SRC EQ 2
                = 358 $       SAVE GEN
                = 359           MOV     R1,#SRC
                = 360           MOV     A,@R1
                = 361 $       RESTORE
                = 362         EXITM
                = 363 ENDIF
                = 364 IF      ?&SRC EQ 0 OR ?&SRC EQ 1
                = 365 $       SAVE GEN
                = 366           MOV     A,SRC
                = 367 $       RESTORE
                = 368         EXITM
                = 369 ENDIF
                = 370 IF      ?&SRC EQ 3
                = 371 $       SAVE GEN
                = 372           MOV     A,#SRC
                = 373 $       RESTORE
                = 374         EXITM
                = 375 ENDIF
                = 376         ERROR   1
                = 377 ENDM
                = 378 ;
                = 379 ;?FORM5 MACRO   FOR GENERALIZING MOVING A CONSTANT INTO A VARIABLE
                = 380 ?FORM5  MACRO   DEST,CONST
                = 381 IF      ?&DEST EQ 0 OR ?&DEST EQ 1 OR ?&DEST EQ 4
                = 382 $       SAVE GEN
                = 383           MOV     DEST,#CONST
                = 384 $       RESTORE
                = 385         EXITM
                = 386 ENDIF
                = 387 IF      ?&DEST EQ 2
                = 388 $       SAVE GEN
                = 389           MOV     R1,#DEST
                = 390           MOV     @R1,#CONST
                = 391 $       RESTORE
                = 392         EXITM
                = 393 ENDIF
                = 394         ERROR   1
                = 395 ENDM
                = 396 ;
                = 397 ;MMOV   MACRO   GENERALIZED MOVE FROM SRC TO DEST
                = 398 MMOV    MACRO   DEST,SRC
                = 399 IF      ?&SRC EQ 3
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                = 400         ?FORM5  DEST,SRC
                = 401         EXITM
                = 402 ENDIF
                = 403 IF      ?&DEST EQ 4
                = 404         ?FORM1  MOV,SRC
                = 405         EXITM
                = 406 ENDIF
                = 407 IF      ?&SRC EQ 4
                = 408         ?FORM2  DEST
                = 409         EXITM
                = 410 ENDIF
                = 411         ?FORM1  MOV,SRC
                = 412         ?FORM2  DEST
                = 413 ENDM
                = 414 ;?BINOP MACRO   GENERALIZES ARITHMETIC AND LOGICAL OPERATIONS
                = 415 ?BINOP  MACRO   OPCODE,DEST,SRC
                = 416 IF      ?&DEST EQ 4
                = 417         ?FORM1  OPCODE,SRC
                = 418         EXITM
                = 419 ENDIF
                = 420 IF      ?&SRC EQ 4
                = 421         ?FORM1  OPCODE,DEST
                = 422         ?FORM3  DEST
                = 423         EXITM
                = 424 ENDIF
                = 425         ?FORM1  MOV,SRC
                = 426         ?FORM1  OPCODE,DEST
                = 427         ?FORM3  DEST
                = 428 ENDM
                = 429 ;MADD   MACRO   FOR GENERALIZING ADD INSTRUCTION
                = 430 MADD    MACRO   DEST,SRC
                = 431         ?BINOP  ADD,DEST,SRC
                = 432         ENDM
                = 433 ;
                = 434 ;MADDC  MACRO   FOR GENERALIZING ADDC INSTRUCTION
                = 435 MADDC   MACRO   DEST,SRC
                = 436         ?BINOP  ADDC,DEST,SRC
                = 437         ENDM
                = 438 ;
                = 439 ;MANL   MACRO   FOR GENERALIZING ANL INSTRUCTION
                = 440 MANL    MACRO   DEST,SRC
                = 441         ?BINOP  ANL,DEST,SRC
                = 442         ENDM
                = 443 ;
                = 444 ;MORL   MACRO   FOR GENERALIZING ORL INSTRUCTION
                = 445 MORL    MACRO   DEST,SRC
                = 446         ?BINOP  ORL,DEST,SRC
                = 447         ENDM
                = 448 ;
                = 449 ;MXRL   MACRO   FOR GENERALIZING XRL INSTRUCTION
                = 450 MXRL    MACRO   DEST,SRC
                = 451         ?BINOP  XRL,DEST,SRC
                = 452         ENDM
                = 453 ;
                = 454 ;MXCH   MACRO   FOR GENERALIZING XCH INSTRUCTION
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                = 455 MXCH    MACRO   DEST,SRC
-               = 456         ?BINOP  XCH,DEST,SRC
                = 457         ENDM
                = 458 ;
                = 459 ?UNARY  MACRO   OPCODE,DEST
-               = 460         ?FORM1  MOV,DEST
-               = 461 $SAVE GEN
-               = 462           OPCODE          A
-               = 463 $RESTORE
-               = 464         ?FORM3  DEST
                = 465         ENDM
                = 466 ;
                = 467 MINC    MACRO   DEST
-               = 468         ?UNARY  INC,DEST
                = 469         ENDM
                = 470 ;
                = 471 MDEC    MACRO   DEST
-               = 472         ?UNARY  DEC,DEST
                = 473         ENDM
                = 474 ;
                = 475 MDJNZ   MACRO   DEST,ADDR
-               = 476         ?UNARY  DEC,DEST
-               = 477 $SAVE GEN
--              = 478           JNZ     ADDR
--              = 479 $RESTORE
                = 480         ENDM
                = 481 ;
                = 482 MRL     MACRO   DEST
-               = 483         ?UNARY  RL,DEST
                = 484         ENDM
                = 485 ;
                = 486 MRR     MACRO   DEST
-               = 487         ?UNARY  RR,DEST
                = 488         ENDM
                = 489 ;
                = 490 MRRC    MACRO   DEST
-               = 491         ?UNARY  RRC,DEST
                = 492         ENDM
                = 493 ;
                = 494 MRLC    MACRO   DEST
-               = 495         ?UNARY  RLC,DEST
                = 496         ENDM
                = 497 ;
                = 498 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                  499 ;
                  500 ;=======================================================
                  501 ;=======================================================
                  502 ;               BEGINNING OF PROGRAM PROPER
                  503 ;=======================================================
                  504 ;=======================================================
                  505 ;
                  506 ;
                  507 ;*********************************************************
                  508 ;
                  509 ;       ALLOCATION OF MP I/O PORTS:
                  510 ;
                  511 ;*********************************************************
                  512 ;
                  513 ;       BUS             ;USED FOR BIDIRECTIONAL ADDRESS AND DATA TRANSFERS
                  514 ;       P1              ;USED AS INDIVIDUAL CONTROL OUTPUTS AND BREAK LOGIC
                  515 ;       P2              ;HIGH-ORDER ADDRESS AND ADDRESS SPACE SELECTION
                  516 ;
000E              517 PDIGIT  EQU     P7      ;USED TO ENABLE CHARACTERS AND STROBE ROWS OF KEYBOARD
000D              518 PSEGHI  EQU     P6      ;USED TO TURN ON HI SEGMENTS OF CURRENTLY ENABLED DIGIT
000C              519 PSEGLO  EQU     P5      ;PORT FOR LOWER FOUR SEGMENTS
000B              520 PINPUT  EQU     P4      ;PORT USED TO SCAN FOR KEY CLOSURES
                  521 ;
                  522 ;*********************************************************
                  523 ;
                  524 ;       INDIVIDUAL PINS OF PORT 1 USED AS FOLLOWS:
                  525 ;
                  526 ;*********************************************************
                  527 ;
0001              528 ENBRAM  EQU     00000001B   ;P10 - HI ENABLES BREAK ON BREAK RAM OUTPUT SIGNAL
0002              529 ENBLNK  EQU     00000010B   ;P11 - HI ENABLES BREAK ON RD OR WR TO LINK BY EP
                  530                             ;       (NOTE: P11 & P10 BOTH HI ENABLES
                  531                             ;       BREAK ON ANY EP INSTRUCTION CYCLE)
0004              532 EPSSTP  EQU     00000100B   ;P12 - LO FORCES EP SS INPUT LOW,
                  533                             ;       HI GATES BREAKPOINT FLIP-FLOP TO EP SS INPUT.
0008              534 CLRBFF  EQU     00001000B   ;P13 - LO CLEARS BREAK FLIP-FLOP
                  535                             ;       AND ENABLES WR CONTROL TO BREAKPOINT RAM.
0010              536 EPRSET  EQU     00010000B   ;P14 - HI RESETS EP
0020              537 MODOUT  EQU     00100000B   ;P15 - LO WHEN EP IS EXECUTING USER PROGRAM,
                  538                             ;       HI WHEN EP FROZEN OR RUNNING OVERLAYS.
0040              539 TTYOUT  EQU     01000000B   ;P16 - SERIAL OUTPUT TO TTY OR CRT
                  540                             ;P17 - UNUSED
                  541 ;
                  542 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                  543 ;*******************************************************
                  544 ;
                  545 ;       INDIVIDUAL PINS OF PORT 2 USED AS FOLLOWS
                  546 ;
                  547 ;*******************************************************
                  548 ;
                  549 ;       P23-P20             ;ADR11-ADR8 FOR ACCESSING PROGRAM OR DATA RAM ARRAY
                  550 ;
0010              551 M0      EQU     00010000B   ;P24 - MEMORY MATRIX CONTROL PIN 0
0020              552 M1      EQU     00100000B   ;P25 - MEMORY MATRIX CONTROL PIN 1
0040              553 MPUSEL  EQU     01000000B   ;P26 - HIGH WHEN MP IN CONTROL OF COMMON MEM ARRAY,
                  554                             ;       LOW WHEN EP IN CONTROL.
0080              555 EXPMON  EQU     10000000B   ;P27 - JUMPERED TO GROUND FOR STANDARD MONITOR,
                  556                             ;       FLOATING WHEN EXPANSION MONITOR PRESENT.
                  557 ;
                  558 ;
                  559 ;WHEN MP IN CONTROL OF MEMORY MATRIX M1-M0 USED AS FOLLOWS:
                  560 ;
                  561 ;       M1 M0   MODE
                  562 ;        0  0   PROGRAM RAM ARRAY ENABLED FOR READ & WRITE
                  563 ;        0  1   DATA RAM ARRAY ENABLED FOR READ & WRITE
                  564 ;        1  X   LINK REGISTER ENABLED FOR READ, RAM ARRAYS DISABLED.
                  565 ;               (NOTE: LINK REGISTER ALWAYS ENABLED FOR MP WRITES)
                  566 ;
                  567 ;WHEN EP IN CONTROL OF MATRIX M1-M0 USED AS FOLLOWS:
                  568 ;
                  569 ;       M1 M0   MODE
                  570 ;        0  X   EP PSEN FETCHES FROM LINK REGISTER (USED TO FORCE OPCODES)
                  571 ;        1  0   EP PSEN FETCHES FROM PROGRAM RAM ARRAY,
                  572 ;               EP RD & WR CONTROL DATA RAM ARRAY.
                  573 ;        1  1   EP PSEN FETCHES FROM PROGRAM RAM ARRAY,
                  574 ;               RD & WR CONTROL LINK REGISTER.
                  575 ;
                  576 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                  577 ;
                  578 ;*******************************************************
                  579 ;
                  580 ;       SYSTEM CONSTANT DEFINITIONS
                  581 ;
                  582 ;*******************************************************
                  583 ;
                  584 DECLARE CHARNO,CONST    ;NUMBER OF DIGITS IN DISPLAY AND ROWS OF KEYS
0008              598         CHARNO  EQU     8
                  599 ;
                  600 DECLARE NCOLS,CONST     ;LESSER DIMENSION OF KEYBOARD MATRIX
0004              614         NCOLS   EQU     4
                  615 ;
                  616 DECLARE DEBNCE,CONST    ;NUMBER OF SUCESSIVE SCANS BEFORE KEY CLOSURE ACCEPTED
0008              630         DEBNCE  EQU     8
                  631 ;
                  632 DECLARE OVSIZE,CONST    ;SIZE OF LARGEST MINI-MONITOR OVERLAY FOR EP
0017              640         OVSIZE  EQU     23
                  647 ;
                  648 DECLARE BUFLEN,CONST    ;LENGTH OF HEX FORMAT XMIT BUFFER (MAX RECORD LENGTH)
0010              662         BUFLEN  EQU     16
                  663 ;
                  664 ;*******************************************************
                  665 ;
                  666 ;       UTILITY CONSTANT DECLARATIONS
                  667 ;
                  668 ;*******************************************************
                  669 ;
                  670 DECLARE ZERO,CONST
0000              684 ZERO    EQU     0
                  685 DECLARE PLUS1,CONST
0001              699 PLUS1   EQU     1
                  700 DECLARE PLUS3,CONST
0003              714 PLUS3   EQU     3
                  715 DECLARE NEG1,CONST
FFFF              729 NEG1    EQU     -1
                  730 ;
                  731 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                732 ;
                733 ;*********************************************************
                734 ;
                735 ;       BANK 0 REGISTER ALLOCATION:
                736 ;
                737 ;*********************************************************
                738 ;
                739 DECLARE LDATA,RB0       ;DATA USED BY LOGICAL ADDRESSING READ/WRITE UTILITIES
0002            752+        LDATA   SET  R2
                756 DECLARE KEY,RB0         ;HOLDS KEYCODE RETURNED FROM KBD INPUT ROUTINE.
0003            769+        KEY     SET  R3
                773 DECLARE ITMP,RB0        ;COUNTER USED AS AN INDEX IN PARSER ROUTINE
0004            786+        ITMP    SET  R4
                790 DECLARE CHKSUM,RB0      ;CHECKSUM OF DATA BYTES TRANSMITTED IN HEX FILE FORMAT
0005            803+        CHKSUM  SET  R5
                807 DECLARE DSPTMP,RB0      ;TEMPORARY STORAGE FOR DISPLAY PATTERNS IN 'DSPACC'
0006            820+        DSPTMP  SET  R6
                824 DECLARE XPCODE,RB0      ;EXPANSION MONITOR ROUTINE CODE NUMBER
0007            837+        XPCODE  SET  R7
                841 ;
                842 ;*********************************************************
                843 ;
                844 ;       BANK 1 REGISTER ALLOCATION
                845 ;
                846 ;*********************************************************
                847 ;
                848 DECLARE ROTPAT,RB1      ;USED TO HOLD INPUT PATTERN BEING ROTATED THROUGH CY
0002            865+        ROTPAT  SET  R2
                869 DECLARE ROTCNT,RB1      ;COUNTS NUMBER OF BITS ROTATED THROUGH CY
0003            886+        ROTCNT  SET  R3
                890 DECLARE LASTKY,RB1      ;HOLDS KEY POSITION OF LAST KEY DEPRESSION DETECTED
0004            907+        LASTKY  SET  R4
                911 DECLARE CURDIG,RB1      ;HOLDS POSITION OF NEXT CHARACTER TO BE DISPLAYED
0005            928+        CURDIG  SET  R5
                932 DECLARE KEYFLG,RB1      ;FLAG TO DETECT WHEN ALL KEYS ARE RELEASED
0006            949+        KEYFLG  SET  R6
                953                         ;(REGISTER 7 NOT USED FOR PRIMARY MONITOR)
                954 ;
                955 ;*********************************************************
                956 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                 957 ;
                 958 ;*******************************************************
                 959 ;
                 960 ;       DATA RAM ALLOCATION
                 961 ;
                 962 ;*******************************************************
                 963 ;
                 964 DECLARE EPACC,RAM       ;STORAGE IN MP FOR EP ACCUMULATOR
0020             969+        EPACC   EQU  32
                 973 DECLARE EPPSW,RAM       ;STORAGE IN MP FOR EP PROGRAM STATUS WORD
0021             978+        EPPSW   EQU  33
                 982 DECLARE EPTIMR,RAM      ;STORAGE IN MP FOR EP TIMER/COUNTER REGISTER
0022             987+        EPTIMR  EQU  34
                 991 DECLARE EPR0,RAM        ;STORAGE IN MP FOR EP REGISTER 0 OF BANK 0
0023             996+        EPR0    EQU  35
                1000 DECLARE EPPCLO,RAM      ;STORAGE IN MP FOR LOW BYTE OF EP PROGRAM COUNTER
0024            1005+        EPPCLO  EQU  36
                1009 DECLARE EPPCHI,RAM      ;STORAGE IN MP FOR HIGH NIBBLE OF EP PROGRAM COUNTER
0025            1014+        EPPCHI  EQU  37
                1018 DECLARE HBITLO,RAM      ;PARAMETER 1 FOR SERIAL LINK DATA RATE GENERATOR
0026            1023+        HBITLO  EQU  38
                1027 DECLARE HBITHI,RAM      ;PARAMETER 2 FOR SERIAL LINK DATA RATE GENERATOR
0027            1032+        HBITHI  EQU  39
                1036 DECLARE DSPTIM,RAM      ;PARAMETER FOR AUTO-STEP AND AUTO-BREAK SEQUENCING RATE
0028            1041+        DSPTIM  EQU  40
                1045 DECLARE VERSNO,RAM      ;MONITOR VERSION NUMBER
0029            1050+        VERSNO  EQU  41
                1054 DECLARE HREGA,RAM       ;  (UNUSED)
002A            1059+        HREGA   EQU  42
                1063 DECLARE HREGB,RAM       ;  (UNUSED)
002B            1068+        HREGB   EQU  43
                1072 DECLARE HREGC,RAM       ;  (UNUSED)
002C            1077+        HREGC   EQU  44
                1081 DECLARE HREGD,RAM       ;  (UNUSED)
002D            1086+        HREGD   EQU  45
                1090 DECLARE HREGE,RAM       ;  (UNUSED)
002E            1095+        HREGE   EQU  46
                1099 DECLARE HREGF,RAM       ;  (UNUSED)
002F            1104+        HREGF   EQU  47
                1108 DECLARE SMALO,RAM       ;PRIMARY COMMAND STARTING MEMORY ADDRESS (LOW BYTE)
0030            1113+        SMALO   EQU  48
                1117 DECLARE SMAHI,RAM       ;PRIMARY COMMAND STARTING MEMORY ADDRESS (HIGH BYTE)
0031            1122+        SMAHI   EQU  49
                1126 DECLARE EMALO,RAM       ;PRIMARY COMMAND ENDING MEMORY ADDRESS (LOW BYTE)
0032            1131+        EMALO   EQU  50
                1135 DECLARE EMAHI,RAM       ;PRIMARY COMMAND ENDING MEMORY ADDRESS (HIGH BYTE)
0033            1140+        EMAHI   EQU  51
                1144 DECLARE MEMLO,RAM       ;THIRD PARSER PARAMETER & HEX RECORD ADDRESS (LOW)
0034            1149+        MEMLO   EQU  52
                1153 DECLARE MEMHI,RAM       ;THIRD PARSER PARAMETER & HEX RECORD ADDRESS (HIGH)
0035            1158+        MEMHI   EQU  53
                1162 DECLARE BCODE,RAM       ;PRIMARY COMMAND NUMBER FROM PARSER TABLES (0-8)
0036            1167+        BCODE   EQU  54
                1171 DECLARE TYPE,RAM        ;PRIMARY COMMAND MODIFIER/OPTION (0-5)
0037            1176+        TYPE    EQU  55
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                1180 DECLARE NUMCON,RAM      ;MAX. NUMBER OF PARAMETERS ALLOWED FOR SELECTED COMMAND
0038            1185+        NUMCON  EQU  56
                1189 DECLARE OPTION,RAM      ;INDEX POINTER USED IN SEARCHING PARSER TABLES
0039            1194+        OPTION  EQU  57
                1198 DECLARE NEXTPL,RAM      ;CHARACTER POSITION FOR DISPLAY UTILITIES TO WRITE NEXT
003A            1203+        NEXTPL  EQU  58
                1207 DECLARE KBDBUF,RAM      ;POSITION OF KEY DEBOUNCED BY SCANNING SUBROUTINE
003B            1212+        KBDBUF  EQU  59
                1216 DECLARE KEYLOC,RAM      ;INCREMENTED AS SUCCESSIVE KEY LOCATIONS SCANNED
003C            1221+        KEYLOC  EQU  60
                1225 DECLARE NREPTS,RAM      ;KEEPS TRACK OF SUCCESSIVE READS OF SAME KEYSTROKE
003D            1230+        NREPTS  EQU  61
                1234 DECLARE ASAVE,RAM       ;HOLDS ACCUMULATOR VALUE DURING SERVICE ROUTINE
003E            1239+        ASAVE   EQU  62
                1243 DECLARE RDELAY,RAM      ;COUNTER DECREMENTED WHEN AUTO-STEP DELAY IN PROGRESS
003F            1248+        RDELAY  EQU  63
                1252 DECLARE STRTMP,RAM      ;INDEX POINTER FOR DISPLAY CHARACTER STRING ACCESSING
0040            1257+        STRTMP  EQU  64
                1261 DECLARE BUFCNT,RAM      ;COUNT OF DATA BYTES IN HEX FORMAT RECORD BUFFER
0041            1266+        BUFCNT  EQU  65
                1270 DECLARE RECTYP,RAM      ;TYPE OF HEX FORMAT RECORD (0 OR 1)
0042            1275+        RECTYP  EQU  66
                1279 DECLARE B,RAM           ;BIT COUNTER FOR ASCII SERIAL I/O UTILITY SUBROUTINES
0043            1284+        B       EQU  67
                1288 DECLARE REGC,RAM        ;CHARACTER BEING SHIFTED DURING SERIAL I/O PROCESS
0044            1293+        REGC    EQU  68
                1297 DECLARE H,RAM           ;COUNTER IN SOFTWARE DELAY DATA RATE GENERATOR
0045            1302+        H       EQU  69
                1306 ;
                1307 MBLOCK  SEGMAP,CHARNO   ;REGISTER ARRAY FOR DISPLAY PATTERNS
0046            1311+        SEGMAP  EQU  70
                1314 ;
                1315 MBLOCK  OVBUF,OVSIZE    ;LOW-ORDER USER PROGRAM DURING MINI-MONITOR OVERLAYS
004E            1319+        OVBUF   EQU  78
                1322 ;
                1323 MBLOCK  HEXBUF,BUFLEN   ;ALLOCATE BLOCK OF RAM FOR USE AS HEX RECORD BUFFER
0065            1327+        HEXBUF  EQU  101
                1330 ;
                1331 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                1332       DATACLK 40
0300            1337+        ORG    768
                1341 ;INVALS TABLE OF CONSTANTS TO BE LOADED INTO MP INTERNAL RAM VARIABLES
                1342 ;       AS PART OF SYSTEM INITIALIZATION PROCEDURE:
                1343 ;
                1344 ;       INITIAL VALUE   VARIABLE       TYPE
                1345 ;       ======= =====   ========       ====
0300 00         1346 INVALS: DB      00H     ;ROTPAT        RB1
0301 00         1347         DB      00H     ;ROTCNT        RB1
0302 00         1348         DB      00H     ;LASTKY        RB1
0303 08         1349         DB      CHARNO  ;CURDIG        RB1
0304 00         1350         DB      00H     ;KEYFLG        RB1
0305 00         1351         DB      00H     ;<REG7>        RB1
0306 00         1352         DB      00H     ;EPACC         RAM
0307 01         1353         DB      01H     ;EPPSW         RAM
0308 00         1354         DB      00H     ;EPTIMR        RAM
0309 00         1355         DB      00H     ;EPR0          RAM
030A 00         1356         DB      00H     ;EPPCLO        RAM
030B 00         1357         DB      00H     ;EPPCHI        RAM
030C 93         1358         DB      93H     ;HBITLO        RAM
030D 04         1359         DB      04H     ;HBITHI        RAM
030E 20         1360         DB      20H     ;DSPTIM        RAM
030F 25         1361         DB      25H     ;VERSNO        RAM
0310 00         1362         DB      00H     ;HREGA         RAM
0311 00         1363         DB      00H     ;HREGB         RAM
0312 00         1364         DB      00H     ;HREGC         RAM
0313 00         1365         DB      00H     ;HREGD         RAM
0314 00         1366         DB      00H     ;HREGE         RAM
0315 00         1367         DB      00H     ;HREGF         RAM
0316 00         1368         DB      00H     ;SMALO         RAM
0317 00         1369         DB      00H     ;SMAHI         RAM
0318 FF         1370         DB      0FFH    ;EMALO         RAM
0319 0F         1371         DB      0FH     ;EMAHI         RAM
031A 00         1372         DB      00H     ;MEMLO         RAM
031B 00         1373         DB      00H     ;MEMHI         RAM
031C 00         1374         DB      00H     ;BCODE         RAM
031D 04         1375         DB      04H     ;TYPE          RAM
031E 01         1376         DB      01H     ;NUMCON        RAM
031F 00         1377         DB      00H     ;OPTION        RAM
0320 08         1378         DB      CHARNO  ;NEXTPL        RAM
0321 FF         1379         DB      0FFH    ;KBDBUF        RAM
0322 00         1380         DB      00H     ;KEYLOC        RAM
0023            1381 NOVALS  EQU     $-INVALS
                1382         SIZECHK
0023            1385+  SIZE  SET   35
                1386+;
                1387+;*************************************************************
                1396 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                 1397 $      INCLUDE(:F0:PARSER.MOD)
                =1398        CODEBLK 45
0000            =1403+         ORG    0
                =1407 ;INIT  INITIALIZES PROCESSOR REGISTERS
                =1408 ;      AND RAM LOCATIONS TO DEFINED VALUES.
0000 C5         =1409 INIT:  SEL    RB0
0001 BF00       =1410        MOV    XPCODE,#0
0003 74D1       =1411        CALL   XPTEST
0005 27         =1412        CLR    A
0006 3D         =1413        MOVD   PSEGLO,A
0007 3E         =1414        MOVD   PSEGHI,A
0008 B81A       =1415        MOV    R0,#1AH ;START AT KD1 (REG2) = RAM LOC 1AH
000A B923       =1416        MOV    R1,#LOW NOVALS
000C BA00       =1417        MOV    R2,#LOW INVALS
000E FA         =1418 INITLP: MOV   A,R2
000F E3         =1419        MOVP3  A,@A
0010 A0         =1420        MOV    @R0,A
0011 18         =1421        INC    R0
0012 1A         =1422        INC    R2
0013 E90E       =1423        DJNZ   R1,INITLP
0015 55         =1424        STRT   T
0016 744F       =1425        CALL   EPBRK
0018 B8BB       =1426        MOV    R0,#LOW(OV1BAS+OVSIZE)
001A 746A       =1427        CALL   OVLORD
001C 54E5       =1428        CALL   COMFIL
001E B937       =1429        MOV    R1,#TYPE
0020 11         =1430        INC    @R1
0021 34F2       =1431        CALL   INCSMA
0023 54E5       =1432        CALL   COMFIL
0025 99EF       =1433        ANL    P1,#(NOT EPRSET)        ;REMOVE EP RESET SIGNAL
0027 0429       =1434        JMP    MAIN
                =1435
                =1436        SIZECHK
0029            =1439+  SIZE  SET   41
                =1440+;
                =1441+;*****************************************************************
                =1450 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =1451 ;
                =1452 ;       KEYBOARD LAYOUT:
                =1453 ;       ======== ======
                =1454 ;
                =1455 ;    ---------- ---------- ---------- ----------   ------ ------ ------ ------
                =1456 ;    !        !!        !!        !!        !  !     !!     !!     !!     !
                =1457 ;    !  LIST  !!GO/RESET!!   GO   !!EXAM/CHA!  !  C  !!  D  !!  E  !!  F  !
                =1458 ;    !        !!        !!        !!        !  !     !!     !!     !!     !
                =1459 ;    ---------- ---------- ---------- ----------   ------ ------ ------ ------
                =1460 ;    ---------- ---------- ---------- ----------   ------ ------ ------ ------
                =1461 ;    !        !!PROG BRK!!PROG MEM!!REGISTER!  !     !!     !!     !!     !
                =1462 ;    ! UPLOAD !! ----- !! ------ !! ------ !  !  8  !!  9  !!  A  !!  B  !
                =1463 ;    !        !!AUTO STP!!SING STP!! NO BRK !  !     !!     !!     !!     !
                =1464 ;    ---------- ---------- ---------- ----------   ------ ------ ------ ------
                =1465 ;    ---------- ---------- ---------- ----------   ------ ------ ------ ------
                =1466 ;    !        !!DATA BRK!!DATA MEM!!        !  !     !!     !!     !!     !
                =1467 ;    ! DNLOAD !! ------ !! ------ !!CLR/PREV!  !  4  !!  5  !!  6  !!  7  !
                =1468 ;    !        !!AUTO BRK!!WITH BRK!!        !  !     !!     !!     !!     !
                =1469 ;    ---------- ---------- ---------- ----------   ------ ------ ------ ------
                =1470 ;    ---------- ---------- ---------- ----------   ------ ------ ------ ------
                =1471 ;    !        !!        !!        !!        !  !     !!     !!     !!     !
                =1472 ;    !  FILL  !!HARD REG!! NEXT/, !! END/   !  !  0  !!  1  !!  2  !!  3  !
                =1473 ;    !        !!        !!        !!        !  !     !!     !!     !!     !
                =1474 ;    ---------- ---------- ---------- ----------   ------ ------ ------ ------
                =1475 ;
                =1476 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =1477 ;
                =1478 ;        THE FOLLOWING EQUATES DETERMINES HOW THE PARSER INTERPRETS
                =1479 ;        VALUES RETURNED BY THE KEYBOARD SCANNING INPUT ROUTINE
                =1480 ;        WHEN THE VARIOUS KEYS OF THE KEYBOARD ARE PRESSED.
                =1481 ;
                =1482 ;
                =1483 ;KEY0   EQU     00H     VALUE RETURNED FOR EACH KEY OF KEYBOARD MATRIX
                =1484 ;KEY1   EQU     01H     BY KEYBOARD SCANNING SUBROUTINE "KBDIN".
                =1485 ;KEY2   EQU     02H
                =1486 ;KEY3   EQU     03H     +----+----+----+----+  +----+----+----+----+
                =1487 ;KEY4   EQU     04H     ! 1C ! 1D ! 1E ! 1F !  ! 0C ! 0D ! 0E ! 0F !
                =1488 ;KEY5   EQU     05H     +----+----+----+----+  +----+----+----+----+
                =1489 ;KEY6   EQU     06H     ! 18 ! 19 ! 1A ! 1B !  ! 08 ! 09 ! 0A ! 0B !
                =1490 ;KEY7   EQU     07H     +----+----+----+----+  +----+----+----+----+
                =1491 ;KEY8   EQU     08H     ! 14 ! 15 ! 16 ! 17 !  ! 04 ! 05 ! 06 ! 07 !
                =1492 ;KEY9   EQU     09H     +----+----+----+----+  +----+----+----+----+
                =1493 ;KEYA   EQU     0AH     ! 10 ! 11 ! 12 ! 13 !  ! 00 ! 01 ! 02 ! 03 !
                =1494 ;KEYB   EQU     0BH     +----+----+----+----+  +----+----+----+----+
                =1495 ;KEYC   EQU     0CH
                =1496 ;KEYD   EQU     0DH
                =1497 ;KEYE   EQU     0EH
                =1498 ;KEYF   EQU     0FH
0010            =1499 KEYFIL  EQU     10H     ;[FILL COMMAND]
0012            =1500 KEYNXT  EQU     12H     ;[NEXT/,]
0013            =1501 KEYEND  EQU     13H     ;[END/.]
0014            =1502 KEYREL  EQU     14H     ;[DOWNLOAD COMMAND]
0015            =1503 KEYBAT  EQU     15H     ;[AUTOBREAK MODIFIER]
0016            =1504 KEYDM   EQU     16H     ;[DATA MEMORY MODIFIER]
0017            =1505 KEYCLR  EQU     17H     ;[CLEAR/PREVIOUS]
0018            =1506 KEYREC  EQU     18H     ;[UPLOAD COMMAND]
0019            =1507 KEYTRA  EQU     19H     ;[AUTOSTEP MODIFIER]
001A            =1508 KEYPM   EQU     1AH     ;[PROGRAM MEMORY MODIFIER]
001B            =1509 KEYREG  EQU     1BH     ;[REGISTER MEMORY MODIFIER]
001C            =1510 KEYLST  EQU     1CH     ;[FORMATTED DATA OUTPUT COMMAND]
001D            =1511 KCORES  EQU     1DH     ;[GO FROM RESET STATE COMMAND]
001E            =1512 KEYGO   EQU     1EH     ;[GO COMMAND]
001F            =1513 KEYMOD  EQU     1FH     ;[EXAMINE/MODIFY COMMAND]
000B            =1514 KSETB   EQU     0BH     ;[SET BREAKPOINT COMMAND]
000C            =1515 KCLRB   EQU     0CH     ;[CLEAR BREAKPOINT COMMAND]
                =1516 ;
                =1517 ;
0019            =1518 PBRK    EQU     19H     ;[PROGRAM BREAKPOINT MEMORY MODIFIER]
0015            =1519 DBRK    EQU     15H     ;[DATA BREAKPOINT MEMORY MODIFIER]
0011            =1520 RINT    EQU     11H     ;[HARDWARE REGISTER MEMORY MODIFIER]
001B            =1521 NOBRK   EQU     1BH     ;[WITHOUT BREAKPOINTS MODIFIER]
001C            =1522 WBRK    EQU     16H     ;[WITH BREAKPOINTS ENABLED MODIFIER]
001A            =1523 SING    EQU     1AH     ;[SINGLE STEP MODIFIER]
                =1524 ;
                =1525 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =1526       CODEBLK 160
0029            =1531+        ORG     41
                =1535 ;MAIN   OUTPUT_MESSAGE(COMMAND_PROMPT)
                =1536 ;       CALL INPUT_BYTE(KEY)
                =1537 ;MAIN2  IF THE KEY=END GO TO MAIN.
                =1538 ;
0029 BF01       =1539 MAIN:   MOV     XPCODE,#1
002B 74D1       =1540         CALL    XPTEST
002D 2301       =1541         MOV     A,#1
002F 3400       =1542         CALL    OUTUTL
0031 14EC       =1543         CALL    INPKEY
0033 FB         =1544 MAIN2:  MOV     A,KEY
0034 D313       =1545         XRL     A,#KEYEND
0036 C629       =1546         JZ      MAIN
                =1547 ;
                =1548 ;FINDOP FIND OUT IF THE KEY PRESSED IS A LEGITIMATE COMMAND INITIATOR:
                =1549 ;       ITMP:=CTAB
                =1550 ;       BCODE:=TYPE:=0
                =1551 ;       WHILE CTAB(ITMP)<>0             /CTAB EXHAUSTED/
                =1552 ;         IF CTAB(ITMP)=KEY GOTO MAINA  /COMMAND ENTRY FOUND IN CTAB/
                =1553 ;         ELSE     ITMP:=ITMP+COMMAND_ENTRY_SIZE
                =1554 ;                  BCODE:=BCODE+1
                =1555 ;       ENDWHILE
                =1556 ;       GOTO ERROR
0038 BC23       =1557         MOV     ITMP,#CTAB
                =1558         MMOV    BCODE,ZERO
003A B936       =1569+          MOV     R1,#BCODE
003C B100       =1570+          MOV     @R1,#ZERO
                =1574         MMOV    TYPE,ZERO
003E B937       =1585+          MOV     R1,#TYPE
0040 B100       =1586+          MOV     @R1,#ZERO
0042 FC         =1590 FINDOP: MOV     A,ITMP
0043 E3         =1591         MOVP3   A,@A
0044 B2BC       =1592         JB5     MERROR
0046 DB         =1593         XRL     A,KEY
0047 C652       =1594         JZ      MAINA
0049 FC         =1595         MOV     A,ITMP
004A 0303       =1596         ADD     A,#COMSIZ
004C AC         =1597         MOV     ITMP,A
004D B936       =1598         MOV     R1,#BCODE
004F 11         =1599         INC     @R1
0050 0442       =1600         JMP     FINDOP
                =1601 ;
                =1602 ;       OUTPUT_MESSAGE(STRCOM(BCODE))  /*PROMPT FOR THE CURRENT COMMAND*/
                =1603 ;       I:=1+1
                =1604 ;       OPTION:=MEM(I)
                =1605 ;       I:=I+1
                =1606 ;       NO_OF_PARAMETERS:=MEM(I)
                =1607 ;       I:=3
                =1608 ;
                =1609 MAINA:  MMOV    A,BCODE
0052 B936       =1618+          MOV     R1,#BCODE
0054 F1         =1619+          MOV     A,@R1
0055 031D       =1623         ADD     A,#STRCOM
0057 3402       =1624         CALL    OUTCLR
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

0059 1C         =1625         INC     ITMP
005A FC         =1626         MOV     A,ITMP
005B E3         =1627         MOVP3   A,@A            ; GET OPTION POINTER
                =1628         MMOV    OPTION,A
005C B939       =1641+          MOV     R1,#OPTION
005E A1         =1642+          MOV     @R1,A
005F 1C         =1646         INC     ITMP
0060 FC         =1647         MOV     A,ITMP
0061 E3         =1648         MOVP3   A,@A            ; GET NO OF PARAMETERS
                =1649         MMOV    NUMCON,A
0062 B938       =1662+          MOV     R1,#NUMCON
0064 A1         =1663+          MOV     @R1,A
                =1667 ;
                =1668 ;       PARAMETER_BUFFER(0=>5) :=0
                =1669 ;
0065 B906       =1670         MOV     R1,#6           ; EACH PARAM IS 2 BYTES
0067 B830       =1671         MOV     R0,#SMALO       ; START OF PARAM BUFFERS
0069 B000       =1672 MAINB:  MOV     @R0,#00H
006B 18         =1673         INC     R0
006C E969       =1674         DJNZ    R1,MAINB
006E 14EC       =1675         CALL    INPKEY
                =1676 ;
                =1677 ;       WHILE KEY<>MEM(OPTION+TYPE)[6-0] DO
                =1678 ;         IF MEM(OPTION+TYPE)[7]=1 GOTO MAIND1
                =1679 ;         TYPE:=TYPE+1
                =1680 ;       ENDWHILE
                =1681 ;
                =1682         MMOV    ITMP,OPTION
0070 B939       =1698+          MOV     R1,#OPTION
0072 F1         =1699+          MOV     A,@R1
0073 AC         =1712+          MOV     ITMP,A
0074 1C         =1715         INC     ITMP
                =1716 MAINC1: MMOV    A,ITMP
0075 FC         =1732+          MOV     A,ITMP
0076 E3         =1736         MOVP3   A,@A
0077 97         =1737         CLR     C
0078 F7         =1738         RLC     A
0079 77         =1739         RR      A       ; STRIP BIT SEVEN INTO CARRY
007A DB         =1740         XRL     A,KEY
007B C693       =1741         JZ      MAIND
007D F687       =1742         JC      MAIND1
                =1743         MINC    TYPE
007F B937       =1748+          MOV     R1,#TYPE
0081 F1         =1749+          MOV     A,@R1
0082 17         =1753+          INC     A
0083 A1         =1758+          MOV     @R1,A
0084 1C         =1761         INC     ITMP
0085 0475       =1762         JMP     MAINC1
                =1763 ;
                =1764 ;       MODIFIER NOT FOUND SO RESET TYPE INDEX TO DEFAULT CASE (ZERO).
                =1765 ;
                =1766 MAIND1: MMOV    TYPE,ZERO
0087 B937       =1777+          MOV     R1,#TYPE
0089 B100       =1778+          MOV     @R1,#ZERO
                =1782         MMOV    A,OPTION
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

008B B939       =1791+          MOV     R1,#OPTION
008D F1         =1792+          MOV     A,@R1
008E E3         =1796         MOVP3   A,@A
008F 3404       =1797         CALL    OUTMSG
0091 049E       =1798         JMP     MAINB0
                =1799 ;
                =1800 ;       CALL OUTPUT_MESSAGE(MODIFIER)
                =1801 MAIND:  MMOV    A,OPTION
0093 B939       =1810+          MOV     R1,#OPTION
0095 F1         =1811+          MOV     A,@R1
0096 E3         =1815         MOVP3   A,@A
                =1816         MADD    A,TYPE
0097 B937       =1822+          MOV     R1,#TYPE
0099 61         =1823+          ADD     A,@R1
009A 3404       =1827         CALL    OUTMSG
009C 14EC       =1828         CALL    INPKEY
                =1829 ;
009E BC00       =1830 MAINB0: MOV     ITMP,#0
00A0 2330       =1831 MAINB1: MOV     A,#SMALO
00A2 6C         =1832         ADD     A,ITMP
00A3 6C         =1833         ADD     A,ITMP
00A4 A8         =1834         MOV     R0,A
00A5 14C0       =1835         CALL    INPADR
00A7 FGBA       =1836         JC      CMDINT
00A9 1C         =1837         INC     ITMP
00AA B938       =1838         MOV     R1,#NUMCON
00AC F1         =1839         MOV     A,@R1
00AD 07         =1840         DEC     A
00AE A1         =1841         MOV     @R1,A
00AF C6BA       =1842         JZ      CMDINT
00B1 FB         =1843         MOV     A,KEY
00B2 D313       =1844         XRL     A,#KEYEND
00B4 C6BA       =1845         JZ      CMDINT
00B6 14EC       =1846         CALL    INPKEY
00B8 04A0       =1847         JMP     MAINB1
                =1848 ;
                =1849 ;CMDINT ENTER THE COMMAND PROCESSOR WITH:
                =1850 ;       BASE_CODE=THE MAIN COMMAND TYPE
                =1851 ;       TYPE=SUBCOMMAND TYPE
                =1852 ;       PARAMETER(1)=FIRST ADDRESS
                =1853 ;       PARAMETER(2)=SECOND ADDRESS
                =1854 ;       PARAMETER(3)=DATA
00BA 4400       =1855 CMDINT: JMP     IMPLEM
                =1856 ;
                =1857 ;MERROR ERROR ENCOUNTERED IN MAIN PARSING ROUTINE.
00BC BA01       =1858 MERROR: MOV     LDATA,#1
00BE 249A       =1859         JMP     PERROR
                =1860         SIZECHK
0097            =1863+  SIZE  SET   151
                =1864+;
                =1865+;*************************************************************
                =1874 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =1875         DATABLK 50
0323            =1880+          ORG     803
                =1884 ;
                =1885 ;*****************************************************
                =1886 ;
                =1887 ;       TABLES FOR PARSER
                =1888 ;
                =1889 ;*****************************************************
                =1890 ;
                =1891 ;       THE CTAB TABLE CONTAINS (COMSIZ) ENTRIES FOR EACH COMMAND.  THE MEANING
                =1892 ;       OF THE ENTRIES IS AS FOLLOWS:
                =1893 ;
                =1894 ;       ENTRY 0  COMMAND KEY TO INITIATE
                =1895 ;       ENTRY 1.  POINTER TO THE LIST OF OPTIONS APPLICABLE TO THIS COMMAND
                =1896 ;       ENTRY 2.  NUMBER OF NUMERIC PARAMETERS REQUIRED BY THE COMMAND
                =1897 ;
0023            =1898 CTAB    EQU     $ AND 0FFH
0003            =1899 COMSIZ  EQU     3
                =1900 ;
0323 1F         =1901         DB      KEYMOD,LOW OPTAB1,1     ;EXAM
0324 3F         =
0325 01         =
0326 1E         =1902         DB      KEYGO,LOW OPTAB3,1      ;GO
0327 49         =
0328 01         =
0329 10         =1903         DB      KEYFIL,LOW OPTAB1,3     ;FILL
032A 3F         =
032B 03         =
032C 1C         =1904         DB      KEYLST,LOW OPTAB1,2     ;DUMP
032D 3F         =
032E 02         =
032F 18         =1905         DB      KEYREC,LOW OPTAB1,2     ;RECORD
0330 3F         =
0331 02         =
0332 14         =1906         DB      KEYREL,LOW OPTAB1,0     ;RELOAD
0333 3F         =
0334 00         =
0335 0B         =1907         DB      KSETB,LOW OPTAB2,1      ;SETBRK
0336 46         =
0337 01         =
0338 0C         =1908         DB      KCLRB,LOW OPTAB2,1      ;CLRBRK
0339 46         =
033A 01         =
033B 1D         =1909         DB      KGORES,LOW OPTAB3,0     ;GO FROM RESET STATE
033C 49         =
033D 00         =
033E FF         =1910         DB      0FFH                    ;ESCOP
                =1911 ;
                =1912 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =1913 ;
                =1914 ;       THE OPTION TABLE GIVES THE VARIOUS OPTIONS ALLOWED FOR EACH
                =1915 ;       BASIC COMMAND, AS FOLLOWS:
                =1916 ;
                =1917 ;       ENTRY 0.  START OF TABLE OF MODIFIER RESPONSES.
                =1918 ;       ENTRY 1+.  ALLOWED MODIFIER KEYSTROKES CORRESPONDING TO OPTIONS 0-5.
                =1919 ;              NOTE THAT THE LAST BYTE IN EACH OPTION GROUP HAS BIT
                =1920 ;              SEVEN SET TO INDICATE THE END.
                =1921 ;
033F 26         =1922 OPTAB1: DB     STRMEM
0340 1A         =1923         DB     KEYPM,KEYDM,KEYREG,RINT
0341 16         =
0342 1B         =
0343 11         =
0344 19         =1924         DB     PBRK,DBRK OR 80H
0345 95         =
0346 26         =1925 OPTAB2: DB     STRMEM
0347 1A         =1926         DB     KEYPM,KEYDM OR 80H
0348 96         =
0349 2C         =1927 OPTAB3: DB     STRGOC
034A 1B         =1928         DB     NOBRK,WBRK,SING
034B 16         =
034C 1A         =
034D 15         =1929         DB     KEYPAT,KEYTRA OR 80H
034E 99         =
                =1930         SIZECHK
002C            =1933+ SIZE   SET    44
                =1934+;
                =1935+;*****************************************************************
                =1944 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =1945         CODEBLK 130
0100            =1955+          ORG     256
                =1959 ;OUTUTL OUTPUT ONE OF FOUR UTILITY DISPLAY PROMPTS (LEFT JUSTIFILD)
                =1960 ;       ACCORDING TO ACC CONTENTS (0-3).
                =1961 ;OUTCLR CLEAR DISPLAY AND OUTPUT CHARACTER STRING STARTING
                =1962 ;       AT THE ADDRESS POINTED TO BY BYTE AT ADDRESS IN ACCUMULATOR.
                =1963 ;OUTMSG SUBROUTINE TO COPY A STRING OF BIT PATTERNS FROM ROM TO THE
                =1964 ;       DISPLAY REGISTERS.
                =1965 ;       STRING SELECTED IS DETERMINED BY ACC WHEN CALLED.
                =1966 ;       ON ENTERING OUTMSG, ACC CONTENTS ARE USED TO ADDRESS A BYTE IN A
                =1967 ;       LOOKUP TABLE ON THE CURRENT PAGE WHICH CONTAINS THE ADDRESS OF
                =1968 ;       A STRING OF SEGMENT PATTERN DATA BYTES TO BE PRINTED ONTO THE
                =1969 ;       DISPLAY.
                =1970 ;       THE END OF THE STRING IS INDICATED WHEN BIT7 =1.
                =1971 ;       CALLS SUBROUTINE 'WDISP'
                =1972 ;       TO ACTUALLY EFFECT WRITING INTO THE DISPLAY REGISTERS.
0100 0319       =1973 OUTUTL: ADD     A,#STRUTL
0102 B4F1       =1974 OUTCLR: CALL    CLEAR
0104 A3         =1975 OUTMSG: MOVP    A,@A
                =1976         MMOV    STRTMP,A
0105 B940       =1989+          MOV     R1,#STRTMP
0107 A1         =1990+          MOV     @R1,A
                =1994 PRNT2:  MMOV    A,STRTMP        ;LOAD NEXT CHARACTER LOCATION
0108 B940       =2003+          MOV     R1,#STRTMP
010A F1         =2004+          MOV     A,@R1
010B A3         =2008         MOVP    A,@A            ;LOAD BIT PATTERN INDIRECT
010C F217       =2009         JB7     PRNT1
010E D4D8       =2010         CALL    WDISP           ;OUTPUT TO NEXT CHARACTER POSITION
                =2011         MINC    STRTMP          ;INDEX POINTER
0110 B940       =2016+          MOV     R1,#STRTMP
0112 F1         =2017+          MOV     A,@R1
0113 17         =2021+          INC     A
0114 A1         =2026+          MOV     @R1,A
0115 2408       =2029         JMP     PRNT2
0117 C4D8       =2030 PRNT1:  JMP     WDISP           ;DONE
                =2031 ;
0019            =2032 STRUTL  EQU     LOW $
0119 31         =2033         DB      LOW(DERROR)     ;UTILITY MESSAGE 0 ADDRESS
011A 37         =2034         DB      LOW(DSGNON)     ;UTILITY MESSAGE 1 ADDRESS
011B 3E         =2035         DB      LOW(DRUN)       ;UTILITY MESSAGE 2 ADDRESS
011C 44         =2036         DB      LOW(DBPNT)      ;UTILITY MESSAGE 3 ADDRESS
001D            =2037 STRCOM  EQU     LOW $
011D 46         =2038         DB      LOW(DMOD)       ;BASIC COMMAND 0 RESPONSE ADDRESS
011E 49         =2039         DB      LOW(DGO)        ;BASIC COMMAND 1 RESPONSE ADDRESS
011F 4B         =2040         DB      LOW(DFILL)      ;BASIC COMMAND 2 RESPONSE ADDRESS
0120 4E         =2041         DB      LOW(DLST)       ;BASIC COMMAND 3 RESPONSE ADDRESS
0121 51         =2042         DB      LOW(DREC)       ;BASIC COMMAND 4 RESPONSE ADDRESS
0122 54         =2043         DB      LOW(DREL)       ;BASIC COMMAND 5 RESPONSE ADDRESS
0123 57         =2044         DB      LOW(DSB)        ;BASIC COMMAND 6 RESPONSE ADDRESS
0124 5A         =2045         DB      LOW(DCB)        ;BASIC COMMAND 7 RESPONSE ADDRESS
0125 5D         =2046         DB      LOW(DGR)        ;BASIC COMMAND 8 RESPONSE ADDRESS
0026            =2047 STRMEM  EQU     LOW $
0126 5F         =2048         DB      LOW(DPRMEM)     ;DATA TYPE MODIFIER 0 RESPONSE ADDRESS
0127 61         =2049         DB      LOW(DDAMEM)     ;DATA TYPE MODIFIER 1 RESPONSE ADDRESS
0128 63         =2050         DB      LOW(DRM)        ;DATA TYPE MODIFIER 2 RESPONSE ADDRESS
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

0129 69         =2051       DB      LOW(DINTRG)     ;DATA TYPE MODIFIER 3 RESPONSE ADDRESS
012A 65         =2052       DB      LOW(DPRBRK)     ;DATA TYPE MODIFIER 4 RESPONSE ADDRESS
012B 67         =2053       DB      LOW(DDABRK)     ;DATA TYPE MODIFIER 5 RESPONSE ADDRESS
002C            =2054 STRGOC EQU    LOW $
012C 6B         =2055       DB      LOW(DNOBRK)     ;EXECUTION MODE MODIFIER 0
012D 6D         =2056       DB      LOW(DWBRK)      ;EXECUTION MODE MODIFIER 1
012E 6F         =2057       DB      LOW(DSS)        ;EXECUTION MODE MODIFIER 2
012F 72         =2058       DB      LOW(DPA)        ;EXECUTION MODE MODIFIER 3
0130 75         =2059       DB      LOW(DTR)        ;EXECUTION MODE MODIFIER 4
                =2060 ;
                =2061 ;         UTILITY OUTPUT MESSAGES
                =2062 ;
                =2063 DERROR:
0131 79         =2064       DB      01111001B       ;"E"
0132 50         =2065       DB      01010000B       ;"R"
0133 50         =2066       DB      01010000B       ;"R"
0134 5C         =2067       DB      01011100B       ;"O"
0135 50         =2068       DB      01010000B       ;"R"
0136 C0         =2069       DB      11000000B       ;"-."
                =2070 DSGNON:
0137 00         =2071       DB      00000000B       ;" "
0138 76         =2072       DB      01110110B       ;"H"
0139 6D         =2073       DB      01101101B       ;"S"
013A 79         =2074       DB      01111001B       ;"E"
013B 40         =2075       DB      01000000B       ;"-"
013C 66         =2076       DB      01100110B       ;"4"
013D E7         =2077       DB      11100111B       ;"9."(TM)
                =2078 DRUN:
013E 00         =2079       DB      00000000B       ;" "
013F 40         =2080       DB      01000000B       ;"-"
0140 50         =2081       DB      01010000B       ;"R"
0141 1C         =2082       DB      00011100B       ;"U"
0142 54         =2083       DB      01010100B       ;"N"
0143 C0         =2084       DB      11000000B       ;"-."
                =2085 DBPNT:
0144 73         =2086       DB      01110011B       ;"P"
0145 B9         =2087       DB      10111001B       ;"C."
                =2088 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =2089 ;
                =2090 ;       PRIMARY COMMAND RESPONSE STRING PATTERNS
                =2091 ;
                =2092 DMOD:
0146 79         =2093         DB      01111001B,00111001B,11110100B   ;"ECH."
0147 39         =
0148 F4         =
                =2094 DGO:
0149 3D         =2095         DB      00111101B,11011100B             ;"GO."
014A DC         =
                =2096 DFILL:
014B 71         =2097         DB      01110001B,00110000B,10111000B   ;"FIL."
014C 30         =
014D B8         =
                =2098 DLST:
014E 38         =2099         DB      00111000B,01101101B,11111000B   ;"LST."
014F 6D         =
0150 F8         =
                =2100 DREC:
0151 3E         =2101         DB      00111110B,01110011B,10111000B   ;"UPL."
0152 73         =
0153 B8         =
                =2102 DREL:
0154 5E         =2103         DB      01011110B,01010100B,10111000B   ;"DNL."
0155 54         =
0156 B8         =
                =2104 DSB:
0157 6D         =2105         DB      01101101B,01111000B,11111100B   ;"STB."
0158 78         =
0159 FC         =
                =2106 DCB:
015A 39         =2107         DB      00111001B,00111000B,11111100B   ;"CLB."
015B 38         =
015C FC         =
                =2108 DGR:
015D 3D         =2109         DB      00111101B,11010000B             ;"GR."
015E D0         =
                =2110 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =2111 ;
                =2112 ;       MEMORY SPACE MODIFIER OPTION RESPONSE STRINGS:
                =2113 ;
                =2114 DPRMEM:
015F 73         =2115         DB      01110011B,11010000B             ;"PR."
0160 D0         =
                =2116 DDAMEM:
0161 5E         =2117         DB      01011110B,11101111B             ;"DA."
0162 F7         =
                =2118 DRM:
0163 50         =2119         DB      01010000B,10111101B             ;"RG."
0164 BD         =
                =2120 DPRBRK:
0165 73         =2121         DB      01110011B,11111100B             ;"PB."
0166 FC         =
                =2122 DDABRK:
0167 5E         =2123         DB      01011110B,11111100B             ;"DB."
0168 FC         =
                =2124 DINTRG:
0169 76         =2125         DB      01110110B,11010000B             ;"HR."
016A D0         =
                =2126 ;
                =2127 ;       RESPONSE MESSAGES FOR GO CONDITION MODIFIERS.
                =2128 ;
                =2129 DNOBRK:
016B 54         =2130         DB              01010100B,11111100B     ;"ND."
016C FC         =
                =2131 DWBRK:
016D 7C         =2132         DB      01111100B,11010000B             ;"BR."
016E D0         =
                =2133 DSS:
016F 6D         =2134         DB      01101101B,01101101B,11111000B   ;"SST."
0170 6D         =
0171 F8         =
                =2135 DPA:
0172 77         =2136         DB      01110111B,01111100B,11010000B   ;"ABR."
0173 7C         =
0174 D0         =
                =2137 DTR:
0175 77         =2138         DB      01110111B,01101101B,11111000B   ;"AST."
0176 6D         =
0177 F8         =
                =2139 ;
                =2140         SIZECHK
0078            =2143+  SIZE  SET   120
                =2144+;
                =2145+;*****************************************************************
                =2154 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =2155          CODEBLK 45
00C0            =2160+           ORG     192
                =2164 ;INPADR INPUT DATA INTO TWO-BYTE PARAMETER BUFFER INDICATED BY R0.
                =2165 ;        RECEIVE NUMERIC KEYS FROM KEYBOARD UNTIL ',' OR '.'.
                =2166 ;        SHIFT INTO ADDRESS BUFFER;
                =2167 ;        RE-WRITE DISPLAY.
                =2168 ;        IF NUMBER OF CONSTANTS NEEDED IS ZERO, NO NEW PARAMETERS ARE ALLOWED.
                =2169 ;
00C0 97         =2170 INPADR: CLR     C
00C1 A7         =2171         CPL     C
                =2172         MMOV    A,NUMCON
00C2 B938       =2181+          MOV     R1,#NUMCON
00C4 F1         =2182+          MOV     A,@R1
00C5 C6D7       =2186         JZ      ELSIF1
00C7 FB         =2187 INPAD1: MOV     A,KEY
00C8 92D7       =2188         JB4     ELSIF1
00CA 20         =2189         XCH     A,@R0
00CB 47         =2190         SWAP    A
00CC 20         =2191         XCH     A,@R0
00CD 30         =2192         XCHD    A,@R0
00CE 18         =2193         INC     R0
00CF 30         =2194         XCHD    A,@R0
00D0 3478       =2195         CALL    UPDADR
00D2 14EC       =2196         CALL    INPKEY
00D4 97         =2197         CLR     C
00D5 04C7       =2198         JMP     INPAD1
                =2199 ;
                =2200 ;ELSIF1 IF KEY=',' OR '.' THEN RETURN.
                =2201 ;
00D7 FB         =2202 ELSIF1: MOV     A,KEY
00D8 D312       =2203         XRL     A,#KEYNXT
00DA C6E5       =2204         JZ      ELSIF2
00DC FB         =2205         MOV     A,KEY
00DD D313       =2206         XRL     A,#KEYEND
00DF C6E5       =2207         JZ      ELSIF2
                =2208 ;
                =2209 ;        ELSE GOTO PERROR.
                =2210 ;
00E1 BA02       =2211         MOV     LDATA,#2
00E3 249A       =2212         JMP     PERROR
00E5 B846       =2213 ELSIF2: MOV     R0,#SEGMAP
00E7 B903       =2214         MOV     R1,#3
00E9 B4F5       =2215         CALL    DBLANK
00EB 83         =2216         RET
                =2217         SIZECHK
002C            =2220+  SIZE  SET   44
                =2221+;
                =2222+;*****************************************************************
                =2231 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =2232          CODEBLK 35
0178            =2242+           ORG    376
                =2246 ;UPDADR UPDATE ADDRESS FIELD
                =2247 ;        (LAST THREE CHARACTERS OF DISPLAY) WITH ADDRESS BUFFER
                =2248 UPDADR: MMOV    NEXTPL,PLUS3
0178 B93A       =2259+           MOV    R1,#NEXTPL
017A B103       =2260+           MOV    @R1,#PLUS3
                =2264 ;        WRITE ADDR INTO NEXT THREE BUFFER LOCATIONS.
017C F0         =2265 UPDAD1: MOV    A,@R0
017D C8         =2266          DEC    R0
017E 530F       =2267          ANL    A,#0FH
0180 968E       =2268          JNZ    DSPHI
0182 D4D8       =2269          CALL   WDISP
0184 F0         =2270          MOV    A,@R0
0185 47         =2271          SWAP   A
0186 530F       =2272          ANL    A,#0FH
0188 9692       =2273          JNZ    DSPM1
018A D4D8       =2274          CALL   WDISP
018C 2494       =2275          JMP    DSPLO
018E D4D3       =2276 DSPHI.   CALL   DSPACC
0190 F0         =2277 DSPMID: MOV    A,@R0
0191 47         =2278          SWAP   A
0192 D4D3       =2279 DSPM1    CALL   DSPACC
0194 F0         =2280 DSPLO:   MOV    A,@R0
0195 D4D3       =2281          CALL   DSPACC
0197 83         =2282          RET
                =2283          SIZECHK
0020            =2286+  SIZE   SET    32
                =2287+;
                =2288+;*****************************************************************
                =2297 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =2298          CODEBLK 35
0198            =2308+           ORG     408
                =2312 ;PERROR:         REPERT
                =2313 ;          OUTPUT_MESSAGE(PERROR_PROMPT)
                =2314 ;          OUTPUT(LDATA)
                =2315 ;          CALL INPUT_BYTE(KEY)
                =2316 ;        UNTIL KEY='CLEAR/PREVIOUS'
0198 BA04       =2317 RERROR: MOV     LDATA,#4
019A BF02       =2318 PERROR: MOV     XPCODE,#2
019C 74D1       =2319         CALL    XPTEST
019E 27         =2320         CLR     A
019F D7         =2321         MOV     PSW,A
01A0 FB         =2322         MOV     A,KEY
01A1 D317       =2323         XRL     A,#KEYCLR
01A3 C6D6       =2324         JZ      ERROR2
01A5 27         =2325         CLR     A
01A6 3400       =2326         CALL    OUTUTL
01A8 FA         =2327         MOV     A,LDATA
01A9 D4D3       =2328         CALL    DSPACC
                =2329         MMOV    KBDBUF,NEG1
01AB B93B       =2340+          MOV     R1,#KBDBUF
01AD B1FF       =2341+          MOV     @R1,#NEG1
01AF 14EC       =2345         CALL    INPKEY
01B1 FB         =2346         MOV     A,KEY
01B2 D313       =2347         XRL     A,#KEYEND
01B4 9698       =2348         JNZ     RERROR
01B6 0429       =2349 ERROR2: JMP     MAIN
                =2350         SIZECHK
0020            =2353+  SIZE  SET   32
                =2354+;
                =2355+;*****************************************************************
                =2364 ;
                =2365          CODEBLK 80
0200            =2380+           ORG     512
                =2384 ;IMPLEM IMPLEMENT COMMAND
0200 2306       =2385 IMPLEM: MOV     A,#LOW(JMPTBL)
                =2386         MADD    A,BCODE
0202 B936       =2392+          MOV     R1,#BCODE
0204 61         =2393+          ADD     A,@R1
0205 B3         =2397         JMPP    @A
                =2398 ;
                =2399 JMPTBL:
0206 0F         =2400         DB      LOW(JTOMOD)
0207 20         =2401         DB      LOW(JTOGO)
0208 22         =2402         DB      LOW(JTOFIL)
0209 1A         =2403         DB      LOW(JTOLST)
020A 11         =2404         DB      LOW(JTOREC)
020B 16         =2405         DB      LOW(JTOREL)
020C 2C         =2406         DB      LOW(COMSBR)
020D 28         =2407         DB      LOW(COMCBR)
020E 26         =2408         DB      LOW(JGORES)
                =2409 ;
020F 444F       =2410 JTOMOD: JMP     EXAMIN
                =2411 ;
0211 85         =2412 JTOREC: CLR     F0      ;F0=0 ==> HEX FORMAT DATA DUMP
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

0212 B472       =2413          CALL    HFILEO
0214 0429       =2414          JMP     MAIN
                =2415 ;
0216 5497       =2416 JTOREL   CALL    HRECIN
0218 0429       =2417          JMP     MAIN
                =2418 ;
021A 85         =2419 JTOLST:  CLR     F0
021B 95         =2420          CPL     F0
021C B472       =2421          CALL    HFILEO
021E 0429       =2422          JMP     MAIN
                =2423 ;
0220 8400       =2424 JTOGO:   JMP     EPRUN
                =2425 ;
0222 54E5       =2426 JTOFIL:  CALL    COMFIL
0224 0429       =2427          JMP     MAIN
                =2428 ;
0226 8461       =2429 JGORES:  JMP     COMGOR
                =2430 ;
                =2431 ;COMCBR COMMAND TO CLEAR BREAKPOINTS
0228 BA00       =2432 COMCBR:  MOV     LDATA,#0
022A 442E       =2433          JMP     BRKFIL
                =2434 ;
                =2435 ;COMSBR COMMAND TO SET BREAKPOINTS
022C BA01       =2436 COMSBR:  MOV     LDATA,#1
022E 2304       =2437 BRKFIL:  MOV     A,#4
                =2438          MADD    TYPE,A
0230 B937       =2448+           MOV     R1,#TYPE
0232 61         =2449+           ADD     A,@R1
0233 A1         =2455+           MOV     @R1,A
0234 F400       =2459 BRKNXT:  CALL    LSTORE
0236 FB         =2460          MOV     A,KEY
0237 D313       =2461          XRL     A,#KEYEND
0239 C64D       =2462          JZ      BRKEND
023B 14EC       =2463          CALL    INPKEY
                =2464          MMOV    NUMCON,PLUS1
023D B938       =2475+           MOV     R1,#NUMCON
023F B101       =2476+           MOV     @R1,#PLUS1
0241 B830       =2480          MOV     R0,#SMALO
0243 B000       =2481          MOV     @R0,#0
                =2482          MMOV    SMAHI,ZERO
0245 B931       =2493+           MOV     R1,#SMAHI
0247 B100       =2494+           MOV     @R1,#ZERO
0249 14C0       =2498          CALL    INPADR
024B E634       =2499          JNC     BRKNXT
024D 0429       =2500 BRKEND:  JMP     MAIN
                =2501          SIZECHK
004F            =2504+ SIZE    SET   79
                =2505+;
                =2506+;*************************************************************
                =2515 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

             =2516          CODEBLK 75
024F         =2531+           ORG    591
             =2535 ;EXAMIN EXAMINE/MODIFY MEMORY COMMAND.
             =2536 ;        DISPLAYS MEMORY ADDRESS SPACE OPTION, ADDRESS VALUE, AND CURRENT DATA.
             =2537 ;        READS KEYBOARD AND INTERPRETS RESPONSE.
             =2538 ;
             =2539 ;        OUTPUT_MESSAGE(<MEMORY_SPACE_OPTION><SMA>'='<DATA_BYTE>)
024F 85      =2540 EXAMIN: CLR     F0
             =2541 EXAM0:  MMOV    A,TYPE
0250 B937    =2550+          MOV     R1,#TYPE
0252 F1      =2551+          MOV     A,@R1
0253 0326    =2555          ADD     A,#STRMEM       ;OFFSET FOR FIRST MEMORY TYPE STRING
0255 3402    =2556          CALL    OUTCLR
0257 B831    =2557          MOV     R0,#SMALO+1
0259 347C    =2558          CALL    UPDAD1
025B 2348    =2559          MOV     A,#01001000B    ;'='
025D D4D8    =2560          CALL    WDISP
025F 14FC    =2561          CALL    LFETCH
0261 FA      =2562          MOV     A,LDATA
0262 47      =2563          SWAP    A
0263 D4D3    =2564          CALL    DSPACC
0265 FA      =2565          MOV     A,LDATA
0266 D4D3    =2566          CALL    DSPACC
             =2567 ;
             =2568 ;
             =2569 ;        INPUT_KEY(KEY)
             =2570 ;        IF (KEY IS NOT NUMERIC)
             =2571 ;                IF (KEY=KEYEND) GO TO PARSER
             =2572 ;                ELSEIF (KEY=KEYNEXT)
             =2573 ;                        INCREMENT <SMA>
             =2574 ;                        GOTO EXAMIN
             =2575 ;                ELSEIF (KEY=KEYPREVIOUS)
             =2576 ;                        DECREMENT <SMA>
             =2577 ;                        GOTO EXAMIN
             =2578 ;                ELSE GOTO PERROR
             =2579 ;
0268 14EC    =2580          CALL    INPKEY
             =2581          MMOV    A,KEY
026A FB      =2597+           MOV     A,KEY
026B 927B    =2601          JB4     EXAM1
             =2602 ;
             =2603 ;        APPEND DATA WITH (LOWNIB_<KEY>)
             =2604 ;        CALL LSTORE
             =2605 ;        GOTO EXAMIN
             =2606 ;
026D FA      =2607          MOV     A,LDATA
026E 47      =2608          SWAP    A
026F 53F0    =2609          ANL     A,#0F0H
0271 B675    =2610          JF0     EXAM5
0273 27      =2611          CLR     A
0274 95      =2612          CPL     F0
0275 6B      =2613 EXAM5:  ADD     A,KEY
0276 AA      =2614          MOV     LDATA,A
0277 F400    =2615          CALL    LSTORE
0279 4450    =2616          JMP     EXAM0
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

             =2617 ;
027B D313       =2618 EXAM1:  XRL     A,#(KEYEND)
027D 9681       =2619         JNZ     EXAM2
027F 0429       =2620         JMP     MAIN
             =2621 ;
0281 FB         =2622 EXAM2:  MOV     A,KEY
0282 D312       =2623         XRL     A,#KEYNXT
0284 968A       =2624         JNZ     EXAM3
0286 34F2       =2625         CALL    INCSMA
0288 444F       =2626         JMP     EXAMIN
028A FB         =2627 EXAM3:  MOV     A,KEY
028B D317       =2628         XRL     A,#KEYCLR
028D 9693       =2629         JNZ     EXAM4
028F 54F4       =2630         CALL    DECSMA
0291 444F       =2631         JMP     EXAMIN
0293 B803       =2632 EXAM4:  MOV     LDATA,#03H
0295 249A       =2633         JMP     PERROR
             =2634         SIZECHK
0048         =2637+  SIZE  SET   72
             =2638+;
             =2639+;*************************************************************
             =2648 ;
             =2649         CODEBLK 4
00EC         =2654+          ORG     236
00EC D4C2       =2658 INPKEY: CALL    KBDIN   ; RETURNS KEY DEPRESSION IN A
00EE AB         =2659         MOV     KEY,A
00EF 83         =2660         RET
             =2661         SIZECHK
0004         =2664+  SIZE  SET   4
             =2665+;
             =2666+;*************************************************************
             =2675 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                 2676 $      INCLUDE(:F0:GOCOMS.MOD)
                =2677        CODEBLK 210
0400            =2697+         ORG     1024
                =2701 ;EPRUN RUN EMULATION MODE.
                =2702 ;      RELOAD EP WITH SYSTEM STATUS AND RELERSE.
                =2703 ;      SEQUENCE IS AS FOLLOWS:
                =2704 ;      IF COMMAND WAS TERMINATED BY THE 'NEXT' KEY:
                =2705 ;          STORE SMA INTO EP PC;
                =2706 ;      STORE EP PC INTO TOP-OF-STACK (RELATIVE TO EP PSW);
                =2707 ;      PASS EP R0;
                =2708 ;      PASS EP PSW;
                =2709 ;      PASS EP TIMER;
                =2710 ;      PASS EP ACCUMULATOR;
                =2711 ;
0400 2302       =2712 EPRUN: MOV     A,#2
0402 3400       =2713        CALL    OUTUTL
                =2714        MMOV    A,NUMCON
0404 B938       =2723+         MOV     R1,#NUMCON
0406 F1         =2724+         MOV     A,@R1
0407 9615       =2728        JNZ     EPCONT
                =2729        MMOV    EPPCLO,SMALO
0409 B930       =2745+         MOV     R1,#SMALO
040B F1         =2746+         MOV     A,@R1
040C B924       =2752+         MOV     R1,#EPPCLO
040E A1         =2753+         MOV     @R1,A
                =2756        MMOV    EPPCHI,SMAHI
040F B931       =2772+         MOV     R1,#SMAHI
0411 F1         =2773+         MOV     A,@R1
0412 B925       =2779+         MOV     R1,#EPPCHI
0414 A1         =2780+         MOV     @R1,A
0415 FB         =2783 EPCONT: MOV     A,KEY
0416 D312       =2784        XRL     A,#KEYNXT
0418 C61F       =2785        JZ      EPCON1
041A 2301       =2786        MOV     A,#01H  ;STACK ONE LEVEL DEEP TO HOLD USER STARTING ADDRESS
                =2787        MMOV    EPPSW,A
041C B921       =2800+         MOV     R1,#EPPSW
041E A1         =2801+         MOV     @R1,A
                =2805 EPCON1: MMOV    LDATA,EPPCLO
041F B924       =2821+         MOV     R1,#EPPCLO
0421 F1         =2822+         MOV     A,@R1
0422 AA         =2835+         MOV     LDATA,A
                =2838        MMOV    A,EPPSW
0423 B921       =2847+         MOV     R1,#EPPSW
0425 F1         =2848+         MOV     A,@R1
0426 07         =2852        DEC     A
0427 5307       =2853        ANL     A,#07H
0429 E7         =2854        RL      A
042A 0308       =2855        ADD     A,#08H
                =2856        MMOV    SMALO,A
042C B930       =2869+         MOV     R1,#SMALO
042E A1         =2870+         MOV     @R1,A
042F F4C3       =2874        CALL    EPSTOR
                =2875        MINC    SMALO
0431 B930       =2880+         MOV     R1,#SMALO
0433 F1         =2881+         MOV     A,@R1
```

```
LOC  OBJ       LINE       SOURCE STATEMENT

0434 17        =2885+       INC    A
0435 A1        =2890+       MOV    @R1,A
               =2893        MMOV   A,EPPSW
0436 B921      =2902+       MOV    R1,#EPPSW
0438 F1        =2903+       MOV    A,@R1
0439 53F0      =2907        ANL    A,#0F0H
               =2908        MORL   A,EPPCHI
043B B925      =2914+       MOV    R1,#EPPCHI
043D 41        =2915+       ORL    A,@R1
043E AA        =2919        MOV    LDATA,A
043F F4C3      =2920        CALL   EPSTOR
0441 B8D1      =2921 EPCNT: MOV    R0,#LOW(OV2BAS+OVSIZE)
0443 746A      =2922        CALL   OVLOAD
               =2923        MMOV   A,EPR0
0445 B923      =2932+       MOV    R1,#EPR0
0447 F1        =2933+       MOV    A,@R1
0448 F4D0      =2937        CALL   EPPASS
               =2938        MMOV   A,EPPSW
044A B921      =2947+       MOV    R1,#EPPSW
044C F1        =2948+       MOV    A,@R1
044D F4D0      =2952        CALL   EPPASS
               =2953        MMOV   A,EPTIMR
044F B922      =2962+       MOV    R1,#EPTIMR
0451 F1        =2963+       MOV    A,@R1
0452 F4D0      =2967        CALL   EPPASS
               =2968        MMOV   A,EPACC
0454 B920      =2977+       MOV    R1,#EPACC
0456 F1        =2978+       MOV    A,@R1
0457 F4D0      =2982        CALL   EPPASS
0459 8903      =2983        ORL    P1,#000000011B
045B F4DB      =2984        CALL   EPSTEP
045D 745A      =2985        CALL   OVSWAP
045F 846B      =2986        JMP    CGO
               =2987 ;
               =2988 ;COMGOR GO FROM RESET COMMAND
               =2989 ;       RESET PROCESSOR
               =2990 ;       RELOAD LOW ORDER PROGRAM BYTES INTO PROGRAM MEMORY
               =2991 ;
0461 2302      =2992 COMGOR: MOV    A,#2
0463 3400      =2993        CALL   OUTUTL
0465 8910      =2994        ORL    P1,#EPRSET
0467 745A      =2995        CALL   OVSWAP
0469 99EF      =2996        ANL    P1,#(NOT EPRSET)
               =2997 ;
               =2998 ;
               =2999 ;CGO    SET UP BREAK LOGIC FOR APPROPRIATE BREAK CONDITIONS,
               =3000 ;       DEPENDING ON CONTENTS OF 'TYPE'.
               =3001 ;
               =3002 CGO:    MMOV   A,TYPE
046B B937      =3011+         MOV    R1,#TYPE
046D F1        =3012+         MOV    A,@R1
046E 0371      =3016        ADD    A,#LOW GOTBL
0470 B3        =3017        JMPP   @A
               =3018 ;
0471 7C        =3019 GOTBL: DB     LOW(CGONE)
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

0472 76         =3020         DB      LOW(CGOWB)
0473 80         =3021         DB      LOW(CGOSS)
0474 76         =3022         DB      LOW(CGOPAT)
0475 80         =3023         DB      LOW(CGOTRA)
                =3024 ;
                =3025 CGOPAT:
0476 99FD       =3026 CGOWB:  ANL     P1,#NOT 00000010B
0478 8901       =3027         ORL     P1,#00000001B
047A 8482       =3028         JMP     EPRUN4
                =3029 ;
047C 99FC       =3030 CGONB:  ANL     P1,#NOT 00000011B
047E 8482       =3031         JMP     EPRUN4
                =3032 ;
                =3033 CGOTRA:
0480 8903       =3034 CGOSS:  ORL     P1,#00000011B
                =3035 ;
                =3036 ;EPRUN4 SET UP CONTROL LOGIC TO RUN USER'S PROGRAM.
                =3037 ;       RELEASE PROCESSOR TO RUN.
                =3038 ;
0482 8A20       =3039 EPRUN4: ORL     P2,#00100000B         ;DISABLE EP LINK REFERENCES.
0484 9AEF       =3040         ANL     P2,#NOT 00010000B     ;SET ALL REFERENCES TO RAM ARRAY.
0486 99DF       =3041         ANL     P1,#NOT MODOUT
0488 F4F4       =3042         CALL    EPREL
                =3043 ;
                =3044 ;       WAIT FOR KEYSTROKE INPUT OR HARDWARE BREAK TO OCCUR.
                =3045 ;
048A F4AC       =3046 EPRUN1: CALL    IOFPOL
048C F4AF       =3047         CALL    KBDPOL
048E 37         =3048         CPL     A
048F F295       =3049         JB7     EPRUN3
0491 8699       =3050         JNI     EPRUN2
0493 848A       =3051         JMP     EPRUN1
                =3052 ;
                =3053 ;EPRUN3 A KEYSTROKE WAS DETECTED WHILE EP WAS RUNNING.
                =3054 ;       BREAK EXECUTION,
                =3055 ;       PROCESS KEYSTROKE.
0495 B400       =3056 EPRUN3: CALL    STSAVE
0497 84B3       =3057         JMP     EPRUN5
                =3058 ;
                =3059 ;EPRUN2 AN ENABLED BREAK CONDITION OCCURRED.
                =3060 ;       BREAK EMULATION MODE,
                =3061 ;       CONTINUE ACCORDING TO GO COMMAND TYPE.
0499 B400       =3062 EPRUN2: CALL    STSAVE
                =3063         MMOV    A,TYPE
049B B937       =3072+          MOV     R1,#TYPE
049D F1         =3073+          MOV     A,@R1
049E 03A1       =3077         ADD     A,#LOW CNTTBL
04A0 B3         =3078         JMPP    @A
                =3079 ;
04A1 A6         =3080 CNTTBL: DB      LOW(BRKERR)
04A2 BA         =3081         DB      LOW(EPRUN6)
04A3 BA         =3082         DB      LOW(EPRUN6)
04A4 AA         =3083         DB      LOW(CNTTRA)
04A5 AA         =3084         DB      LOW(CNTTRA)
                =3085 ;
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =3086 ;BRKERR BREAKPOINT LATCH WAS SET THOUGH BREAKPOINTS NOT ENABLED.
                =3087 ;       DISPLAY HARDWARE ERROR MESSAGE.
04A6 BA0B       =3088 BRKERR: MOV     LDATA,#0BH
04A8 249A       =3089         JMP     PERROR
                =3090 ;
                =3091 CNTTRA: MMOV    A,DSPTIM
04AA B928       =3100+          MOV     R1,#DSPTIM
04AC F1         =3101+          MOV     A,@R1
04AD 94F2       =3105         CALL    DELAY
04AF F4AF       =3106         CALL    KBDPOL
04B1 F241       =3107         JB7     EPCNT           ;B7 SET INDICATES NO KEYSTROKE.
                =3108 ;
                =3109 ;EPRUN5 INPUT(KEY),
                =3110 ;       IF KEY=END GO TO PARSER,
                =3111 ;       INPUT KEY,
                =3112 ;       IF KEY<>NEXT GO TO PARSER,
                =3113 ;       CONTINUE IN SAME MODE.
                =3114 ;
04B3 14EC       =3115 EPRUN5: CALL    INPKEY
04B5 FB         =3116         MOV     A,KEY
04B6 D313       =3117         XRL     A,#KEYEND
04B8 96C7       =3118         JNZ     EPRET
04BA 14EC       =3119 EPRUN6: CALL    INPKEY
04BC FB         =3120         MOV     A,KEY
04BD D312       =3121         XRL     A,#KEYNXT
04BF 96C7       =3122         JNZ     EPRET
04C1 2302       =3123         MOV     A,#2
04C3 3400       =3124         CALL    OUTUTL
04C5 8441       =3125         JMP     EPCNT
                =3126 ;
                =3127 ;EPRET  EXECUTION MODE IS TO BE TERMINATED.
                =3128 ;       JUMP INTO PARSER TO INTERPRET KEY ALREADY DETECTED.
04C7 0433       =3129 EPRET:  JMP     MAIN2
                =3130 ;
                =3131         SIZECHK
00C9            =3134+  SIZE  SET   201
                =3135+;
                =3136+;*****************************************************************
                =3145 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

             =3146         CODEBLK 115
0500         =3171+          ORG     1200
             =3175 ;STSAVE EP STATUS SAVE SUBROUTINE.
             =3176 ;       FORCE CALL TO LOC 014H;
             =3177 ;       SAVE EP ACC;
             =3178 ;       SAVE EP TIMER;
             =3179 ;       SAVE EP PSW;
             =3180 ;       SAVE EP R0;
             =3181 ;       SAVE EP TOP-OF-STACK IN EP PC;
             =3182 ;       RETURN.
0500 744F    =3183 STSAVE: CALL    EPBRK
0502 2303    =3184         MOV     A,#3
0504 3400    =3185         CALL    OUTUTL
0506 745A    =3186         CALL    OVSWAP
0508 B88F    =3187         MOV     R0,#LOW(OV0BAS+OVSIZE)
050A 746A    =3188         CALL    OVLOAD
050C 8A20    =3189         ORL     P2,#00100000B
050E 2314    =3190         MOV     A,#14H
0510 91      =3191         MOVX    @R1,A
0511 9ADF    =3192         ANL     P2,#NOT 00100000B
0513 8903    =3193         ORL     P1,#00000011B
0515 F4DB    =3194         CALL    EPSTEP
0517 8A20    =3195         ORL     P2,#00100000B
0519 9AEF    =3196         ANL     P2,#NOT 00010000B
051B 8903    =3197         ORL     P1,#(ENBRAM OR ENBLNK)
051D F4DB    =3198         CALL    EPSTEP
             =3199 ;
             =3200 ;       EXECUTION PROCESSOR IS NOW AT LOCATION 009H INTERNAL WITH
             =3201 ;       (RETURN ADDRESS+2) PUSHED ON STACK.
             =3202 ;
051F B8A5    =3203         MOV     R0,#LOW(OV3BAS+OVSIZE)
0521 746A    =3204         CALL    OVLOAD
0523 F4D0    =3205         CALL    EPPASS
             =3206         MMOV    EPACC,A
0525 B920    =3219+          MOV     R1,#EPACC
0527 A1      =3220+          MOV     @R1,A
0528 F4D0    =3224         CALL    EPPASS
             =3225         MMOV    EPTIMR,A
052A B922    =3238+          MOV     R1,#EPTIMR
052C A1      =3239+          MOV     @R1,A
052D F4D0    =3243         CALL    EPPASS
             =3244         MMOV    EPPSW,A
052F B921    =3257+          MOV     R1,#EPPSW
0531 A1      =3258+          MOV     @R1,A
0532 F4D0    =3262         CALL    EPPASS
             =3263         MMOV    EPR0,A
0534 B923    =3276+          MOV     R1,#EPR0
0536 A1      =3277+          MOV     @R1,A
0537 B8BB    =3281         MOV     R0,#LOW(OV1BAS+OVSIZE)
0539 746A    =3282         CALL    OVLOAD
             =3283         MMOV    A,EPPSW
053B B921    =3292+          MOV     R1,#EPPSW
053D F1      =3293+          MOV     A,@R1
053E 07      =3297         DEC     A
053F 5307    =3298         ANL     A,#07H
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

0541 E7         =3299         RL      A
0542 0308       =3300         ADD     A,#08H
                =3301         MMOV    SMALO,A
0544 B930       =3314+          MOV     R1,#SMALO
0546 A1         =3315+          MOV     @R1,A
0547 F4B7       =3319         CALL    EPFET
0549 03FE       =3320         ADD     A,#-2
054B AA         =3321         MOV     LDATA,A
                =3322         MMOV    EPPCLO,A
054C B924       =3335+          MOV     R1,#EPPCLO
054E A1         =3336+          MOV     @R1,A
054F F4C3       =3340         CALL    EPSTOR
0551 B930       =3341         MOV     R1,#SMALO
0553 11         =3342         INC     @R1
0554 F4B7       =3343         CALL    EPFET
0556 AA         =3344         MOV     LDATA,A
0557 53F0       =3345         ANL     A,#11110000B
0559 2A         =3346         XCH     A,LDATA
055A 13FF       =3347         ADDC    A,#-1
055C 530F       =3348         ANL     A,#00001111B
                =3349         MMOV    EPPCHI,A
055E B925       =3362+          MOV     R1,#EPPCHI
0560 A1         =3363+          MOV     @R1,A
0561 4A         =3367         ORL     A,LDATA
0562 AA         =3368         MOV     LDATA,A
0563 F4C3       =3369         CALL    EPSTOR
0565 B825       =3370         MOV     R0,#EPPCHI
0567 347C       =3371         CALL    UPDAD1
0569 2340       =3372         MOV     A,#01000000B    ;"-" FOR DISPLAY
056B D4D8       =3373         CALL    WDISP
056D B820       =3374         MOV     R0,#EPACC
056F 3490       =3375         CALL    DSPMID
0571 83         =3376         RET
                =3377         SIZECHK
0072            =3380+  SIZE  SET   114
                =3381+;
                =3382+;*******************************************************
                =3391 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                 3392 $      INCLUDE(:F0:HFILE.MOD)
0080            =3393 CHARCR EQU     0DH            ;<CR>
008A            =3394 CHARLF EQU     0AH            ;<LF>
001A            =3395 CNTRLZ EQU     1AH            ;CONTROL-Z
                =3396 ;
                =3397        CODEBLK 80
0297            =3412+         ORG    663
                =3416 ;HRECIN HEXFILE RECORD INPUT ROUTINE
0297 34CD       =3417 HRECIN: CALL    CHARIN
0299 D31A       =3418         XRL     A,#CNTRLZ
029B C6E0       =3419         JZ      DONE
029D D31A       =3420         XRL     A,#CNTRLZ
029F D33A       =3421         XRL     A,#(':')
02A1 9697       =3422         JNZ     HRECIN
                =3423         MMOV    CHKSUM,ZERO
02A3 B000       =3428+          MOV     CHKSUM,#ZERO
02A5 14F0       =3432         CALL    BYTEIN
                =3433         MMOV    BUFCNT,A
02A7 B941       =3446+          MOV     R1,#BUFCNT
02A9 A1         =3447+          MOV     @R1,A
02AA 14F0       =3451         CALL    BYTEIN
                =3452         MMOV    SMAHI,A
02AC B931       =3465+          MOV     R1,#SMAHI
02AE A1         =3466+          MOV     @R1,A
02AF 14F0       =3470         CALL    BYTEIN
                =3471         MMOV    SMALO,A
02B1 B930       =3484+          MOV     R1,#SMALO
02B3 A1         =3485+          MOV     @R1,A
02B4 14F0       =3489         CALL    BYTEIN
                =3490         MMOV    RECTYP,A
02B6 B942       =3503+          MOV     R1,#RECTYP
02B8 A1         =3504+          MOV     @R1,A
                =3508 ;
                =3509 ;HDATIN HEX DATA BYTE IN
                =3510 HDATIN: MMOV    A,BUFCNT
02B9 B941       =3519+          MOV     R1,#BUFCNT
02BB F1         =3520+          MOV     A,@R1
02BC C6CC       =3524         JZ      RECDON
02BE 14F0       =3525         CALL    BYTEIN
02C0 AA         =3526         MOV     LDATA,A
02C1 F400       =3527         CALL    LSTORE
02C3 34F2       =3528         CALL    INCSMA
                =3529         MDEC    BUFCNT
02C5 B941       =3534+          MOV     R1,#BUFCNT
02C7 F1         =3535+          MOV     A,@R1
02C8 07         =3539+          DEC     A
02C9 A1         =3544+          MOV     @R1,A
02CA 44B9       =3547         JMP     HDATIN
                =3548 ;
02CC 34CD       =3549 RECDON: CALL    CHARIN
02CE D33F       =3550         XRL     A,#('?')
02D0 C6DB       =3551         JZ      CKSMOK
02D2 D33F       =3552         XRL     A,#('?')       ;SWITCH BACK TO DATA CHARACTER
02D4 34BA       =3553         CALL    NIBIN2         ;JOIN SUBROUTINE ALREADY IN PROGRESS
02D6 14F2       =3554         CALL    BYTEI1         ;DITTO
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =3555                               ;(RESULT FOR NON-'?' CHARACTERS IS AS IF
                =3556                               ;  BYTEIN WAS CALLED )
                =3557          MMOV    A,CHKSUM
02D8 FD         =3573+           MOV     A,CHKSUM
02D9 9GE1       =3577          JNZ     CHKERR
                =3578 CKSMOK:  MMOV    A,RECTYP
02DB B942       =3587+           MOV     R1,#RECTYP
02DD F1         =3588+           MOV     A,@R1
02DE C697       =3592          JZ      HRECIN
                =3593 ;
                =3594 ;DONE    HEX FILE CORRECTLY RECEIVED
02E0 83         =3595 DONE:    RET
                =3596 ;
                =3597 ;CHKERR CHECKSUM ERROR IN INPUT RECORD DETECTED
02E1 BA0C       =3598 CHKERR:  MOV     LDATA,#0CH
02E3 249A       =3599          JMP     PLRROR
                =3600          SIZECHK
004E            =3603+  SIZE   SET   78
                =3604+,
                =3605+;*************************************************************
                =3614 ;
                =3615          CODEBLK 12
00F0            =3620+           ORG     240
                =3624 ;BYTEIN BYTE INPUT SUBROUTINE.
                =3625 ;        RECEIVES TWO HEXIDECIMAL CHARACTERS FROM THE TAPE INPUT DEVICE
                =3626 ;        AND ASSEMBLES THEM INTO A SINGLE BYTE OF DATA.
00F0 34B8       =3627 BYTEIN:  CALL    NIBIN
00F2 47         =3628 BYTEI1:  SWAP    A
00F3 AA         =3629          MOV     LDATA,A
00F4 34B8       =3630          CALL    NIBIN
                =3631          MORL    LDATA,A
00F6 4A         =3640+           ORL     A,LDATA
00F7 AA         =3660+           MOV     LDATA,A
00F8 6D         =3664          ADD     A,CHKSUM
00F9 AD         =3665          MOV     CHKSUM,A
00FA FA         =3666          MOV     A,LDATA
00FB 83         =3667          RET
                =3668          SIZECHK
000C            =3671+  SIZE   SET   12
                =3672+;
                =3673+;*************************************************************
                =3682 ;
                =3683          CODEBLK 25
01B8            =3693+           ORG     440
                =3697 ;NIBIN  RECEIVES A HEXIDECIMAL CHARACTER AND PRODUCES A MASKED FOUR BIT VALUE.
                =3698 ;        NOTE- ERROR CHECKING DONE TO VERIFY HEXIDECIMAL VALIDITY
01B8 34CD       =3699 NIBIN:   CALL    CHARIN
01BA 03C6       =3700 NIBIN2:  ADD     A,#-3AH          ;ACC=0F6-0FF FOR CHARACTERS '0'-'9'
                =3701                                   ;CHARACTERS > '9' PRODUCE OVERFLOW
01BC E6C2       =3702          JNC     NIBI3
01BE 03F9       =3703          ADD     A,#-7            ;ACC=0-5 FOR CHARACTERS 'A'-'F'
01C0 E6C9       =3704          JNC     ASCLRR           ;ERROR IF CHARACTER BETWEEN '9' AND 'A'
                =3705 ;
                =3706 ;        ACC=0F6H-05H FOR CHARACTERS '0'-'F'
                =3707 ;
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

01C2 03FA      =3708 NIBI3:  ADD     A,#-6          ;ACC=0F0H-0FFH FOR CHARACTERS '0'-'F'
01C4 0310      =3709         ADD     A,#10H         ;ACC=00H-0FH FOR CHARACTERS '0'-'F';
               =3710                                ;OVERFLOW IF ABOVE IS TRUE.
01C6 E6C9      =3711         JNC     ASCERR
01C8 83        =3712         RET
               =3713 ;
               =3714 ;ASCERR ILLEGAL HEXIDECIMAL CHARACTER RECEIVED
01C9 BA0A      =3715 ASCERR: MOV     LDATA,#0AH
01CB 249A      =3716         JMP     PERROR
               =3717         SIZECHK
0015           =3720+  SIZE  SET   21
               =3721+;
               =3722+;*************************************************************
               =3731 ;
               =3732 ;
               =3733         CODEBLK 5
01CD           =3743+          ORG     461
               =3747 ;CHARIN CHARACTER INPUT ROUTINE.
               =3748 ;       RECEIVES ONE ASCII CHARACTER FROM THE LOGICAL READER DEVICE.
01CD D449      =3749 CHARIN: CALL    CIN
01CF 537F      =3750         ANL     A,#7FH
01D1 83        =3751         RET
               =3752         SIZECHK
0005           =3755+  SIZE  SET   5
               =3756+;
               =3757+;*************************************************************
               =3766 ;
               =3767 ;
               =3768 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =3769          CODEBLK 100
0572            =3794+           ORG     1394
                =3798 ;HFILEO HEX FILE OUTPUT SUBROUTINE
                =3799 ;        WHEN CALLED WITH F0=0 OUTPUT IS STANDARD HEX FILE FORMAT.
                =3800 ;        WHEN CALLED WITH F0=1 OUTPUT IS FORMATTED DATA DUMP TO CRT.
                =3801 HFILEO:  MMOV    MEMHI,SMAHI
0572 B931       =3817+           MOV     R1,#SMAHI
0574 F1         =3818+           MOV     A,@R1
0575 B935       =3824+           MOV     R1,#MEMHI
0577 A1         =3825+           MOV     @R1,A
                =3828          MMOV    MEMLO,SMALO
0578 B930       =3844+           MOV     R1,#SMALO
057A F1         =3845+           MOV     A,@R1
057B B934       =3851+           MOV     R1,#MEMLO
057D A1         =3852+           MOV     @R1,A
                =3855          MMOV    CHKSUM,ZERO
057E BD00       =3860+           MOV     CHKSUM,#ZERO
0580 B865       =3864          MOV     R0,#HEXBUF
                =3865 ;
                =3866 ;LDBYTE LOAD NEXT BYTE FROM MEMORY INTO HEX BUFFER
0582 14FC       =3867 LDBYTE:  CALL    LFETCH
0584 FA         =3868          MOV     A,LDATA
0585 A0         =3869          MOV     @R0,A
0586 18         =3870          INC     R0
0587 B4E2       =3871          CALL    CMPMAS
0589 E696       =3872          JNC     ENDFIL
058B 34F2       =3873          CALL    INCSMA
058D F8         =3874          MOV     A,R0
058E 038B       =3875          ADD     A,#-(BUFLEN+HEXBUF)
0590 E682       =3876          JNC     LDBYTE
0592 D400       =3877          CALL    HRECO
0594 A472       =3878          JMP     HFILEO
                =3879 ;
                =3880 ;ENDFIL END HEX FILE TRANSMISSION:
                =3881 ;        PRINT OUT BUFFER FOR LAST DATA RECORD
                =3882 ;        PRINT OUT CANNED 'END-OF-FILE' RECORD
                =3883 ;        RETURN.
0596 D400       =3884 ENDFIL:  CALL    HRECO
0598 B6A7       =3885          JF0     HFDONE
059A 34D2       =3886          CALL    TCRLFO
059C B8AE       =3887          MOV     R0,#(LOW EOFREC)
059E F8         =3888 ENDF1:   MOV     A,R0
059F A3         =3889          MOVP    A,@A
05A0 C6A7       =3890          JZ      HFDONE
05A2 B4BD       =3891          CALL    CHARO
05A4 18         =3892          INC     R0
05A5 A49E       =3893          JMP     ENDF1
05A7 34D2       =3894 HFDONE:  CALL    TCRLFO
05A9 231A       =3895          MOV     A,#CNTRLZ
05AB B4BD       =3896          CALL    CHARO
05AD 83         =3897          RET
                =3898 ;
                =3899 ;EOFREC CHARACTER STRING FOR CANNED END-OF-FILE RECORD FOR
                =3900 ;        INTEL HEX FILE FORMAT STANDARD.
05AE 203A3030   =3901 EOFREC:  DB      ' :00000001FF'
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

05B2 30303030
05B6 30314646
05BA 00         =3902        DB     0              ;END OF STRING CODE BYTE
                =3903        SIZECHK
0049            =3906+ SIZE  SET  73
                =3907+;
                =3908+;*****************************************************
                =3917 ;
                =3918 ;
                =3919        CODEBLK 90
0600            =3949+         ORG    1536
                =3953 ;HRECO  HEXIDECIMAL RECORD OUTPUT SEQUENCE.
                =3954 ;       HEX BUFFER ALREADY LOADED.
0600 F8         =3955 HRECO:  MOV    A,R0
0601 039B       =3956         ADD    A,#-HEXBUF
                =3957         MMOV   BUFCNT,A
0603 B941       =3970+          MOV    R1,#BUFCNT
0605 A1         =3971+          MOV    @R1,A
0606 34D2       =3975         CALL   TCRLFO
0608 2320       =3976         MOV    A,#' '
060A B4BD       =3977         CALL   CHARO
060C B617       =3978         JF0    FDUMP1
060E 233A       =3979         MOV    A,#':'
0610 B4BD       =3980         CALL   CHARO
                =3981         MMOV   A,BUFCNT
0612 B941       =3990+          MOV    R1,#BUFCNT
0614 F1         =3991+          MOV    A,@R1
0615 34DB       =3995         CALL   BYTEO
                =3996 FDUMP1: MMOV   A,MEMHI
0617 B935       =4005+          MOV    R1,#MEMHI
0619 F1         =4006+          MOV    A,@R1
061A 34DB       =4010         CALL   BYTEO
                =4011         MMOV   A,MEMLO
061C B934       =4020+          MOV    R1,#MEMLO
061E F1         =4021+          MOV    A,@R1
061F 34DB       =4025         CALL   BYTEO
0621 B628       =4026         JF0    FDUMP2
0623 27         =4027         CLR    A
0624 34DB       =4028         CALL   BYTEO
0626 C42C       =4029         JMP    DATO
0628 233D       =4030 FDUMP2: MOV    A,#'='
062A B4BD       =4031         CALL   CHARO
                =4032 ;DATO   DATA OUTPUT
062C B865       =4033 DATO:   MOV    R0,#HEXBUF
062E B632       =4034 DATO1:  JF0    FDUMP5
0630 C436       =4035         JMP    FDUMP3
0632 2320       =4036 FDUMP5: MOV    A,#' '
0634 B4BD       =4037         CALL   CHARO
0636 F0         =4038 FDUMP3: MOV    A,@R0
0637 34DB       =4039         CALL   BYTEO
0639 18         =4040         INC    R0
                =4041         MDJN2  BUFCNT,DATO1
063A B941       =4046+          MOV    R1,#BUFCNT
063C F1         =4047+          MOV    A,@R1
063D 07         =4051+          DEC    A
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

063E A1         =4056+          MOV     @R1,A
063F 9G2E       =4060+          JNZ     DAT01
                =4062 ;
                =4063 ;ENDREC END RECORD BEING TRANSMITTED
0641 B648       =4064 ENDREC: JF0     FDUMP4
                =4065         MMOV    A,CHKSUM
0643 FD         =4081+          MOV     A,CHKSUM
0644 37         =4085         CPL     A
0645 17         =4086         INC     A
0646 34DB       =4087         CALL    BYTE0
0648 83         =4088 FDUMP4: RET
                =4089         SIZECHK
0049            =4092+  SIZE  SET   73
                =4093+;
                =4094+;*****************************************************
                =4103 ;
                =4104         CODEBLK 9
01D2            =4114+          ORG     466
                =4118 ;TCRLF0 TAPE <CR><LF> OUTPUT
01D2 230D       =4119 TCRLF0: MOV     A,#CHARCR
01D4 B4BD       =4120         CALL    CHAR0
01D6 230A       =4121         MOV     A,#CHARLF
01D8 B4BD       =4122         CALL    CHAR0
01DA 83         =4123         RET
                =4124         SIZECHK
0009            =4127+  SIZE  SET   9
                =4128+;
                =4129+;*****************************************************
                =4138 ;
                =4139         CODEBLK 11
01DB            =4149+          ORG     475
                =4153 ;BYTE0  BYTE OUTPUT
01DB AA         =4154 BYTE0:  MOV     LDATA,A
01DC 6D         =4155         ADD     A,CHKSUM
01DD AD         =4156         MOV     CHKSUM,A
01DE FA         =4157         MOV     A,LDATA
01DF 47         =4158         SWAP    A
01E0 B4DB       =4159         CALL    NIB0
01E2 FA         =4160         MOV     A,LDATA
01E3 B4BB       =4161         CALL    NIB0
01E5 83         =4162         RET
                =4163         SIZECHK
000B            =4166+  SIZE  SET   11
                =4167+;
                =4168+;*****************************************************
                =4177 ;
                =4178         CODEBLK 12
01E6            =4188+          ORG     486
                =4192 ;HEXASC HEXIDECIMAL NIBBLE TO ASCII CHARACTER CONVERSION.
01E6 530F       =4193 HEXASC: ANL     A,#0FH
01E8 03F6       =4194         ADD     A,#(-10)
01EA F6EF       =4195         JC      HEXNIB
01EC 033A       =4196         ADD     A,#(10+'0')
01EE 83         =4197         RET
01EF 0341       =4198 HEXNIB: ADD     A,#('A')
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

01F1 83         =4199          RET
                =4200          SIZECHK
000C            =4203+  SIZE  SET   12
                =4204+;
                =4205+;*******************************************************
                =4214 ;
                =4215 ;
                =4216 DECLARE BITSO,CONST
000B            =4230 BITSO    EQU     11      ;DATA BITS PUT OUT (INCLUDING TWO STOP BITS)
                =4231 ;
                =4232          CODEBLK 30
04C9            =4252+           ORG     1225
                =4256 ;HBDLAY HALF-BIT TIME DELAY
                =4257 HBDLAY:  MMOV    H,HBITHI
04C9 B927       =4273+           MOV     R1,#HBITHI
04CB F1         =4274+           MOV     A,@R1
04CC B945       =4280+           MOV     R1,#H
04CE A1         =4281+           MOV     @R1,A
                =4284          MMOV    R1,HBITLO
04CF B926       =4300+           MOV     R1,#HBITLO
04D1 F1         =4301+           MOV     A,@R1
04D2 A9         =4314+           MOV     R1,A
04D3 84D7       =4317          JMP     HBD1
04D5 B900       =4318 HBD2:    MOV     R1,#0
04D7 E9D7       =4319 HBD1:    DJNZ    R1,HBD1
                =4320          MDJNZ   H,HBD2
04D9 B945       =4325+           MOV     R1,#H
04DB F1         =4326+           MOV     A,@R1
04DC 07         =4330+           DEC     A
04DD A1         =4335+           MOV     @R1,A
04DE 96D5       =4339+           JNZ     HBD2
04E0 83         =4341          RET
                =4342          SIZECHK
0018            =4345+  SIZE  SET   24
                =4346+;
                =4347+;*******************************************************
                =4356 ;
                =4357 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =4358      CODEBLK 40
05BB            =4383+       ORG    1467
                =4387 ;NIBO  MASK ACC TO MAKE HEX NIBBLE, TRANSLATE TO ASCII AND OUTPUT
05BB 34E6       =4388 NIBO:  CALL   HEXASC
                =4389 ;
                =4390 ;CHARO CONSOLE OUTPUT SUBROUTINE
                =4391 ;      WRITES THE CONTENTS OF THE ACC TO THE CRT DISPLAY SCREEN
                =4392 CHARO: MMOV   REGC,A
05BD B944       =4405+       MOV    R1,#REGC
05BF A1         =4406+       MOV    @R1,A
                =4410        MMOV   B,BITSO ;SET NUMBER OF BITS TO BE TRANSMITTED
05C0 B943       =4421+       MOV    R1,#B
05C2 B108       =4422+       MOV    @R1,#BITSO
05C4 97         =4426        CLR    C       ;CLEAR CARRY
05C5 F6CB       =4427 CO1:   JC     CO2
05C7 998F       =4428        ANL    P1,#NOT TTYOUT
05C9 A4CF       =4429        JMP    CO3
05CB 8940       =4430 CO2:   ORL    P1,#TTYOUT
05CD 00         =4431        NOP            ;EVEN OUT TWO BRANCH EXECUTION TIMES
05CE 00         =4432        NOP
05CF 94C9       =4433 CO3:   CALL   HBDLAY
05D1 94C9       =4434        CALL   HBDLAY
05D3 97         =4435        CLR    C       ;SET WHAT WILL EVENTUALLY BECOME A STOP BIT
05D4 A7         =4436        CPL    C
                =4437        MRRC   REGC    ;ROTATE CHARACTER RIGHT ONE BIT,
05D5 B944       =4442+       MOV    R1,#REGC
05D7 F1         =4443+       MOV    A,@R1
05D8 67         =4447+       RRC    A
05D9 A1         =4452+       MOV    @R1,A
                =4455                       ;\ MOVING NEXT DATA BIT INTO CARRY
                =4456        MDJNZ  B,CO1   ;CHECK IF CHARACTER (AND STOP BIT(S)) DONE
05DA B943       =4461+       MOV    R1,#B
05DC F1         =4462+       MOV    A,@R1
05DD 07         =4466+       DEC    A
05DE A1         =4471+       MOV    @R1,A
05DF 96C5       =4475+       JNZ    CO1
05E1 83         =4477        RET
                =4478        SIZECHK
0027            =4481+ SIZE  SET   39
                =4482+;
                =4483+;*******************************************************
                =4492 ;
                =4493        CODEBLK 47
0649            =4523+       ORG    1609
                =4527 ;CIN   CONSOL INPUT SUBROUTINE WAITS FOR A KEYSTROKE AND
                =4528 ;      RETURNS WITH 8 BITS IN REG ACC.
0649 B943       =4529 CIN:   MOV    R1,#B
064B B108       =4530        MOV    @R1,#8  ;DATA BITS TO BE READ
064D 464D       =4531 CI0:   JNT1   CI0
064F 464D       =4532        JNT1   CI0
0651 5651       =4533 CI1:   JT1    CI1
0653 5651       =4534        JT1    CI1
0655 94C9       =4535        CALL   HBDLAY
0657 5651       =4536        JT1    CI1
0659 94C9       =4537 CI2:   CALL   HBDLAY
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

065B 94C9       =4538        CALL    HBDLAY
065D 5662       =4539        JT1     CI3     ;CHECK SID LINE LEVEL
065F 97         =4540        CLR     C       ;DATA BIT IN CY
0660 C465       =4541        JMP     CI4
0662 97         =4542 CI3:   CLR     C
0663 A7         =4543        CPL     C
0664 00         =4544        NOP             ;EVEN OUT BRANCH EXECUTION TIMES
0665 00         =4545 CI4:   NOP
0666 00         =4546        NOP
0667 00         =4547        NOP
                =4548        MRRC    REGC
0668 B944       =4553+         MOV     R1,#REGC
066A F1         =4554+         MOV     A,@R1
066B 67         =4558+         RRC     A
066C A1         =4563+         MOV     @R1,A
                =4566        MDJNZ   B,CI2
066D B943       =4571+         MOV     R1,#B
066F F1         =4572+         MOV     A,@R1
0670 07         =4576+         DEC     A
0671 A1         =4581+         MOV     @R1,A
0672 9659       =4585+         JNZ     CI2
                =4587        MMOV    A,REGC
0674 B944       =4596+         MOV     R1,#REGC
0676 F1         =4597+         MOV     A,@R1
0677 83         =4601        RET             ;CHARACTER COMPLETE
                =4602        SIZECHK
002F            =4605+  SIZE SET   47
                =4606+;
                =4607+;*****************************************************
                =4616 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                 4617 $      INCLUDE(:F0:MEMREF.MOD)
                =4618        CODEBLK 15
02E5            =4633+         ORG    741
                =4637 ;COMFIL COMMAND TO FILL ADDRESS SPACE BETWEEN SMA AND EMA WITH DATA
                =4638 ;       IN LOW BYTE OF MEM.
                =4639 COMFIL: MMOV   LDATA,MEMLO
02E5 B934       =4655+         MOV    R1,#MEMLO
02E7 F1         =4656+         MOV    A,@R1
02E8 AA         =4669+         MOV    LDATA,A
02E9 F400       =4672 LFILL:  CALL   LSTORE
02EB B4E2       =4673         CALL   CMPMAS
02ED E6F3       =4674         JNC    LFILL1
02EF 34F2       =4675         CALL   INCSMA
02F1 44E9       =4676         JMP    LFILL
02F3 83         =4677 LFILL1: RET
                =4678         SIZECHK
000F            =4681+  SIZE  SET   15
                =4682+;
                =4683+;*************************************************************
                =4692 ;
                =4693         CODEBLK 4
00FC            =4698+         ORG    252
                =4702 ;LFETCH FETCHES CONTENTS OF LOGICAL MEMORY ADDRESS DETERMINED BY
                =4703 ;       (TYPE),(SMAHI), & (SMALO) INTO (LDATA).
00FC D478       =4704 LFETCH: CALL   AFETCH
00FE AA         =4705         MOV    LDATA,A
00FF 83         =4706         RET
                =4707         SIZECHK
0004            =4710+  SIZE  SET   4
                =4711+;
                =4712+;*************************************************************
                =4721 ;
                =4722         CODEBLK 75
0678            =4752+         ORG    1656
                =4756 ;
                =4757 ;AFETCH LOGICAL FETCH SUBROUTINE
                =4758 ;       FETCHS CONTENTS OF VARIOUS MEMORY SPACES TO ACC.
                =4759 AFETCH: MMOV   A,TYPE
0678 B937       =4768+         MOV    R1,#TYPE
067A F1         =4769+         MOV    A,@R1
067B 037E       =4773         ADD    A,#LOW LFETBL
067D B3         =4774         JMPP   @A
                =4775 ;
067E 84         =4776 LFETBL: DB     LOW LFEPM
067F 98         =4777         DB     LOW LFEDM
0680 9C         =4778         DB     LOW LFEREG
0681 A9         =4779         DB     LOW LFEINT
0682 B1         =4780         DB     LOW LFEBRK
0683 B1         =4781         DB     LOW LFEBRK
                =4782 ;
                =4783 LFEPM:  MMOV   A,SMAHI
0684 B931       =4792+         MOV    R1,#SMAHI
0686 F1         =4793+         MOV    A,@R1
0687 9698       =4797         JNZ    LFEDM
                =4798         MMOV   A,SMALO
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

0689 B930       =4807+          MOV     R1,#SMALO
068B F1         =4808+          MOV     A,@R1
068C 03E9       =4812         ADD     A,#-OVSIZE
068E F698       =4813         JC      LFEDM
                =4814         MMOV    A,SMALO
0690 B930       =4823+          MOV     R1,#SMALO
0692 F1         =4824+          MOV     A,@R1
0693 034E       =4828         ADD     A,#OVBUF
0695 A9         =4829         MOV     R1,A
0696 F1         =4830         MOV     A,@R1
0697 83         =4831         RET
0698 94E1       =4832 LFEDM:  CALL    LPGSEL
069A 81         =4833         MOVX    A,@R1
069B 83         =4834         RET
                =4835 ;
                =4836 LFEREG: MMOV    A,SMALO
069C B930       =4845+          MOV     R1,#SMALO
069E F1         =4846+          MOV     A,@R1
069F 537F       =4850         ANL     A,#01111111B    ;CHECK IF LOW 7 BITS =0
06A1 C6A5       =4851         JZ      LFER0
06A3 E4B7       =4852         JMP     EPFET
                =4853 ;
                =4854 LFER0:  MMOV    A,EPR0
06A5 B923       =4863+          MOV     R1,#EPR0
06A7 F1         =4864+          MOV     A,@R1
06A8 83         =4868         RET
                =4869 ;
                =4870 LFEINT: MMOV    A,SMALO
06A9 B930       =4879+          MOV     R1,#SMALO
06AB F1         =4880+          MOV     A,@R1
06AC 0320       =4884         ADD     A,#EPACC
06AE A9         =4885         MOV     R1,A
06AF F1         =4886         MOV     A,@R1
06B0 83         =4887         RET
                =4888 ;
                =4889 ;LFEBRK LOGICAL FETCH OF BREAK-POINT DATA
06B1 94E1       =4890 LFEBRK: CALL    LPGSEL
06B3 99F7       =4891         ANL     P1,#NOT 00001000B
06B5 8908       =4892         ORL     P1,#00001000B
06B7 99FD       =4893         ANL     P1,#NOT 00000010B
06B9 8901       =4894         ORL     P1,#00000001B
06BB 81         =4895         MOVX    A,@R1
06BC 2301       =4896         MOV     A,#01H
06BE 86C1       =4897         JNI     LFEBR1
06C0 27         =4898         CLR     A
06C1 83         =4899 LFEBR1: RET
                =4900         SIZECHK
004A            =4903+  SIZE  SET   74
                =4904+;
                =4905+;*******************************************************
                =4914 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =4915       CODEBLK 85
0700            =4950+        ORG    1792
                =4954 ;
                =4955 ;LSTORE LOGICAL STORE SUBROUTINE
                =4956 ;       STORES CONTENTS OF LDATA INTO VARIOUS MEMORY SPACES.
                =4957 LSTORE: MMOV   A,TYPE
0700 B937       =4966+          MOV    R1,#TYPE
0702 F1         =4967+          MOV    A,@R1
0703 0306       =4971         ADD    A,#LOW LSTTBL
0705 B3         =4972         JMPP   @A
                =4973 ;
0706 0C         =4974 LSTTBL: DB     LOW LSTPM
0707 21         =4975         DB     LOW LSTDM
0708 26         =4976         DB     LOW LSTREG
0709 34         =4977         DB     LOW LSTINT
070A 3D         =4978         DB     LOW LSTBRK
070B 3D         =4979         DB     LOW LSTBRK
                =4980 ;
                =4981 LSTPM:  MMOV   A,SMAHI
070C B931       =4990+          MOV    R1,#SMAHI
070E F1         =4991+          MOV    A,@R1
070F 9621       =4995         JNZ    LSTDM
                =4996         MMOV   A,SMALO
0711 B930       =5005+          MOV    R1,#SMALO
0713 F1         =5006+          MOV    A,@R1
0714 03E9       =5010         ADD    A,#-OVSIZE
0716 F621       =5011         JC     LSTDM
                =5012         MMOV   A,SMALO
0718 B930       =5021+          MOV    R1,#SMALO
071A F1         =5022+          MOV    A,@R1
071B 034E       =5026         ADD    A,#OVBUF
071D A9         =5027         MOV    R1,A
071E FA         =5028         MOV    A,LDATA
071F A1         =5029         MOV    @R1,A
0720 83         =5030         RET
                =5031 ;
0721 94E1       =5032 LSTDM:  CALL   LPGSEL
0723 FA         =5033         MOV    A,LDATA
0724 91         =5034         MOVX   @R1,A
0725 83         =5035         RET
                =5036 ;
                =5037 LSTREG: MMOV   A,SMALO
0726 B930       =5046+          MOV    R1,#SMALO
0728 F1         =5047+          MOV    A,@R1
0729 537F       =5051         ANL    A,#01111111B    ;CHECK IF LOW ORDER BITS = 0
072B C62F       =5052         JZ     LSTR0
072D E4C3       =5053         JMP    EPSTOR
                =5054 ;
                =5055 LSTR0:  MMOV   EPR0,LDATA
072F FA         =5078+          MOV    A,LDATA
0730 B923       =5084+          MOV    R1,#EPR0
0732 A1         =5085+          MOV    @R1,A
0733 83         =5088         RET
                =5089 ;
                =5090 LSTINT: MMOV   A,SMALO
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

0734 B930      =5099+          MOV     R1,#SMALO
0736 F1        =5100+          MOV     A,@R1
0737 0320      =5104          ADD     A,#EPACC
0739 A9        =5105          MOV     R1,A
073A FA        =5106          MOV     A,LDATA
073B A1        =5107          MOV     @R1,A
073C 83        =5108          RET
               =5109 ;
               =5110 ;LSTBRK LOGICAL STORE OF BREAK-POINT DATA
073D 94E1      =5111 LSTBRK: CALL    LPGSEL
073F FA        =5112          MOV     A,LDATA
0740 1246      =5113          JB0     LSTBR1
0742 8901      =5114          ORL     P1,#00000001B
0744 E448      =5115          JMP     LSTBR2
0746 99FE      =5116 LSTBR1: ANL     P1,#NOT 00000001B
0748 99F7      =5117 LSTBR2: ANL     P1,#NOT 00001000B
074A 81        =5118          MOVX    A,@R1
074B 8908      =5119          ORL     P1,#00001000B
074D 83        =5120          RET
               =5121          SIZECHK
004E           =5124+  SIZE  SET   78
               =5125+;
               =5126+;*****************************************************************
               =5135 ;
               =5136          CODEBLK 17
04E1           =5156+           ORG     1249
               =5160 ;LPGSEL LOGICAL PAGE SELECT.
               =5161 ;        SETS UP PORT 2 TO ADDRESS APPROPRIATE BYTE OF RAM BLOCK.
               =5162 LPGSEL: MMOV    A,TYPE
04E1 B937      =5171+           MOV     R1,#TYPE
04E3 F1        =5172+           MOV     A,@R1
04E4 5301      =5176          ANL     A,#00000001B            ;MASK OFF DATA TYPE SELECTOR BIT
04E6 47        =5177          SWAP    A
               =5178          MORL    A,SMAHI
04E7 B931      =5184+           MOV     R1,#SMAHI
04E9 41        =5185+           ORL     A,@R1
04EA 4340      =5189          ORL     A,#01000000B
04EC 3A        =5190          OUTL    P2,A
               =5191          MMOV    A,SMALO
04ED B930      =5200+           MOV     R1,#SMALO
04EF F1        =5201+           MOV     A,@R1
04F0 A9        =5205          MOV     R1,A
04F1 83        =5206          RET
               =5207          SIZECHK
0011           =5210+  SIZE  SET   17
               =5211+;
               =5212+;*****************************************************************
               =5221 ;
               =5222 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =5223          CODEBLK 11
01F2            =5233+           ORG     498
                =5237 ;INCSMA INCREMENT STARTING MEMORY ADDRESS WORD.
01F2 B930       =5238 INCSMA:  MOV     R1,#SMALO
01F4 11         =5239 INCW:    INC     @R1
01F5 F1         =5240          MOV     A,@R1
01F6 96FC       =5241          JNZ     INCW1
01F8 19         =5242          INC     R1
01F9 F1         =5243          MOV     A,@R1
01FA 17         =5244          INC     A
01FB 31         =5245          XCHD    A,@R1
01FC 83         =5246 INCW1:   RET
                =5247          SIZECHK
000B            =5250+  SIZE   SET   11
                =5251+;
                =5252+;*************************************************************
                =5261 ;
                =5262          CODEBLK 12
02F4            =5277+           ORG     756
                =5281 ;DECSMA DECREMENT SMA WORD.
02F4 B930       =5282 DECSMA:  MOV     R1,#SMALO
02F6 F1         =5283          MOV     A,@R1
02F7 07         =5284          DEC     A
02F8 21         =5285          XCH     A,@R1
02F9 96FF       =5286          JNZ     DECSM1
02FB 19         =5287          INC     R1
02FC F1         =5288          MOV     A,@R1
02FD 07         =5289          DEC     A
02FE 31         =5290          XCHD    A,@R1
02FF 83         =5291 DECSM1:  RET
                =5292          SIZECHK
000C            =5295+  SIZE   SET   12
                =5296+;
                =5297+;*************************************************************
                =5306 ;
                =5307          CODEBLK 15
05E2            =5332+           ORG     1506
                =5336 ;CMPMAS COMPARE MEMORY ADDRESSES
                =5337 ;        COMPARE SMA BYTES WITH EMA BYTES TO DETERMINE RELATIVE MAGNITUDE.
                =5338 ;        RETURNS WITH CARRY=1 IFF (SMA) >= (EMA).
                =5339 ;        IS CALLED AFTER ACTION HAS BEEN PERFORMED ON (SMA) TO DETERMINE IF
                =5340 ;        TASK IS COMPLETED:
                =5341 ;            IF CY=0 THEN (SMA) >= (EMA)   ==>   TERMINATE TASK.
                =5342 ;            IF CY=1 THEN (SMA) <  (EMA)   ==>   INC SMA AND REPEAT.
                =5343 CMPMAS:  MMOV    A,SMALO
05E2 B930       =5352+           MOV     R1,#SMALO
05E4 F1         =5353+           MOV     A,@R1
05E5 37         =5357          CPL     A
                =5358          MADD    A,EMALO
05E6 B932       =5364+           MOV     R1,#EMALO
05E8 61         =5365+           ADD     A,@R1
                =5369          MMOV    A,SMAHI
05E9 B931       =5378+           MOV     R1,#SMAHI
05EB F1         =5379+           MOV     A,@R1
05EC 37         =5383          CPL     A
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =5384          MADDC   A,EMAHI
05ED B933       =5390+           MOV     R1,#EMAHI
05EF 71         =5391+           ADDC    A,@R1
05F0 83         =5395 CMPRET:  RET
                =5396          SIZECHK
000F            =5399+  SIZE   SET   15
                =5400+;
                =5401+;*****************************************************
                =5410 $EJECT
```

1

```
LOC  OBJ       LINE       SOURCE STATEMENT

               5411 $       INCLUDE(:F0:KBD.MOD)
               =5412        CODEBLK 100
074E           =5447+         ORG    1870
               =5451 ;
               =5452 ;      KEYBOARD AND DISPLAY PROCESSING ROUTINE
               =5453 ;      CALLED PERIODICALLY WHEN KBD AND DISPLAY ARE TO BE ALIVE.
074E D5        =5454 TIINT: SEL    RB1
               =5455        MMOV   ASAVE,A
074F B93E      =5468+         MOV    R1,#ASAVE
0751 A1        =5469+         MOV    @R1,A
0752 23F0      =5473        MOV    A,#(-10H)
0754 62        =5474        MOV    T,A             ;RELOAD TIMER INTERVAL
0755 27        =5475        CLR    A
0756 3E        =5476        MOVD   PSEGHI,A        ;WRITE BLANK PATTERN TO SEG DRIVERS
0757 3D        =5477        MOVD   PSEGLO,A
0758 FD        =5478        MOV    A,CURDIG
0759 07        =5479        DEC    A
075A 3F        =5480        MOVD   PDIGIT,A        ;ENERGIZE CHARACTER
075B 0C        =5481        MOVD   A,PINPUT        ;LOAD ANY SWITCH CLOSURES
075C AA        =5482        MOV    ROTPAT,A
               =5483                               ;WRITE NEXT SEGMENT PATTERN
075D FD        =5484        MOV    A,CURDIG
075E 07        =5485        DEC    A
075F 0346      =5486        ADD    A,#SEGMAP       ;ADD CURDIG DISPLACMENT TO BASE
0761 A8        =5487        MOV    R0,A
0762 F0        =5488        MOV    A,@R0           ;LOAD ACC W/ NEXT SEGMENT PATTERN
0763 3D        =5489        MOVD   PSEGLO,A        ;ENABLE APPROPRIATE SEGMENTS
0764 47        =5490        SWAP   A
0765 3E        =5491        MOVD   PSEGHI,A
               =5492 ;
               =5493 ;*********************************************************
               =5494 ;      THE NEXT CHARACTER IS NOW BEING DISPLAYED.
               =5495 ;      THE KEYBOARD SCAN ROUTINE IS INTEGRATED INTO THE DISPLAY SCAN.
               =5496 ;      WITH THE CURRENT ROW ENERGIZED, CHECK IF THERE ARE ANY INPUTS.
               =5497 ;*********************************************************
               =5498 ;
               =5499 ;      ROTATE BITS THROUGH THE CY WHILE INCREMENTING KEYLOC.
               =5500 ;
0766 BB04      =5501        MOV    ROTCNT,#NCOLS   ;SET UP FOR <NCOLS> LOOPS THROUGH 'NXTLOC'
               =5502 NXTLOC: MRRC  ROTPAT
0768 FA        =5514+         MOV    A,ROTPAT
0769 67        =5518+         RRC    A
076A AA        =5529+         MOV    ROTPAT,A
076B F68B      =5532        JC     SCAN5           ;ONE BIT IN CY INDICATES KEY NOT DOWN
076D BE01      =5533        MOV    KEYFLG,#1       ;MARK THAT AT LEAST ONE KEY WAS DETECTED
               =5534                               ;\ IN THE CURRENT SCAN
               =5535 ;
               =5536 ;*********************************************************
               =5537 ;      A KEYSTROKE WAS DETECTED FOR THE CURRENT COLUMN.  ITS
               =5538 ;      POSITION IS IN REGISTER KEYLOC.  SEE IF SAME KEY SENSED LAST CYCLE.
               =5539 ;*********************************************************
               =5540 ;
               =5541        MMOV   A,KEYLOC
076F B93C      =5550+         MOV    R1,#KEYLOC
0771 F1        =5551+         MOV    A,@R1
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

0772 2C         =5555           XCH     A,LASTKY
0773 DC         =5556           XRL     A,LASTKY
0774 C67C       =5557           JZ      SCAN3
                =5558 ;
                =5559 ;*********************************************************
                =5560 ;       A DIFFERENT KEY WAS READ ON THIS CYCLE THAN ON THE PREVIOUS CYCLE.
                =5561 ;       SET NREPTS TO THE DEBOUNCE PARAMETER FOR A NEW COUNTDOWN.
                =5562 ;*********************************************************
                =5563 ;
0776 B93D       =5564           MOV     R1,#NREPTS
0778 B106       =5565           MOV     @R1,#6
077A E48B       =5566           JMP     SCAN5
                =5567 ;
                =5568 ;*********************************************************
                =5569 ;       SAME KEY WAS DETECTED 3S ON PREVIOUS CYCLE
                =5570 ;       LOOK AT NREPTS: IF ALREADY ZERO, DO NOTHING.
                =5571 ;       ELSE DECREMENT NREPTS.
                =5572 ;       IF THIS RESULTS IN ZERO, MOVE LASTKY INTO KBDBUF
                =5573 ;*********************************************************
                =5574 ;
                =5575 SCAN3:  MMOV    A,NREPTS
077C B93D       =5584+          MOV     R1,#NREPTS
077E F1         =5585+          MOV     A,@R1
077F C68B       =5589           JZ      SCAN5           ;IF ALREADY ZERO
0781 07         =5590           DEC     A               ;INDICATE ONE MORE SUCCESIVE KEY DETECTION
                =5591           MMOV    NREPTS,A
0782 B93D       =5604+          MOV     R1,#NREPTS
0784 A1         =5605+          MOV     @R1,A
0785 968B       =5609           JNZ     SCAN5           ;IF DECREMENT DOES NOT RESULT IN ZERO
                =5610           MMOV    KBDBUF,LASTKY   ;TO MARK NEW KEY CLOSURE
0787 FC         =5633+          MOV     A,LASTKY
0788 B93B       =5639+          MOV     R1,#KBDBUF
078A A1         =5640+          MOV     @R1,A
                =5643 ;
078B B93C       =5644 SCAN5:  MOV     R1,#KEYLOC
078D 11         =5645           INC     @R1
078E EB68       =5646           DJNZ    ROTCNT,NXTLOC
0790 EBA8       =5647           DJNZ    CURDIG,TIRET1
0792 BD08       =5648           MOV     CURDIG,#CHARNO
                =5649 ;
                =5650 ;*********************************************************
                =5651 ;       THE FOLLOWING CODE SEGMENT IS USED BY THE KEYBOARD SCANNING ROUTINE.
                =5652 ;       IT IS EXECUTED ONLY AFTER A REFRESH SEQUENCE IS COMPLETED
                =5653 ;*********************************************************
                =5654 ;
                =5655           MMOV    KEYLOC,ZERO
0794 B93C       =5666+          MOV     R1,#KEYLOC
0796 B100       =5667+          MOV     @R1,#ZERO
0798 FE         =5671           MOV     A,KEYFLG
0799 969D       =5672           JNZ     SCAN8           ;JUMP IF ANY KEYS WERE DETECTED
                =5673           MMOV    LASTKY,NEG1     ;CHANGE <LASTKY> WHEN NO KEYS ARE DOWN
079B BCFF       =5678+          MOV     LASTKY,#NEG1
079D BE00       =5682 SCAN8:  MOV     KEYFLG,#0
                =5683 ;
                =5684 ;*********************************************************
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =5685 ;
                =5686 ;       KBD/DISP RETURN CODE- RESTORES SYSTEM STATUS.
                =5687         MMOV    A,RDELAY
079F B93F       =5696+          MOV     R1,#RDELAY
07A1 F1         =5697+          MOV     A,@R1
07A2 C6A8       =5701         JZ      TIRET1
07A4 07         =5702         DEC     A
                =5703         MMOV    RDELAY,A
07A5 B93F       =5716+          MOV     R1,#RDELAY
07A7 A1         =5717+          MOV     @R1,A
                =5721 TIRET1: MMOV    A,ASAVE
07A8 B93E       =5730+          MOV     R1,#ASAVE
07AA F1         =5731+          MOV     A,@R1
07AB 93         =5735         RETR
                =5736 ;
                =5737 ;
                =5738 ;TOFPOL TIMER OVERFLOW POLLING SUBROUTINE.
                =5739 ;       CALLED REPEATEDLY FROM WHEREVER KBD/DISP MUST BE ALIVE.
                =5740 ;       MONITORS THE TIMER OVERFLOW FLAG (TOF) AND CALLS SERVICE
                =5741 ;       ROUTINE WHEN APPROPRIATE.
07AC 164E       =5742 TOFPOL: JTF     TIINT
07AE 83         =5743         RET
                =5744         SIZECHK
0061            =5747+  SIZE  SET   97
                =5748+;
                =5749+;*****************************************************************
                =5750 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =5759          CODEBLK 17
06C2            =5789+           ORG     1730
                =5793 ;
                =5794 ;KBDIN   KEYBOARD INPUT SUBROUTINE.
                =5795 ;        RETURNS ONLY AFTER A NEW KEYSTROKE HAS BEEN DETECTED AND DEBOUNCED.
                =5796 ;        VALUE OF KEY POSITION IN SWITCH MATRIX IS
                =5797 ;        RETURNED IN THE ACCUMULATOR.
                =5798 ;        DISPLAY CHARACTER NOW ON BLANKED BEFORE RETURNING.
06C2 BF03       =5799 KBDIN:   MOV     XPCODE,#3
06C4 74D1       =5800          CALL    XPTEST
06C6 F4AC       =5801 KBDI1:   CALL    TOFPOL
                =5802          MMOV    A,KBDBUF
06C8 B93B       =5811+           MOV     R1,#KBDBUF
06CA F1         =5812+           MOV     A,@R1
06CB F2C6       =5816          JB7     KBDI1
06CD 27         =5817          CLR     A
06CE 3E         =5818          MOVD    PSEGHI,A
06CF 3D         =5819          MOVD    PSEGLO,A
06D0 37         =5820          CPL     A
06D1 21         =5821          XCH     A,@R1
06D2 83         =5822          RET
                =5823          SIZECHK
0011            =5826+  SIZE   SET   17
                =5827+;
                =5828+;*************************************************************
                =5837 ;
                =5838          CODEBLK 15
05F1            =5863+           ORG     1521
                =5867 ;CLEAR   WRITES 'BLANK' CHARACTERS INTO ALL DISPLAY REGISTERS.
                =5868 ;        RETURNS WITH NEXTPL SET TO LEFTMOST CHARACTER POSITION
                =5869 ;        DOES NOT AFFECT ACC OR CY.
05F1 B846       =5870 CLEAR:   MOV     R0,#SEGMAP
05F3 B908       =5871          MOV     R1,#CHARNO
05F5 B000       =5872 DBLANK:  MOV     @R0,#0          ;STORE THE BLANK CODE
05F7 18         =5873          INC     R0              ;POINT TO NEXT CHARACTER TO THE LEFT
05F8 E9F5       =5874          DJNZ    R1,DBLANK
                =5875          MMOV    NEXTPL,CHARNO
05FA B93A       =5886+           MOV     R1,#NEXTPL
05FC B108       =5887+           MOV     @R1,#CHARNO
05FE 83         =5891          RET
                =5892          SIZECHK
000E            =5895+  SIZE   SET   14
                =5896+;
                =5897+;*************************************************************
                =5906 ;
                =5907          CODEBLK 44
06D3            =5937+           ORG     1747
                =5941 ;DSPACC DISPLAY VALUE OF LOW NIBBLE OF ACC
06D3 530F       =5942 DSPACC:  ANL     A,#0FH
06D5 03EF       =5943          ADD     A,#DGPATS
06D7 A3         =5944          MOVP    A,@A
                =5945 ;WDISP   WRITES BIT PATTERN NOW IN ACC INTO NEXT CHARACTER POSITION
                =5946 ;        OF THE DISPLAY (NEXTPL).  INCREMENTS NEXTPL.
                =5947 ;        RESULTS IN DISPLAY BEING FILLED LEFT TO RIGHT, THEN RESTARTING
06D8 AE         =5948 WDISP:   MOV     DSPTMP,A
```

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LOC  OBJ        LINE        SOURCE STATEMENT

06D9 BF04       =5949          MOV     XPCODE,#4
06DB 74D1       =5950          CALL    XPTEST
                =5951          MMOV    A,NEXTPL
06DD B93A       =5960+           MOV     R1,#NEXTPL
06DF F1         =5961+           MOV     A,@R1
06E0 0345       =5965          ADD     A,#SEGMAP-1
06E2 A9         =5966          MOV     R1,A
06E3 FE         =5967          MOV     A,DSPTMP
06E4 A1         =5968          MOV     @R1,A
                =5969          MDJNZ   NEXTPL,WDISP1
06E5 B93A       =5974+           MOV     R1,#NEXTPL
06E7 F1         =5975+           MOV     A,@R1
06E8 07         =5979+           DEC     A
06E9 A1         =5984+           MOV     @R1,A
06EA 96EE       =5988+           JNZ     WDISP1
06EC B108       =5990          MOV     @R1,#CHARNO
06EE 83         =5991 WDISP1:  RET
                =5992 ;
                =5993 ;DGPATS IS THE BASE FOR THE TABLE OF SEGMENT PATTERNS FOR HEX DIGITS.
                =5994 ;HERE THE FULL HEX SET (0-F) IS INCLUDED.
                =5995 ;
00EF            =5996 DGPATS   EQU     $ AND 0FFH
                =5997 ;
                =5998 ;FORMAT IS       PGFEDCBA        IN STANDARD SEVEN-SEGMENT ENCODING CONVENTION
                =5999 ;                                WHERE P REPRESENTS THE DECIMAL POINT
06EF 3F         =6000          DB      00111111B       ;SEGMENT PATTERN FOR DIGIT '0'
06F0 06         =6001          DB      00000110B       ;SEGMENT PATTERN FOR DIGIT '1'
06F1 5B         =6002          DB      01011011B       ;SEGMENT PATTERN FOR DIGIT '2'
06F2 4F         =6003          DB      01001111B       ;SEGMENT PATTERN FOR DIGIT '3'
06F3 66         =6004          DB      01100110B       ;SEGMENT PATTERN FOR DIGIT '4'
06F4 6D         =6005          DB      01101101B       ;SEGMENT PATTERN FOR DIGIT '5'
06F5 7D         =6006          DB      01111101B       ;SEGMENT PATTERN FOR DIGIT '6'
06F6 07         =6007          DB      00000111B       ;SEGMENT PATTERN FOR DIGIT '7'
06F7 7F         =6008          DB      01111111B       ;SEGMENT PATTERN FOR DIGIT '8'
06F8 67         =6009          DB      01100111B       ;SEGMENT PATTERN FOR DIGIT '9'
06F9 77         =6010          DB      01110111B       ;SEGMENT PATTERN FOR DIGIT 'A'
06FA 7C         =6011          DB      01111100B       ;SEGMENT PATTERN FOR DIGIT 'B'
06FB 39         =6012          DB      00111001B       ;SEGMENT PATTERN FOR DIGIT 'C'
06FC 5E         =6013          DB      01011110B       ;SEGMENT PATTERN FOR DIGIT 'D'
06FD 79         =6014          DB      01111001B       ;SEGMENT PATTERN FOR DIGIT 'E'
06FE 71         =6015          DB      01110001B       ;SEGMENT PATTERN FOR DIGIT 'F'
                =6016          SIZECHK
002C            =6019+  SIZE   SET   44
                =6020+;
                =6021+;*****************************************************************
                =6030 ;
                =6031          CODEBLK 12
04F2            =6051+           ORG     1266
                =6055 ;DELAY   SUBROUTINE WAITS FOR THE NUMBER OF COMPLETE
                =6056 ;        DISPLAY SCANS CORRESPONDING TO THE ACC CONTENTS.
                =6057 ;        USED WITH CRUDE HUMAN INTERFACES- AS WHEN OPERATOR SHOULD SEE
                =6058 ;        SOME DISPLAY CHANGE WHILE IT IS CHANGING.
                =6059 DELAY:   MMOV    RDELAY,A
04F2 B93F       =6072+           MOV     R1,#RDELAY
04F4 A1         =6073+           MOV     @R1,A
```

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LOC  OBJ        LINE        SOURCE STATEMENT

04F5 F4AC      =6077 DELAY1: CALL    TOFFOL
               =6078         MMOV    A,RDELAY
04F7 B93F      =6087+          MOV     R1,#RDELAY
04F9 F1        =6088+          MOV     A,@R1
04FA 96F5      =6092         JNZ     DELAY1
04FC 83        =6093         RET
               =6094         SIZECHK
0008           =6097+  SIZE  SET   11
               =6098+;
               =6099+;*****************************************************************
               =6108 ;
               =6109         CODEBLK 8
07AF           =6144+          ORG     1967
               =6148 ;KBDPOL POLL STATUS OF KEYBOARD INPUT ROUTINE.
               =6149 ;       RETURN WITH ACC BIT 7 = 0 IF KEYBOARD INPUT HAS BEEN RECEIVED.
07AF BF05      =6150 KBDPOL: MOV     XPCODE,#5
07B1 74D1      =6151         CALL    XPTEST
               =6152         MMOV    A,KBDBUF
07B3 B93B      =6161+          MOV     R1,#KBDBUF
07B5 F1        =6162+          MOV     A,@R1
07B6 83        =6166         RET
               =6167         SIZECHK
0008           =6170+  SIZE  SET   8
               =6171+;
               =6172+;*****************************************************************
               =6181 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                 6182 $       INCLUDE(:F0:LINK.MOD)
                =6183         CODEBLK 15
07B7            =6218+          ORG     1975
                =6222 ;EPFET  FETCH DATA BYTE FROM EP INTERNAL RAM ADDRESSED BY SMALO
                =6223 EPFET:  MMOV    A,SMALO
07B7 B930       =6232+          MOV     R1,#SMALO
07B9 F1         =6233+          MOV     A,@R1
07BA F4D0       =6237         CALL    EPPASS
07BC 2380       =6238         MOV     A,#10000000B
07BE F4D0       =6239         CALL    EPPASS
07C0 F4D0       =6240         CALL    EPPASS
07C2 83         =6241         RET
                =6242         SIZECHK
000C            =6245+  SIZE  SET   12
                =6246+;
                =6247+;*************************************************************
                =6256 ;
                =6257         CODEBLK 15
07C3            =6292+          ORG     1987
                =6296 ;EPSTOR STORE DATA IN LDATA IN EP INTERNAL RAM AT <SMALO>
07C3 FA         =6297 EPSTOR: MOV     A,LDATA
07C4 F4D0       =6298         CALL    EPPASS
                =6299         MMOV    A,SMALO
07C6 B930       =6308+          MOV     R1,#SMALO
07C8 F1         =6309+          MOV     A,@R1
07C9 537F       =6313         ANL     A,#01111111B
07CB F4D0       =6314         CALL    EPPASS
07CD F4D0       =6315         CALL    EPPASS
07CF 83         =6316         RET
                =6317         SIZECHK
000D            =6320+  SIZE  SET   13
                =6321+;
                =6322+;*************************************************************
                =6331 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

             =6332 ;        THE FOLLOWING UTILITIES INVOLVE INTERCHANGES BETWEEN THE MP AND EP.
             =6333 ;
             =6334          CODEBLK 11
07D0         =6369+           ORG     2000
             =6373 ;EPPASS PASSES A SINGLE PARAMETER BYTE TO THE EP THROUGH THE LINK.
             =6374 ;        WRITE THE CONTENTS OF THE ACC TO THE LINK;
             =6375 ;        RELEASE THE EP;
             =6376 ;        READ THE LINK INTO THE ACC;
             =6377 ;        RETURN.
07D0 8A30    =6378 EPPASS:  ORL     P2,#00110000B          ;ENABLE LINK WRITES.
07D2 91      =6379          MOVX    @R1,A                  ;WRITE ACC TO LINK.
07D3 99FE    =6380          ANL     P1,#NOT ENBRAM         ;DISABLE BREAKPOINTS.
07D5 8902    =6381          ORL     P1,#ENBLNK             ;SET TO BREAK ON LINK REFERENCE.
07D7 F4DB    =6382          CALL    EPSTEP
07D9 81      =6383          MOVX    A,@R1
07DA 83      =6384          RET
             =6385          SIZECHK
000B         =6388+  SIZE   SET   11
             =6389+;
             =6390+;*********************************************************
             =6399 ;
             =6400          CODEBLK 25
07DB         =6435+           ORG     2011
             =6439 ;EPSTEP RELEASES EP TO RUN IN PRESENT MODE UNTIL AN ANTICIPATED
             =6440 ;        HARDWARE BREAK OCCURS.
             =6441 ;        (DUE TO SINGLE STEPPING, LINK OPCODE FETCH, OR LINK DATA FETCH.)
             =6442 ;        MUST OCCUR WITHIN A FINITE NUMBER OF CYCLES (<40 MP CYCLES)
             =6443 ;        OR WATCHDOG TIMER WILL ASSUME A COMMUNICATIONS ERROR
             =6444 ;        BETWEEN THE MP AND EP.
07DB F4F4    =6445 EPSTEP:  CALL    EPREL
07DD B90A    =6446          MOV     R1,#10
07DF 86F1    =6447 EPSTE1:  JNI     EPSTE2
07E1 E9DF    =6448          DJNZ    R1,EPSTE1
07E3 8910    =6449          ORL     P1,#EPRSET
07E5 744F    =6450          CALL    EPBRK
07E7 B8BB    =6451          MOV     R0,#LOW(OV1BAS+OVSIZE)
07E9 746A    =6452          CALL    OVLOAD
07EB 99EF    =6453          ANL     P1,#NOT EPRSET
07ED BA0E    =6454          MOV     LDATA,#0EH
07EF 249A    =6455          JMP     PERROR
07F1 744F    =6456 EPSTE2:  CALL    EPBRK
07F3 83      =6457          RET
             =6458          SIZECHK
0019         =6461+  SIZE   SET   25
             =6462+;
             =6463+;*********************************************************
             =6472 ;
             =6473 ;
             =6474 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =6475          CODEBLK 9
07F4            =6510+           ORG     2036
                =6514 ;EPREL   RELEASES EP TO RUN IN PRESENT MODE.
                =6515 ;        SEQUENCE IS AS FOLLOWS:
                =6516 ;        PUT MEMORY ARRAY IN EP MODE;
                =6517 ;        RAISE /SSTEP;
                =6518 ;        RETURN.
07F4 99F7       =6519 EPREL:   ANL     P1,#NOT CLRBFF          ;CLEAR BREAK F/F.
07F6 8908       =6520          ORL     P1,#CLRBFF              ;RE-ENABLE BREAK F/F.
07F8 9ABF       =6521          ANL     P2,#NOT 010000000B      ;ENABLE EP CONTROL OF MEM ARRAY
07FA 8904       =6522          ORL     P1,#000001000B          ;FREE EP TO RUN UNTIL BREAK.
07FC 83         =6523          RET
                =6524          SIZECHK
0009            =6527+  SIZE   SET   9
                =6528+;
                =6529+;*************************************************************
                =6538 ;
                =6539 ;
                =6540          CODEBLK 11
034F            =6580+           ORG     847
                =6584 ;EPBRK   REGAIN CONTROL OF MEMORY ARRAY FROM EP.
                =6585 ;        DROP /SSTEP;
                =6586 ;        WAIT 30 USECS.;
                =6587 ;        PUT MEMORY ARRAY IN MP MODE;
                =6588 ;        RETURN.
034F 99FB       =6589 EPBRK:   ANL     P1,#NOT 000001000B      ;FREEZE EMULATION PROCESSOR.
0351 8920       =6590          ORL     P1,#MODOUT              ;SIGNAL EP IS NOT RUNNING USER CODE.
0353 B905       =6591          MOV     R1,#5
0355 E955       =6592          DJNZ    R1,$                    ;DELAY FOR EP TO FINISH INSTRUCTION.
0357 8A40       =6593          ORL     P2,#010000000B          ;SEIZE CONTROL OF MEM ARRAY.
0359 83         =6594          RET
                =6595          SIZECHK
000B            =6598+  SIZE   SET   11
                =6599+;
                =6600+;*************************************************************
                =6609 ;
                =6610 ;
                =6611          CODEBLK 16
035A            =6651+           ORG     858
                =6655 ;OVSWAP  OVERLAY SWAP.
                =6656 ;        SWAPS BLOCK OF DATABYTES (USER'S PROGRAM) BETWEEN MP RAM & EP PM.
035A B865       =6657 OVSWAP:  MOV     R0,#OVBUF+OVSIZE
035C B917       =6658          MOV     R1,#OVSIZE
035E 2340       =6659          MOV     A,#010000000B
0360 3A         =6660          OUTL    P2,A
0361 C8         =6661 OVSW1:   DEC     R0
0362 C9         =6662          DEC     R1
0363 81         =6663          MOVX    A,@R1
0364 20         =6664          XCH     A,@R0
0365 91         =6665          MOVX    @R1,A
0366 F9         =6666          MOV     A,R1
0367 9661       =6667          JNZ     OVSW1
0369 83         =6668          RET
                =6669          SIZECHK
0010            =6672+  SIZE   SET   16
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

             =6673+;
             =6674+;*************************************************************
             =6683 ;
             =6684          CODEBLK 14
036A         =6724+           ORG    874
             =6728 ;OVLOAD OVERLAY LOAD.
             =6729 ;        MOVES BLOCK OF DATABYTES (ASSEMBLED SOURCE) FROM PG3 TO EP PM.
             =6730 ;        TOP OF DATA BLOCK LOADED AND BLOCK LENGTH DETERMINED BY R0 AND R1.
036A B917    =6731 OVLOAD: MOV     R1,#OVSIZE
036C 2340    =6732         MOV     A,#01000000B
036E 3A      =6733         OUTL    P2,A
036F C8      =6734 MML01:  DEC     R0
0370 C9      =6735         DEC     R1
0371 F8      =6736         MOV     A,R0
0372 E3      =6737         MOVP3   A,@A
0373 91      =6738         MOVX    @R1,A
0374 F9      =6739         MOV     A,R1
0375 966F    =6740         JNZ     MML01
0377 83      =6741         RET
             =6742         SIZECHK
000E         =6745+ SIZE   SET   14
             =6746+;
             =6747+;*************************************************************
             =6756 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =6757 ;
                =6758 ;=====================================
                =6759 ;
                =6760 ;       THE REST OF THIS MODULE CONTAINS THE MINI-MONITORS WHICH OVERLAY
                =6761 ;       THE EMULATION PROCESSOR PROGRAM RAM TO GIVE THE
                =6762 ;       MASTER PROCESSOR ACCESS TO INTERNAL REGISTERS AND RAM OF THE EP.
                =6763 ;
                =6764 ;=====================================
                =6765 ;
                =6766         DATABLK 22
0378            =6771+          ORG     888
                =6775 ;
                =6776 ;OV0-   OVERLAY TO BREAK EP EXECUTION AND JUMP TO LOCATION 009H.
                =6777 ;       LOCATION 009H REACHED WITH TOP-OF-STACK = RETURN ADDRESS+2
                =6778 ;       DUE TO FORCED "CALL" DURING WHICH PC WAS INCREMENTED.
                =6779 ;       LOCS 003H & 007H CALL 009H TO SIMULATE SAME CONDITION
                =6780 ;       IF BREAK OCCURS DURING INTERRUPT CYCLE.
                =6781 ;       SOURCE CODE FOR MINI-MONITOR OVERLAYED OVER LOW ORDER PROGRAM RAM.
                =6782 ;
0378            =6783 OV0BAS  EQU     $
0378            =6784 ORG     OV0BAS
0378 1409       =6785         CALL    009H
037A 00         =6786         NOP
                =6787 ;
037B            =6788 ORG     OV0BAS+003H
037B 1409       =6789         CALL    009H
037D 00         =6790         NOP
037E 00         =6791         NOP
                =6792 ;
037F            =6793 ORG     OV0BAS+007H
037F 1409       =6794         CALL    009H
0381 00         =6795         NOP
0382 00         =6796         NOP
0383 00         =6797         NOP
0384 00         =6798         NOP
0385 00         =6799         NOP
0386 00         =6800         NOP
0387 00         =6801         NOP
0388 00         =6802         NOP
0389 00         =6803         NOP
038A 00         =6804         NOP
038B 00         =6805         NOP
                =6806 ;
038C            =6807 ORG     OV0BAS+014H
038C 0409       =6808         JMP     009H
                =6809 ;
                =6810         SIZECHK
0016            =6813+  SIZE  SET   22
                =6814+;
                =6815+;*************************************************************
                =6824 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

             =6825         DATABLK 22
038E         =6830+          ORG     910
             =6834 ;
             =6835 ;OV3-   OVERLAY TO SAVE STATUS DATA AFTER BREAK.
             =6836 ;       ACC, TIMER/COUNTER, PSW (WITH F1), & RAM LOC 0 PASSED SEQUENTIALLY
             =6837 ;       TO MP.
             =6838 ;       SOURCE CODE FOR MINI-MONITOR OVERLAYED OVER LOW ORDER PROGRAM RAM.
             =6839 ;
038E         =6840 OV3BAS  EQU     $
038E         =6841 ORG     OV3BAS
038E 0400    =6842         JMP     000H
0390 00      =6843         NOP
             =6844 ;
0391         =6845 ORG     OV3BAS+003H
0391 83      =6846         RET
0392 00      =6847         NOP
0393 00      =6848         NOP
0394 00      =6849         NOP
             =6850 ;
0395         =6851 ORG     OV3BAS+007H
0395 83      =6852         RET
0396 00      =6853         NOP
             =6854 ;
0397         =6855 ORG     OV3BAS+009H
0397 90      =6856         MOVX    @R0,A
0398 42      =6857         MOV     A,T
0399 90      =6858         MOVX    @R0,A
039A C7      =6859         MOV     A,PSW
039B 7611    =6860         JF1     OV3B1
039D 53F7    =6861         ANL     A,#11110111B
0311         =6862 OV3B1   EQU     $-(LOW OV3BAS)
039F 90      =6863         MOVX    @R0,A
03A0 C5      =6864         SEL     RB0
03A1 F8      =6865         MOV     A,R0
03A2 0409    =6866         JMP     009H
             =6867 ;
             =6868         SIZECHK
0016         =6871+  SIZE  SET   22
             =6872+;
             =6873+;*************************************************************
             =6882 $EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                =6883          DATABLK 22
03A4            =6888+           ORG    932
                =6892 ;
                =6893 ;OV1-    OVERLAY 1 TO GIVE MP ACCESS TO EP RAM LOCS. 01H-7FH.
                =6894 ;        SOURCE CODE FOR MINI-MONITOR OVERLAYED OVER LOW ORDER PROGRAM RAM.
                =6895 ;
03A4            =6896 OV1BAS   EQU    $
                =6897 ;
03A4 040A       =6898          JMP    OV1B1
03A6 00         =6899          NOP
                =6900 ;
03A7            =6901 ORG      OV1BAS+003H
03A7 83         =6902          RET
03A8 00         =6903          NOP
03A9 00         =6904          NOP
03AA 00         =6905          NOP
                =6906 ;
03AB            =6907 ORG      OV1BAS+007H
03AB 83         =6908          RET
03AC 00         =6909          NOP
                =6910 ;
03AD            =6911 ORG      OV1BAS+009H
03AD 90         =6912          MOVX   @R0,A
                =6913 ;
000A            =6914 OV1B1    EQU    $-OV1BAS
                =6915 ;
03AE 80         =6916          MOVX   A,@R0
03AF A8         =6917          MOV    R0,A
03B0 80         =6918          MOVX   A,@R0
03B1 F213       =6919          JB7    OV1B2
03B3 28         =6920          XCH    A,R0
03B4 A0         =6921          MOV    @R0,A
03B5 0409       =6922          JMP    009H
                =6923 ;
0313            =6924 OV1B2    EQU    $-LOW OV1BAS
                =6925 ;
03B7 F0         =6926          MOV    A,@R0
03B8 0409       =6927          JMP    009H
                =6928 ;
                =6929          SIZECHK
0016            =6932+  SIZE   SET    22
                =6933+;
                =6934+;*****************************************************************
                =6943 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                =6944       DATABLK 23
03BA            =6949+        ORG    954
                =6953 ;
                =6954 ;OV2-   OVERLAY TO RESTORE EP STATUS SAVED ON BREAK AND RESUME USER'S PROGRAM.
                =6955 ;       SOURCE CODE FOR MINI-MONITOR OVERLAYED OVER LOW ORDER PROGRAM RAM.
                =6956 ;
03BA            =6957 OV2BAS  EQU    $
03BA            =6958 ORG     OV2BAS
03BA 0400       =6959         JMP    000H
03BC 00         =6960         NOP
                =6961 ;
03BD            =6962 ORG     OV2BAS+003H
03BD 83         =6963         RET
03BE 00         =6964         NOP
03BF 00         =6965         NOP
03C0 00         =6966         NOP
                =6967 ;
03C1            =6968 ORG     OV2BAS+007H
03C1 83         =6969         RET
03C2 00         =6970         NOP
                =6971 ;
03C3            =6972 ORG     OV2BAS+009H
03C3 90         =6973         MOVX   @R0,A
                =6974 ;
03C4 80         =6975         MOVX   A,@R0
03C5 A8         =6976         MOV    R0,A
03C6 80         =6977         MOVX   A,@R0
03C7 D7         =6978         MOV    PSW,A
03C8 A5         =6979         CLR    F1
03C9 B5         =6980         CPL    F1
03CA 7213       =6981         JB3    OV2B1
03CC A5         =6982         CLR    F1
                =6983 ;
0313            =6984 OV2B1   EQU    $-LOW OV2BAS
                =6985 ;
03CD 80         =6986         MOVX   A,@R0
03CE 62         =6987         MOV    T,A
03CF 80         =6988         MOVX   A,@R0
03D0 93         =6989         RETR
                =6990         SIZECHK
0017            =6993+  SIZE  SET    23
                =6994+;
                =6995+;*************************************************************
                =7004 $EJECT
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

                7005 ;
                7006          CODEBLK 11
03D1            7046+           ORG     977
03D1 8A80       7050 XPTEST:  ORL     P2,#80H
03D3 0A         7051          IN      A,P2
03D4 9A7F       7052          ANL     P2,#(NOT 80H)
03D6 F2D9       7053          JB7     $+3
03D8 83         7054          RET
03D9 F5         7055          SEL     MB1
03DA 0400       7056          JMP     800H
                7057          SIZECHK
000B            7060+  SIZE   SET   11
                7061+;
                7062+;*******************************************************
                7071 ;
                7072          CODEBLK 13
03DC            7112+           ORG     988
03DC 28432931   7116          DB      '(C)1979 INTEL'
03E0 39373920
03E4 494E5445
03E8 4C
                7117          SIZECHK
000D            7120+  SIZE   SET   13
                7121+;
                7122+;*******************************************************
                7131 ;
                7132 ;
                7133          RSOURCE
0100            7135+           PGSIZE  SET   ORGPG0-000H     ;BYTES USED ON PAGE 0
00FD            7136+           PGSIZE  SET   ORGPG1-100H     ;BYTES USED ON PAGE 1
0100            7137+           PGSIZE  SET   ORGPG2-200H     ;BYTES USED ON PAGE 2
00E9            7138+           PGSIZE  SET   ORGPG3-300H     ;BYTES USED ON PAGE 3
00FD            7139+           PGSIZE  SET   ORGPG4-400H     ;BYTES USED ON PAGE 4
00FF            7140+           PGSIZE  SET   ORGPG5-500H     ;BYTES USED ON PAGE 5
00FF            7141+           PGSIZE  SET   ORGPG6-600H     ;BYTES USED ON PAGE 6
00FD            7142+           PGSIZE  SET   ORGPG7-700H     ;BYTES USED ON PAGE 7
                7143+$EJECT
```

```
LOC  OBJ        LINE       SOURCE STATEMENT

                7145 ;*******************************************************
                7146 ;
                7147 ;       FILL ALL UNUSED MEMORY LOCATIONS WITH NOP OPCODES
                7148 ;
                7149 ;*******************************************************
                7150 ;
                7151 $GEN
                7158 ;
01FD            7160          ORG   ORGPG1
                7161        REPT (200H - ORGPG1)
-               7162          DB    0
                7163        ENDM
01FD 00         7164+         DB    0
01FE 00         7165+         DB    0
01FF 00         7166+         DB    0
                7168 ;
                7175 ;
03E9            7177          ORG   ORGPG3
                7178        REPT (400H - ORGPG3)
-               7179          DB    0
                7180        ENDM
03E9 00         7181+         DB    0
03EA 00         7182+         DB    0
03EB 00         7183+         DB    0
03EC 00         7184+         DB    0
03ED 00         7185+         DB    0
03EE 00         7186+         DB    0
03EF 00         7187+         DB    0
03F0 00         7188+         DB    0
03F1 00         7189+         DB    0
03F2 00         7190+         DB    0
03F3 00         7191+         DB    0
03F4 00         7192+         DB    0
03F5 00         7193+         DB    0
03F6 00         7194+         DB    0
03F7 00         7195+         DB    0
03F8 00         7196+         DB    0
03F9 00         7197+         DB    0
03FA 00         7198+         DB    0
03FB 00         7199+         DB    0
03FC 00         7200+         DB    0
03FD 00         7201+         DB    0
03FE 00         7202+         DB    0
03FF 00         7203+         DB    0
                7205 ;
04FD            7207          ORG   ORGPG4
                7208        REPT (500H - ORGPG4)
-               7209          DB    0
                7210        ENDM
04FD 00         7211+         DB    0
04FE 00         7212+         DB    0
04FF 00         7213+         DB    0
                7215 ;
05FF            7217          ORG   ORGPG5
                7218        REPT (600H - ORGPG5)
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

-               7219          DB    0
                7220        ENDM
05FF 00         7221+         DB    0
                7223 ;
06FF            7225          ORG   ORGPG6
                7226        REPT (700H - ORGPG6)
-               7227          DB    0
                7228        ENDM
06FF 00         7229+         DB    0
                7231 ;
07FD            7233          ORG   ORGPG7
                7234        REPT (800H - ORGPG7)
--              7235          DB    0
                7236        ENDM
07FD 00         7237+         DB    0
07FE 00         7238+         DB    0
07FF 00         7239+         DB    0
                7241 ;
                7242 $EJECT
```

```
PLUS3   714#  2260
PRNT1  2009  2030#
PRNT2  1994#  2029
PSEGHI  518#  1414  5476  5491  5818
PSEGLO  519#  1413  5477  5489  5819
RDELAY 1248#  5696  5716  6072  6087
RECDON 3524  3549#
RECTYP 1275#  3503  3587
REGC   1293#  4405  4442  4553  4596
REORG   191#  1335  1401  1529  1878  1948  1953  2158  2235  2240  2301  2306  2368  2373  2378  2519
       2524  2529  2652  2680  2685  2690  2695  3149  3154  3159  3164  3169  3400  3405  3410  3618
       3686  3691  3736  3741  3772  3777  3782  3787  3792  3922  3927  3932  3937  3942  3947  4107
       4112  4142  4147  4181  4186  4235  4240  4245  4250  4361  4366  4371  4376  4381  4496  4501
       4506  4511  4516  4521  4621  4626  4631  4696  4725  4730  4735  4740  4745  4750  4918  4923
       4928  4933  4938  4943  4948  5139  5144  5149  5154  5226  5231  5265  5270  5275  5310  5315
       5320  5325  5330  5415  5420  5425  5430  5435  5440  5445  5762  5767  5772  5777  5782  5787
       5841  5846  5851  5856  5861  5910  5915  5920  5925  5930  5935  6034  6039  6044  6049  6112
       6117  6122  6127  6132  6137  6142  6186  6191  6196  6201  6206  6211  6216  6260  6265  6270
       6275  6280  6285  6290  6337  6342  6347  6352  6357  6362  6367  6403  6408  6413  6418  6423
       6428  6433  6478  6483  6488  6493  6498  6503  6508  6543  6548  6553  6558  6563  6568  6573
       6578  6614  6619  6624  6629  6634  6639  6644  6649  6687  6692  6697  6702  6707  6712  6717
       6722  6769  6828  6886  6947  7009  7014  7019  7024  7029  7034  7039  7044  7075  7080  7085
       7090  7095  7100  7105  7110
RERROR 2317#  2348
RINT   1520#  1923
ROTCNT  886#  5501  5646
ROTPAT  865#  5482  5507  5514  5529
RSOURC  276#  7133
SCAN3  5557  5575#
SCAN5  5532  5566  5589  5609  5644#
SCAN8  5672  5682#
SEGMAP 1311#  2213  5486  5870  5965
SING   1523#  1928
SIZE   1385#  1388  1439#  1442  1863#  1866  1933#  1936  2143#  2146  2220#  2223  2286#  2289  2353#  2356
       2504#  2507  2637#  2640  2664#  2667  3134#  3137  3380#  3383  3603#  3606  3671#  3674  3720#  3723
       3755#  3758  3906#  3909  4092#  4095  4127#  4130  4166#  4169  4203#  4206  4345#  4348  4481#  4484
       4605#  4608  4681#  4684  4710#  4713  4903#  4906  5124#  5127  5210#  5213  5250#  5253  5295#  5298
       5399#  5402  5747#  5750  5826#  5829  5895#  5898  6019#  6022  6097#  6100  6170#  6173  6245#  6248
       6320#  6323  6388#  6391  6461#  6464  6527#  6530  6598#  6601  6672#  6675  6745#  6748  6813#  6816
       6871#  6874  6932#  6935  6993#  6996  7060#  7063  7120#  7123
SIZECH  270#  1382  1436  1860  1930  2140  2217  2283  2350  2501  2634  2661  3131  3377  3600  3668
       3717  3752  3903  4089  4124  4163  4200  4342  4478  4602  4678  4707  4900  5121  5207  5247
       5292  5396  5744  5823  5892  6016  6094  6167  6242  6317  6385  6458  6524  6595  6669  6742
       6810  6868  6929  6990  7057  7117
SMAHI  1122#  2487  2493  2772  3465  3817  4792  4990  5184  5378
SMALO  1113#  1671  1831  2480  2557  2745  2869  2880  3314  3341  3484  3844  4807  4823  4845  4879
       5005  5021  5046  5099  5200  5238  5282  5352  6232  6308
STRCOM 1623  2037#
STRGUC 1927  2054#
STRMEM 1922  1925  2047#  2555
STRTMP 1257#  1989  2003  2016
STRUTL 1973  2032#
STSAVE 3056  3062  3183#
TCRLFO 3886  3894  3975  4119#
TIINT  5454#  5742
TIRET1 5647  5701  5721#
TOFPOL 3046  5742#  5801  6077
```

```
TTYOUT  539#  4428   4430
TYPE   1176#  1429   1579   1585   1748   1771   1777   1822   2448   2550   3011   3072   4768   4966   5171
UPDAD1 2265#  2558   3371
UPDADR 2195   2248#
VERSNO 1050#
WBRK   1522#  1928
WDISP  2010   2030   2269   2274   2560   3373   5948#
WDISP1 5988   5991#
XPCODE  837#  1410   1539   2318   5799   5949   6150
XPTEST 1411   1540   2319   5800   5950   6151   7050#
ZERO    684#  1570   1586   1778   2494   3428   3860   5667

CROSS REFERENCE COMPLETE
```

```
DEBNCE  630#
DECLAR  170#   584   600   616   632   648   670   685   700   715   739   756   773   790   807   824
         848   869   890   911   932   964   973   982   991  1000  1009  1018  1027  1036  1045  1054
        1063  1072  1081  1090  1099  1108  1117  1126  1135  1144  1153  1162  1171  1180  1189  1198
        1207  1216  1225  1234  1243  1252  1261  1270  1279  1288  1297  4216
DECSM1 5286  5291#
DECSMA 2630  5282#
DELAY  3105  6059#
DELAY1 6077#  6092
DERROR 2033  2063#
DFILL  2040  2096#
DGO    2039  2094#
DGPRTS 5943  5996#
DGR    2046  2108#
DINTRG 2051  2124#
DLST   2041  2098#
DMOD   2038  2092#
DNOBRK 2055  2129#
DONE   3419  3595#
DPA    2058  2135#
DPRBRK 2052  2120#
DPRMEM 2048  2114#
DREC   2042  2100#
DREL   2043  2102#
DRM    2050  2118#
DRUN   2035  2078#
DSB    2044  2104#
DSGNON 2034  2070#
DSPACC 2276  2279   2281   2328   2564   2566   5942#
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ASSEMBLY COMPLETE,  NO ERRORS
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CGOPAT 0476   CGOSS  0480   CGOTRA 0480   CGOWB  0476   CHARCK 000D   CHARIN 01CD   CHARLF 000A   CHARNO 0008
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FDUMP2 0628   FDUMP3 0636   FDUMP4 0648   FDUMP5 0632   FINDOP 0042   GOTOL  0471   H      0045   HBD1   04D7
HBD2   04D5   HBDLAY 04C9   HBITHI 0027   HBITLO 0026   HDATIN 02B9   HEXASC 01E6   HEXBUF 0065   HEXNIB 01EF
HFDONE 05A7   HFILEO 0572   HRECIN 0297   HRECO  0600   HREGA  002A   HRLGB  002B   HREGC  002C   HREGD  002D
HREGE  002E   HREGF  002F   IMPLEM 0200   INCSMA 01F2   INCW   01F4   INCW1  01FC   INIT   0000   INITLP 000E
INPAD1 00C7   INPADR 00C0   INPKEY 00EC   INVALS 0300   ITMP   0004   JGOKES 0226   JMPTBL 0206   JTOFIL 0222
JTOGO  0220   JTOLST 021A   JTOMOD 020F   JTOREC 0211   JTOREL 0216   KBDBUF 003B   KBDI1  06C6   KBDIN  06C2
KBDPOL 07AF   KCLRB  000C   KEY    0003   KEYCLR 0017   KEYDM  0016   KEYEND 0013   KEYFIL 0010   KEYFLG 0006
KEYGO  001E   KEYLOC 003C   KEYLST 001C   KEYMOD 001F   KEYNX1 0012   KEYPAT 0015   KEYPM  001A   KEYREC 0018
KEYREG 001B   KEYREL 0014   KEYTRA 0019   KGORES 001D   KSETB  000B   LASTKY 0004   LDATA  0002   LDBYTE 0582
LFEBR1 06C1   LFEBRK 06B1   LFEDM  0698   LFEINT 06A9   LFEPM  0684   LFER0  06A5   LFEREG 069C   LFETBL 067E
LFETCH 00FC   LFILL  02E9   LFILL1 02F3   LPGSEL 04E1   LSTBR1 0746   LSTBR2 0748   LSTBRK 073D   LSTDM  0721
LSTINT 0734   LSTORE 0700   LSTPM  070C   LSTR0  072F   LSTREG 0726   LSTTBL 0706   M0     0010   M1     0020
MADD   0024   MADDC  0025   MAIN   0029   MAIN2  0033   MAINA  0052   MAINB  0069   MAINB0 009E   MAINB1 00A8
MAINC1 0075   MAIND  0093   MAIND1 0087   MANL   0026   MBLOCK 0002   MDEC   002C   MDJNZ  002D   MEMHI  0035
MEMLO  0034   MERROR 00BC   MINC   002B   MMLO1  036F   MMOV   0020   MODOUT 0020   MORL   0027   MPUSEL 0040
MRL    002E   MRLC   0031   MRR    002F   MRRC   0030   MXCH   0029   MXRL   0028   NCOLS  0004   NEG1   FFFF
NEXTPL 003A   NIBI3  01C2   NIBIN  01B8   NIBIN2 01BA   NIBO   05BB   NOBRK  001B   NOVALS 0023   NREPTS 003D
NUMCON 0038   NXTLOC 0768   OPTAB1 033F   OPTAB2 0346   OPTAB3 0349   OPTION 0039   ORGPG0 0100   ORGPG1 01FD
ORGPG2 0300   ORGPG3 03E9   ORGPG4 04FD   ORGPG5 05FF   ORGPG6 06FF   ORGPG7 07FD   OUTCLR 0102   OUTMSG 0104
OUTUTL 0100   OV0BAS 0378   OV1B1  000A   OV1B2  0313   OV1BAS 03A4   OV2B1  0313   OV2BAS 03BA   OV3B1  0311
OV3BAS 038E   OVBUF  004E   OVLOAD 036A   OVSIZE 0017   OVSW1  0361   OVSWAP 035A   PBRK   0019   PDIGIT 000E
PERROR 019A   PGSIZE 00FD   PINPUT 600B   PLUS1  0001   PLUS3  0003   PRNT1  0117   PRNT2  0108   PSEGHI 0000
```

APPENDIX C
COMMAND SUMMARY

The following is a summary of the commands implemented by the HSE-49 emulator monitor. Within each command group, tokens in each column indicate options the user has when invoking those commands.

Tokens in square brackets indicate dedicated keys on the keyboard (some keys having shared functions); angle brackets enclose hex digit strings used to specify an address or data parameter. Parameters in parentheses are optional, with the effects explained above. The notation used is as follows:

<SMA> — Starting Memory Address for block command,
<EMA> — Ending Memory Address for block command,
<LOC> — LOCation for individual accesses,
<DATA> — DATA byte.

Asterisks (*) indicate the default condition for each command; thus that token is optional and serves to regularize the command syntax.

Program/data entry and verification commands:

[EXAM]	[PROG MEM]* <LOC> [,]	[NEXT]
	[DATA MEM]	[PREV]
	[REGISTER]	[.]
	[HWRE REG]	
	[PROG BRK]	
	[DATA BRK]	

Program/data initialization commands:

[FILL]	[PROG MEM]*	<SMA>	[,]	<EMA>	[,] <DATA>	[.]
	[DATA MEM]					
	[REGISTER]					
	[HWRE REG]					
	[PROG BRK]					
	[DATA BRK]					

Intellec® development system or TTY interface commands (for transferring HEX format files):

[UPLOAD]	[PROG MEM]*	<SMA>	[,]	<EMA>	[.]
	[DATA MEM]				
	[REGISTER]				
	[HWRE REG]				
	[PROG BRK]				
	[DATA BRK]				

[DNLOAD]	[PROG MEM]*	[.]			
	[DATA MEM]				
	[REGISTER]				
	[HWRE REG]				
	[PROG BRK]				
	[DATA BRK]				

Formatted data dump to TTY or CRT:

[LIST]	[PROG MEM]*	<SMA>	[,]	<EMA>	[.]
	[DATA MEM]				
	[REGISTER]				
	[HWRE REG]				
	[PROG BRK]				
	[DATA BRK]				

Program execution commands:

[GO]	[NO BREAK]*	(<SMA>)	[.]
	[W/ BREAK]		[,]
	[SING STP]		
	[AUTO BRK]		
	[AUTO STP]		

[GO/RST]	[NO BREAK]*	[.]	
	[W/ BREAK]		
	[SING STP]		
	[AUTO BRK]		
	[AUTO STP]		

Breakpoint setting and clearing:

[SET BRK]	[PROG MEM]*	<LOC>	([,]	<LOC> ...)	[.]
	[DATA MEM]				

[CLR BRK]	[PROG MEM]*	<LOC>	([,]	<LOC> ...)	[.]
	[DATA MEM]				

APPENDIX D
ERROR MESSAGES

The following error message codes are used by the monitor software to report an operator or hardware error. Errors may be cleared by pressing [CLR/PREV] or [END/.]. The format used for reporting errors is "Error – .n" where "n" is a hex digit.

Operator Errors

1. Illegal command initiator.
2. Illegal command modifier or parameter digit.
3. Illegal terminator for Examine command.
4. Illegal attempt to clear Error mode.

5-9. Not used.

Hardware Errors

A. ASCII error — non-hex digit encountered in data field of hex format record.

B. Breakpoint error. Break logic activated though breakpoints not enabled.

C. Hex format record checksum error. Note — the checksum will not be verified if the first character of the checksum field is a question mark ("?") rather than a hexidecimal digit. This allows object files to be patched using the ISIS text editor without the necessity of manually recomputing the checksum value.

D. Not used.

E. Execution processor failed to respond to a command or parameter passed to it by the master processor. EP automatically reset. EP internal status may be lost. Program memory not affected.

F. Not used.

Using the 8049 as an 80 Column Printer Controller

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AFN-01364A-01

USING THE 8049 AS AN 80 COLUMN PRINTER CONTROLLER

I. INTRODUCTION

This Application Note details using INTEL's 8049 microcomputer as a dot matrix printer controller. Previous INTEL Application notes, (e.g. AP-27 and AP-54) described using intelligent processors and peripherals to control single printer mechanisms. This Application note expands upon the theme established in these prior notes and extends the concept to include a complete bi-directional 80 column printer using a single line buffer. For convenience this application note is divided into six sections:

1. INTRODUCTION
2. PRINT MECHANISM DESCRIPTION
3. INTERFACE CIRCUITRY
4. SOFTWARE
5. CONCLUSION
6. APPENDIX

Over the last few years 80 column output devices have become somewhat of a defacto output standard for business and some data processing applications. It should be mentioned that by no means is the 80 column format a "new" standard. 80 column computer cards have been around for more than 20 years and perhaps the existence of these cards in the early days of computers is why the 80 column format is a standard today.

Many CRT terminals use the 80 by N format and to complement this a number of printers use this same format. One reason, aside from those historic in nature, for the 80 column standard is that 80 columns of 12 pitch text on standard typewritten 8.5 inch by 11 inch paper completely fills up an entire line and allow ample room for margins. So, the 80 column format is an aesthetically convenient format.

Printers are usually divided into either impact or non-impact and a character or line oriented device. Impact printers actually use some type of "striker" to place ink on the paper. More often than not the ink is contained on a ribbon which is placed between the striker and the paper. Non-impact printers use some means other than direct pressure to place the characters on the paper. This type of printer is very fast because there is very little mechanical motion associated with placing the characters on the paper. However, because the paper is required to be treated with a special substance, it is not as convenient as an impact printer.

Character printers are capable of printing one character at a time. (Any standard home typewriter is in effect a character printer.) Line printers must print an entire line at a time. Line printers are usually quite a bit faster than character printers, but they usually don't offer the print quality of character printers.

In recent years, the "computer boom" has caused the price of printers to tumble markedly. High volume production, competition, and the tremendous demand for reliable print mechanisms have all contributed to the decrease in price. Because of their simplicity, line printer mechanisms have decreased in price faster than other mechanisms. Therefore, when high quality print is not needed, a line printer is a very attractive choice.

This application note describes how to control an 80 column impact-line printer with an 8049/8039. The complete software listing is included in the appendix. The 8049 is the high-performance member of the MCS-48™ microcontroller family. The Processor has all of the features of the 8048 plus twice the amount of program and data memory and an 11MHz clock speed. For details about the 8049, please refer to the MCS-48 user's manual.

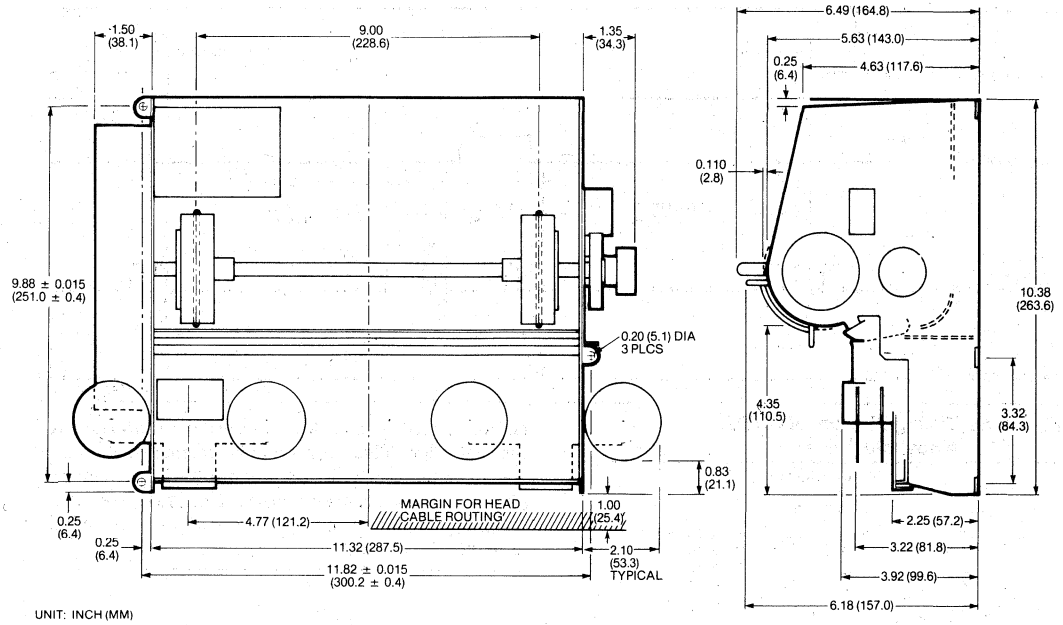
II. PRINT MECHANISM DESCRIPTION

The model 820 printer is available from C. ITOH ELECTRONICS (5301 BEETHOVEN STREET, LOS ANGELES, CA 90066). This inexpensive and simple printer is ideal for applications requiring 80 columns of dot matrix alpha-numeric information.

The model 820 printer is comprised of three basic sub-assemblies; the chassis or frame, the paper feed mechanism, and the print head. The diagram in Figure 2.1 gives the physical dimensions of the basic print mechanism. The basic chassis for the printer is constructed out of four sheet metal stampings. These stampings are screwed together to form a sturdy base on which all other components of the printer are mounted.

The paper feed mechanism consists of a toothed wheel, a solenoid, a tension spring, and a "catcher." When the solenoid is activated, the arm of the solenoid pulls against the spring and drags over the toothed wheel. When the solenoid is released, its arm is pulled by the spring, but this time the arm grabs a tooth on the wheel and pulls the wheel forward which advances the paper. A "catcher," which is merely a piece of plastic held against the toothed wheel, is added to assure that the paper is advanced only one "tooth" position each time the solenoid is activated.

The print head is comprised of seven solenoids which are mounted in a common housing. The solenoids are physically mounted in a circle, but their hammers are positioned linearly along the vertical axis. These seven vertically positioned hammers are the strikers that actually do the printing.



UNIT: INCH (MM)
DIMENSIONS IN INCH GOVERN

Figure 2.1 Physical Dimensions of C. ITOH Model 820 Printer

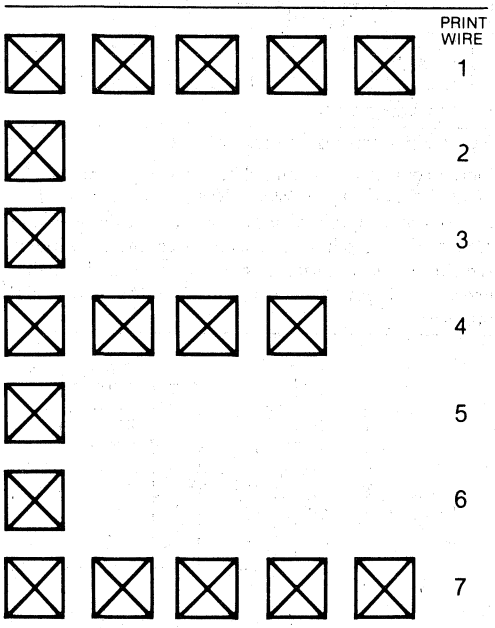


Figure 2.2 "Formation" of a Character by a Dot Matrix Printer

A motor, mounted toward the back of the print mechanism, drives a rubber toothed belt which turns a roller guide. A motor turns a guide that moves the print head from right to left and left to right. By properly timing the current flow through the solenoids while the print head is moving across the paper, characters can be formed. Figure 2.2 illustrates how the dot matrix printer "forms" its characters.

The timing pulses for the print head mechanism are generated by an opto-electronic sensor. This sensor, located on the left side plate of the printer, informs the print controller when to apply current to the print head mechanism. This "on-board timing wheel" assures that all characters will be properly spaced and that they will all be "in-line" in a vertical sense.

The print mechanism is also equipped with two additional sensors. These are the left home position sensor, located near the left front of the mechanism, and the right home position sensor, located near the right front of the print mechanism. These sensors simply tell the controller when the print head is in either the left or right home position. A complete timing chart for the printer is shown in Figure 2.3.

III. INTERFACE CIRCUITRY

The manual supplied with the printer recommends some specific interface circuitry. For the most part the circuitry used in this Application Note followed these suggestions. The circuitry needed to drive the print head solenoid is shown in Figure 3.1. This same

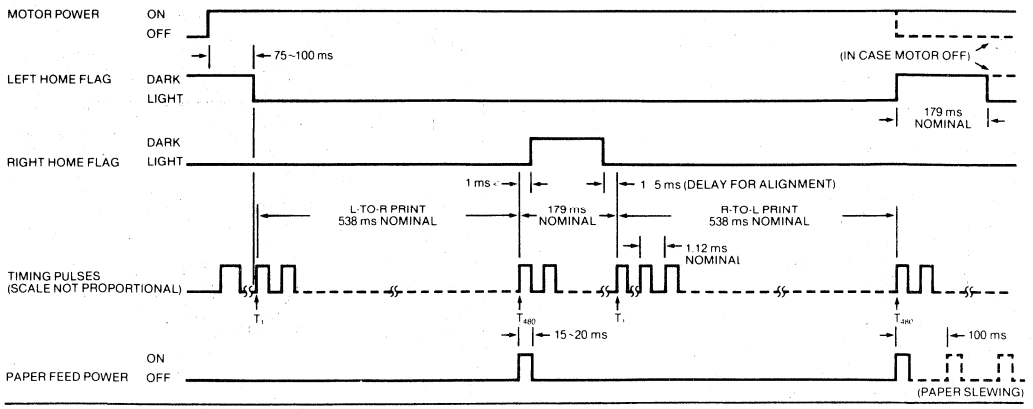


Figure 2.3 Timing Diagram of C. ITOH Model 820 Printer

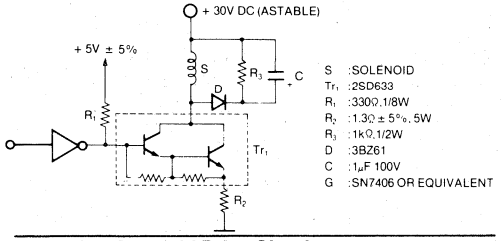


Figure 3.1 Solenoid Drive Circuit (Eliminate R_2 for Line Feed Solenoid)

circuit is used to drive the line feed solenoid except that the current limiting resistor R2 is eliminated. This resistor is not needed because the line feed solenoid is physically much larger than the print head solenoids and can tolerate much higher levels of current.

The print head drivers are connected to an 8212 latch. The latch is interfaced to the BUS PORT on the 8049 and is enabled whenever the WR pin and the BIT 4 of PORT 1 are coincidentally low. The line feed driver is connected to PORT 1 BIT 1 of the 8049.

Note that the driver is simply a Darlington transistor that is driven by an open collector TTL gate. Resistor R2 is the current limiting resistor and diode D, capacitor C, and resistor R3 are used to "dampen" the inductive spike that occurs when driving solenoid S. This circuit is repeated for each of the seven solenoids in the print head. It should be mentioned that, although the type of Darlington transistor needed to drive the print head is not critical, a collector current rating of at least 5 amps and a breakdown voltage (Vceo) of at least 100 volts is needed. Transistors that do not meet these requirements will be damaged by the inductive kickback of the solenoids.

As mentioned in Section 2, the printer provides some sensor interface signals that are derived via three opto-electronic sensors. These signals must be amplified and converted to TTL levels in order to interface to the controller. This conversion is accomplished with a simple voltage comparator. Figure 3.2 is a schematic of the sensor interface circuitry. Note that hysterisis is employed on the voltage comparators. This eliminates "false" sensing.

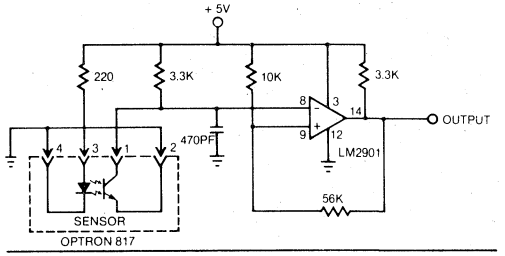


Figure 3.2 Example of Sensor Circuit

Motor control is accomplished by using a Monsanto MCS-6200 optically-coupled TRIAC. This part is ideal in this kind of application because it provides a simple means of controlling a line-operated motor without sacrificing the isolation needed for safe and reliable operation. Figure 3.3 is a schematic of the motor driving circuit.

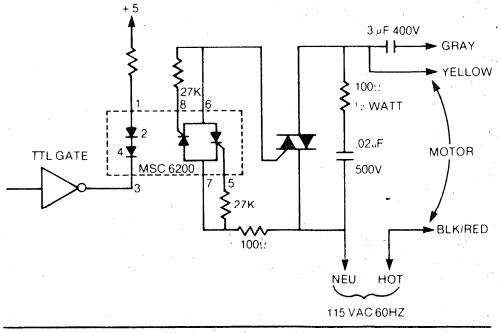


Figure 3.3 Motor Driving Circuit

To interface 8049 to the outside world one 8212 latch was used. This latch was connected to the BUS PORT and is enabled by an INS or MOVX instruction coincident with BIT 4 of PORT 1 being in a logical zero state. In this configuration, the 8212 was used to hold the data until read by the 8049. The connection of the 8212 to the 8049 is shown in Figure 3.4 and the parallel port timing diagram is shown in Figure 3.5. The 8212 parallel port was connected to the LINE PRINTER OUTPUT of an INTELLEC MICROCOMPUTER DEVELOPMENT SYSTEM.

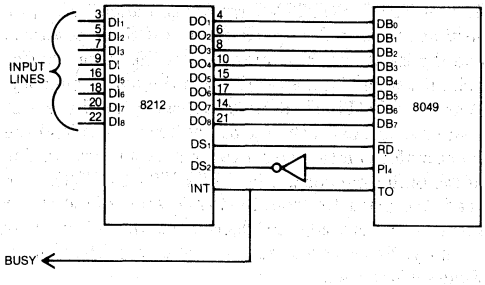


Figure 3.4 Connection of the 8212 Input Port to the 8049

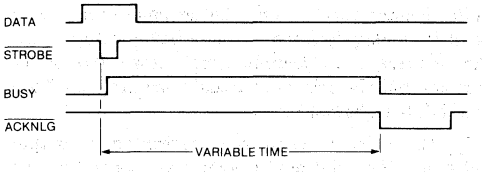


Figure 3.5 Parallel Port Timing

IV. SOFTWARE

As mentioned in Section 2, the bulk of the timing needed to control the printer is actually generated by the printer itself. Therefore, all the software must do is harness these timing signals and turn on and off the right solenoids at the right time.

To make things easy, the software needed to drive the printer is broken into four separate routines. These are:

1. INITIALIZATION ROUTINE
2. INPUT ROUTINE
3. OUTPUT ROUTINE
4. LOOKUP ROUTINE

The INITIALIZATION ROUTINE turns the motor on and checks the opto-electronic sensors. If a failure is found, the routine turns off the motor and loops on itself. This insures that the print mechanism is cycled properly before characters are accepted for printing. This routine also initializes all of the variables used by the printer.

The INPUT ROUTINE reads the characters that are present in the 8212 input port and writes them into the 8049's buffer memory. The routine then checks the characters to see if a CARRIAGE RETURN (ASCII OCH) has been transmitted. If a CR is detected, the input routine automatically inserts a LINE FEED as the next character. When the input routine detects a LINE FEED, it stops reading characters and sets the direction bits and the print bit in the status register. This action evokes the OUTPUT ROUTINE. A detailed flowchart of the INPUT ROUTINE is shown in Figure 4.1.

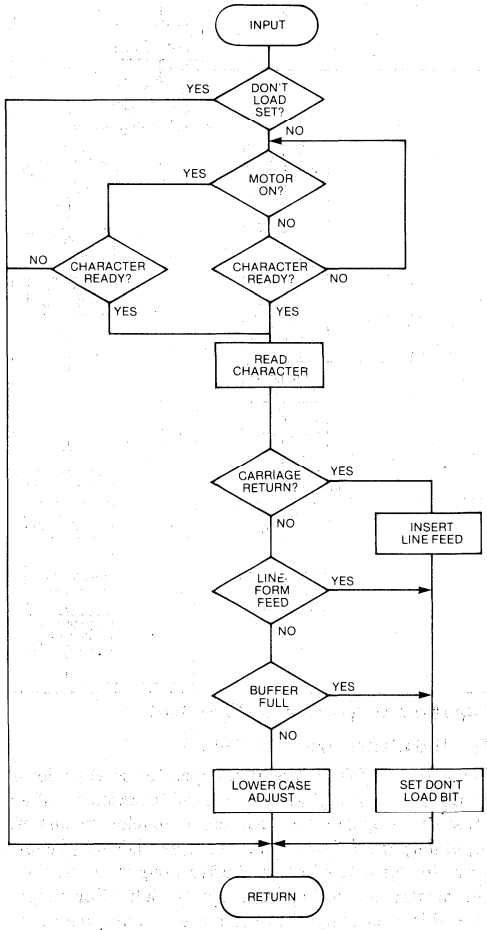


Figure 4.1 Input Routine Flowchart

The OUTPUT ROUTINE initializes both the input and output buffer pointers and then reads the characters from the 8049's buffer memory. After a character is read the OUTPUT ROUTINE calls the LOOKUP ROUTINE which reads the proper bit pattern to form that character. This bit pattern is then used to strobe the solenoids. After each character is printed, the OUTPUT ROUTINE calls the INPUT ROUTINE and another character is placed into the buffer memory. This type of operation guarantees that the input buffer cannot "overrun" the output buffer. A flowchart of the OUTPUT ROUTINE is shown in Figure 4.2.

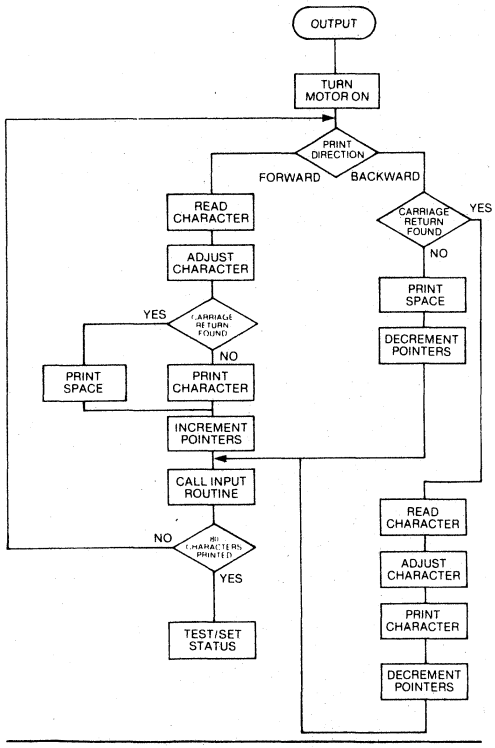


Figure 4.2 Output Routine Flowchart

IV-I. HANDLING THE I/O BUFFER

Since the C. ITOH Model 820 printer is capable of printing in both directions the 80 character buffer must be manipulated in a manner as to allow maximum input-output efficiency. This is accomplished by reversing the "direction" of the buffer memory each time the printer is printing from right to left. For simplicity, if it is assumed that the buffer is only five bytes long, Figure 4.3 can be used to help explain the buffer operation.

Initially the input buffer pointer is loaded with the address of the first location in the buffer memory. As characters are read, the input buffer pointer increments and fills the buffer memory as shown in Figure 4.3(b) through 4.3(f). When a CARRIAGE RETURN-LINE FEED (CRLF) is encountered the input buffer pointer and the output buffer pointer are reset back to the first location. The OUTPUT ROUTINE then reads the character from the first location in the buffer memory, increments the output buffer pointer and calls the INPUT ROUTINE, which reads another character from the parallel input port.

The OUTPUT ROUTINE reads the entire buffer, inserting space codes (20H) after a CR is detected, and the input buffer pointer follows the output buffer pointer as they "increment" up to the buffer memory. When the OUTPUT ROUTINE has printed the last character or space, the output buffer pointer and the input buffer pointer are set to point at the last location of the buffer memory. The OUTPUT ROUTINE then reads the character from the last location of the buffer memory and proceeds to "decrement" down the buffer memory. Space codes are inserted until a CR is found. Figure 4.3(1) to 4.3(0).

The input buffer pointer follows the output buffer pointer just as in the previous case. When the last, or in this case the first character is printed, the output buffer pointer and the input buffer pointer are set to point at the last location of the buffer memory. Now the pointers are "decrementing" down the buffer memory, but the printer is actually printing in a "normal" left to right fashion.

When the last character or space is printed, the output buffer and the input buffer pointer are set to the first location of the buffer memory and printing takes place in a reverse or right to left manner. After this line is printed, the print head and both buffer pointers are in the same position as they were initially. So, four lines must be printed before the buffer pointers and the print head complete a cycle. Each of these situations is handled separately by four different subroutines: CASE0, CASE1, CASE2, and CASE3.

IV-II. TIMING

All critical timing for the printer controller came from two basic sources; the timing sensors on the printer and the internal eight-bit timer of the 8049.

The internal timer of the 8049 was used to control the length of time the solenoids were fired (600 microseconds) and was also used as a "one-shot" to align the printer. This alignment is needed to make the "backward" printing line up vertically with the normal or forward printing. The "one-shot" is used to measure the time from the last column of the last character position until the right sensor flag is covered.

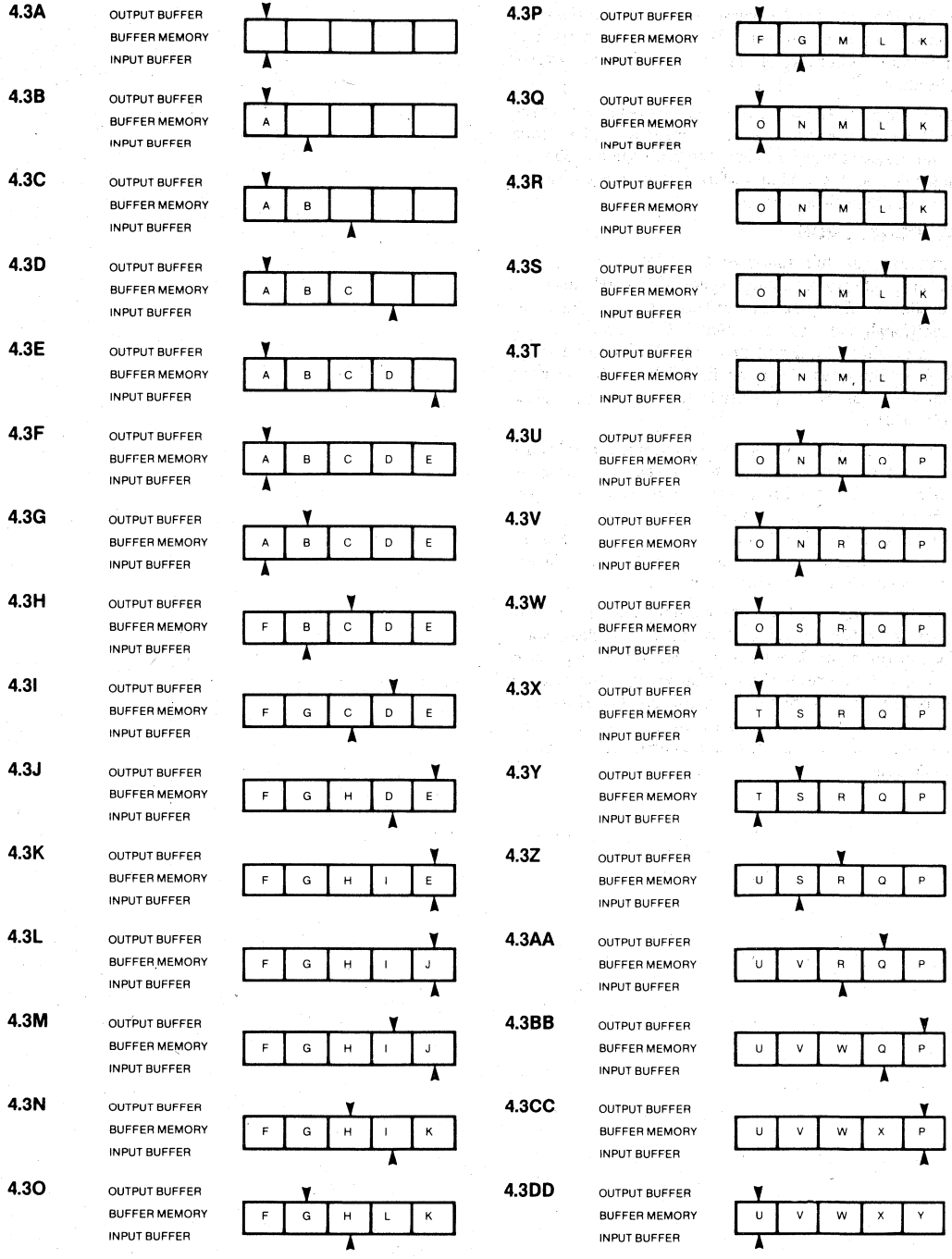


Figure 4.3 I/O Buffer Handler

When the print head reverses direction and the right sensor flag is uncovered, the timer is then used to determine where to start printing in the reverse direction.

The timer and the print wheel on the printer are used to determine when to place a character. The strobe from the print wheel informs the 8049 when to fire the solenoids and the timer allows the proper spacing between the characters.

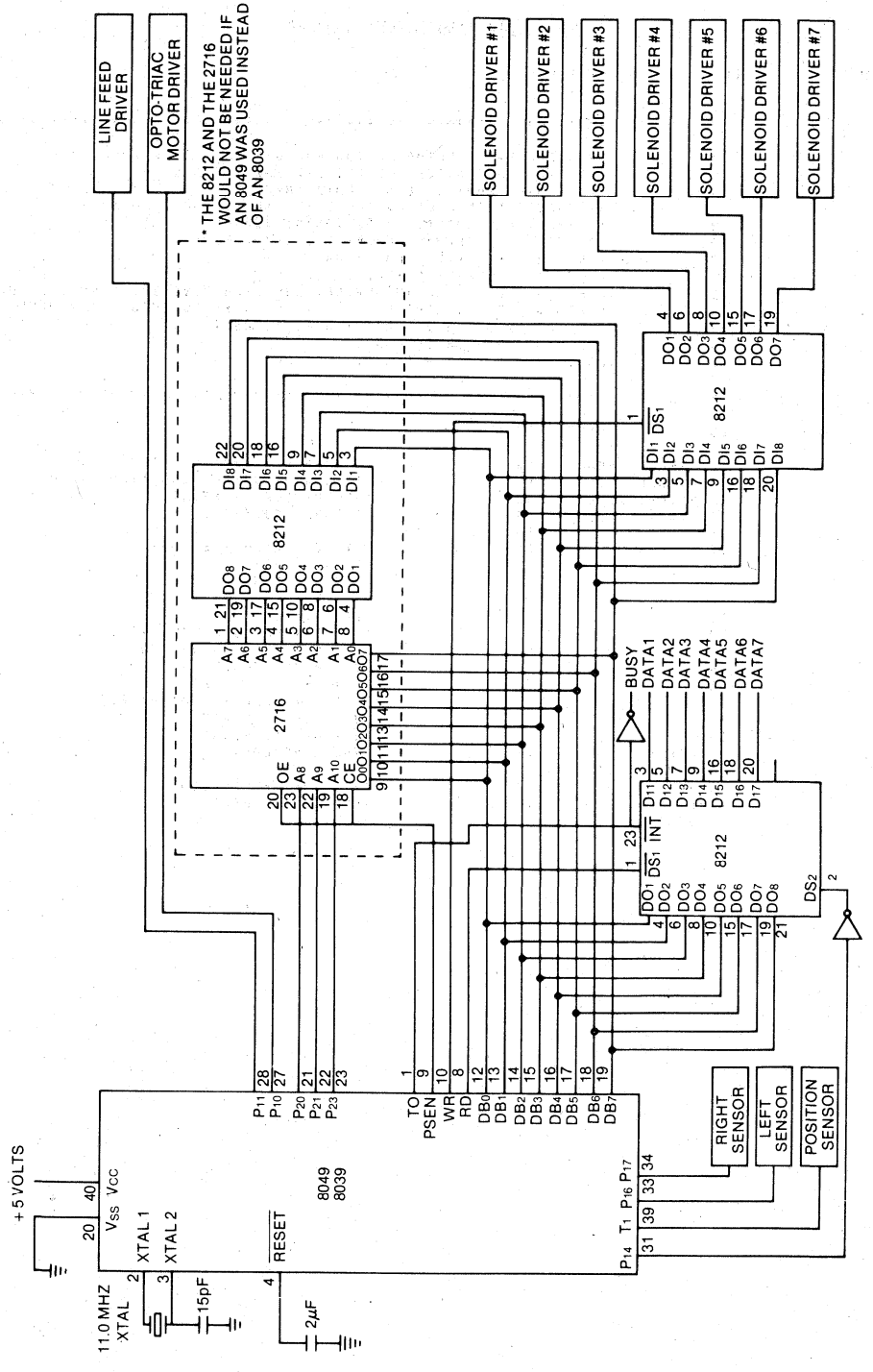
V. CONCLUSION

Although the full speed of the 8049 was not used in this application, the high speed of the 8049 makes it possible to "fine-tune" any critical timing parameters. Additionally, the extra available CPU time could be used to add an interrupt driven keyboard and display, such as the ones discussed in AP-40, to the printer. This would allow the printer to function as a complete "terminal".

Very little attempt was made to optimize the software, but still the entire program fits easily in 1.25K of memory; 750 bytes for printer control and 500 bytes for character lookup. Adding lower case to the printer would require an additional 500 bytes of lookup table. The remaining 250 bytes should be used to add "user" features such as tabs, double width printing, etc.

The high speed of the 8049 combined with its hardware and software architecture make it an ideal choice for controlling an 80 column, bi-directional line printer. The I/O structure of the 8049 minimizes the amount of external hardware needed to control the printer and the large amount of on-board program and data memory allow quite a sophisticated control program to be implemented.

APPENDIX A. SCHEMATIC DIAGRAM



APPENDIX B. MONITOR LISTING

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                     1          ;
                     2          ;*****************************************************************
                     3          ;
                     4          ;THIS PROGRAM IMPLEMENTS CONTROL OF THE C.ITOH MODEL 820
                     5          ;PRINTER.  THE HARDWARE CONFIGURATION IS AS SUCH:
                     6          ;8212 INPUT PORT ON BUS = DATA INPUT
                     7          ;8212 OUTPUT PORT ON BUS = OUTPUT TO SOLENOID HAMMERS
                     8          ;T1 INPUT = CHARACTER POSITIONING SENSOR ON PRINTER
                     9          ;T0 INPUT = INTERRUPT FROM 8212 INPUT PORT
                    10          ;PORT 10 = MOTOR ON, LOW = ON
                    11          ;PORT 11 = LINE FEED STROBE, LOW = ON
                    12          ;PORT 16 = LEFT MARGIN SENSOR, LOW WHEN COVERED, HIGH WHEN OPEN
                    13          ;PORT 17 = RIGHT MARGIN SENSOR, LOW WHEN COVERED, HIGH WHEN OPEN
                    14          ;T1 = PIN 2 OF LM339, PRINT WHEEL SENSOR
                    15          ;PORT 16 = PIN 13 OF LM339
                    16          ;PORT 17 = PIN 14 OF LM339
                    17          ;
                    18          ;*****************************************************************
                    19          ;
                    20          ;SYSTEM EQUATES
                    21          ;
0000                22 INBUF    EQU     R0              ;POINTS AT INPUT LOCATION
0001                23 OUTBUF   EQU     R1              ;POINTS AT OUTPUT LOCATION
0002                24 SAVPNT   EQU     R2              ;STATUS FOR PRINTING
0003                25 STBCNT   EQU     R3              ;STROBE COUNTER
0004                26 TEMP1    EQU     R4
0005                27 STATUS   EQU     R5              ;BIT 0 = LINE FEED SET
                    28                                  ;BIT 1 = PRINT
                    29                                  ;BIT 2 = CONTINUE
                    30                                  ;BIT 3 = CR FOUND
                    31                                  ;BIT 4 = LF FOUND
                    32                                  ;BIT 5 = LF FOUND IN PRINTING
                    33                                  ;BIT 6 = PRINT DIRECTION
                    34                                  ;0 = RIGHT TO LEFT
                    35                                  ;1 = LEFT TO RIGHT
                    36                                  ;BIT 7 = BUFFER LOAD DIRECTION
                    37                                  ;0 = FIRST TO MAX
                    38                                  ;1 = MAX TO FIRST
0006                39 LINCNT   EQU     R6              ;THE LINE COUNTER
0007                40 JUNK1    EQU     R7
006F                41 MAX      EQU     6FH             ;MAX BUFFER LOCATION
0020                42 FIRST    EQU     20H             ;BOTTOM OF BUFFER
                    43 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                    44          ;
0000                45          ORG     0800H
                    46          ;
                    47          ;JUMP OVER THE INTERRUPT LOCATIONS
                    48          ;
0800 15             49          DIS     I                   ;DON'T USE INTERRUPTS
0801 3408           50          JMP     BGIN                ;BEGIN THE PROGRAM
                    51          ;
080A                52          ORG     0AH
                    53          ;
                    54          ;START THE PROGRAM
                    55          ;
                    56          ;LOOP UNTIL THE BUFFER FILLS UP
                    57          ;
080A FD             58 PRNT:    MOV     A,STATUS            ;GET THE STATUS
080B 3211           59          JB1     LPRNT               ;IF PRINTING, CONTINUE
080D 3408           60          CALL    LDBUF               ;READ INTO THE BUFFER
080F 040A           61          JMP     PRNT                ;LOOP
                    62          ;
                    63          ;THIS ROUTINE PRINTS A LINE
                    64          ;IT FIRST SAVES THE STATUS
                    65          ;AND THEN DETERMINES WHICH DIRECTION TO PRINT
                    66          ;AND HOW TO MANIPULATE THE BUFFER
                    67          ;
0811 34C9           68 LPRNT:   JMP     STACHK              ;GO FIX UP THE STATUS
0813 F224           69 LPRNT1:  JB7     CASE23              ;JUMP TO CASE 2 AND 3
0815 0417           70          JMP     CASE01              ;JUMP TO CASE 0 AND 1
                    71          ;
                    72          ;CASE01, LOADING THE BUFFER FROM FIRST TO MAX
                    73          ;
0817 B920           74 CASE01:  MOV     OUTBUF,#FIRST       ;SET UP OUTBUF
0819 B820           75          MOV     INBUF,#FIRST        ;SET UP INBUF
081B FA             76          MOV     A,SAVPNT            ;GET THE SAVED STATUS
081C 34DC           77          CALL    MOTON               ;TURN ON THE MOTOR
081E D252           78          JB6     CASE1               ;PRINT FOWARD
0820 3483           79          CALL    PRNTBK              ;GET READY TO PRINT BACKWARDS
0822 0431           80          JMP     CASE0               ;PRINT BACKWARDS
                    81          ;
                    82          ;CASE23, LOADING BUFFER FROM MAX TO FIRST
                    83          ;
0824 B96F           84 CASE23:  MOV     OUTBUF,#MAX         ;SET UP OUTBUF
0826 B86F           85          MOV     INBUF,#MAX          ;SET UP INBUF
0828 FA             86          MOV     A,SAVPNT            ;GET THE PRINT STATUS
0829 34DC           87          CALL    MOTON               ;TURN ON THE MOTOR
082B D2C2           88          JB6     CASE3               ;PRINT LEFT TO RIGHT
082D 3483           89          CALL    PRNTBK              ;GET READY TO PRINT BACKWARDS
082F 043D           90          JMP     CASE2               ;PRINT RIGHT TO LEFT
                    91          ;
                    92 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

0831 F1             93 CASE0:  MOV     A,@OUTBUF        ;GET THE CHARACTER
0832 3491           94         CALL    FXPRNT           ;ADJUST FOR PRINTING
0834 B128           95         MOV     @OUTBUF,#28H     ;PUT A SPACE IN BUFFER RAM
0836 F242           96         JB7     FDC              ;FOUND A CR
0838 945E           97         CALL    INCTST           ;UPDATE OUTBUF
083A C6AE           98         JZ      WATCHD           ;WAIT FOR END
083C BF28           99         MOV     JUNK1,#28H       ;GET A SPACE TO PRINT
083E 9463          100         CALL    GTPRNT           ;GO PRINT A SPACE
0840 8431          101         JMP     CASE0            ;LOOP
0842 BF28          102 FDC:    MOV     JUNK1,#28H       ;GO PRINT THE LAST SPACE
0844 9463          103 FDC1:   CALL    GTPRNT           ;GO PRINT A CHARACTER
0846 945E          104         CALL    INCTST           ;CHECK OUT BUFFER
0848 C6AE          105         JZ      WATCHD           ;WAIT FOR THE END
084A F1            106         MOV     A,@OUTBUF        ;GET THE CHARACTER
084B B128          107         MOV     @OUTBUF,#28H     ;PUT A SPACE THERE
084D 3491          108         CALL    FXPRNT           ;FIX THE CHARACTER UP
084F AF            109         MOV     JUNK1,A          ;SAVE IT
0850 8444          110         JMP     FDC1             ;LOOP
                   111         ;
                   112         ;
                   113         ;CASE 1, PRINTING LEFT TO RIGHT, LOADING BUFFER FROM
                   114         ;FIRST TO MAX
                   115         ;
0852 F1            116 CASE1:  MOV     A,@OUTBUF        ;GET THE CHARACTER
0853 3491          117         CALL    FXPRNT           ;ADJUST FOR PRINTING
0855 AF            118         MOV     JUNK1,A          ;SAVE ACC
0856 B128          119         MOV     @OUTBUF,#28H     ;PUT A SPACE IN THE BUFFER
0858 F262          120         JB7     CRFOND           ;FOUND A CR?
085A 9463          121         CALL    GTPRNT           ;GO PRINT THE CHARACTER
085C 945E          122         CALL    INCTST           ;CHECK THE BUFFER
085E C675          123         JZ      WATCH            ;IS THE LAST CHARACTER BEING PRINTED?
0860 8452          124         JMP     CASE1            ;LOOP
0862 B128          125 CRFOND: MOV     @OUTBUF,#28H     ;PUT A SPACE IN THE BUFFER MEMORY
0864 BF28          126         MOV     JUNK1,#28H       ;PUT A SPACE IN TEMP LOCATION
0866 9463          127         CALL    GTPRNT           ;GO PRINT THE SPACE
0868 945E          128         CALL    INCTST           ;CHECK THE BUFFER
086A C675          129         JZ      WATCH            ;LAST CHARACTER PRINTED?
086C F1            130         MOV     A,@OUTBUF        ;GET THE NEXT CHARACTER
086D 3491          131         CALL    FXPRNT           ;ADJUST IT
086F 8462          132         JMP     CRFOND           ;LOOP
                   133 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                   134          ;
                   135          ;THIS ROUTINE CALLS THE LINE FEED
                   136          ;
0071 9478          137 DOLF:    CALL    LINEFD          ;STROBE LINE FEED SOLENOID
0073 B40A          138          JMP     PRNT            ;GO BACK TO THE PRINT ROUTINE
                   139          ;
                   140          ;THIS ROUTINE COMPLETES A LINE WHEN THE PRINT
                   141          ;HEAD IS MOVING LEFT TO RIGHT
                   142          ;
0075 27            143 WATCH:   CLR     A               ;ZERO ACC
0076 62            144          MOV     T,A             ;ZERO TIMER
0077 55            145          STRT    T               ;START THE TIMER
0078 3488          146          CALL    LOBUF           ;GO READ THE LAST CHARACTER
007A 89            147 LOOPW:   IN      A,P1            ;EXAMIN PORT ONE
007B F27A          148          JB7     LOOPW           ;CHECK RIGHT HAND SENSOR
007D 65            149          STOP    TCNT            ;STOP THE TIMER
007E FD            150          MOV     A,STATUS        ;GET THE STATUS
007F 5285          151          JB2     OVR1            ;JUMP IF CONTINUE IS SET
0081 94DF          152          CALL    MOTOF           ;TURN MOTOR OFF
0083 53FD          153          ANL     A,#0FDH         ;RESET BIT ONE
0085 53FB          154 OVR1:    ANL     A,#0FBH         ;RESET CONTINUE BIT
0087 AD            155          MOV     STATUS,A        ;RESTORE STATUS
0088 FA            156          MOV     A,SAVPNT        ;GET THE SAVED STATUS
0089 B271          157          JB5     DOLF            ;DO A LINE FEED IF BIT IS SET
008B B40A          158          JMP     PRNT            ;GO BACK TO PRINT ROUTINE
                   159          ;
                   160          ;
                   161          ;CASE 2, PRINTING RIGHT TO LEFT, LOADING BUFFER FROM
                   162          ;MAX TO FIRST
                   163          ;
                   164          ;
008D F1            165 CASE2:   MOV     A,@OUTBUF       ;GET THE CHARACTER
008E 3491          166          CALL    FXPRNT          ;ADJUST FOR PRINTING
0090 B120          167          MOV     @OUTBUF,#20H    ;PUT A SPACE IN BUFFER RAM
0092 F29E          168          JB7     FDCR            ;FIND A CR YET
0094 9472          169          CALL    DECTST          ;CHECK THE BUFFER
0096 C6AE          170          JZ      WATCHD          ;IF ZERO WAIT FOR SENSOR FLAG
0098 BF20          171          MOV     JUNK1,#20H      ;PUT SPACE IN TEMP LOCATION
009A 9463          172          CALL    GTPRNT          ;GO PRINT SPACE
009C B48D          173          JMP     CASE2           ;LOOP
009E BF20          174 FDCR:    MOV     JUNK1,#20H      ;GET A SPACE
00A0 9463          175 FDCR1:   CALL    GTPRNT          ;GO PRINT THE CHARACTER
00A2 9472          176          CALL    DECTST          ;CHECK THE BUFFER
00A4 C6AE          177          JZ      WATCHD          ;LEAVE IF DONE
00A6 F1            178          MOV     A,@OUTBUF       ;GET A CHARACTER
00A7 3491          179          CALL    FXPRNT          ;ADJUST THE CHARACTER FOR PRINTING
00A9 AF            180          MOV     JUNK1,A         ;SAVE IT
00AA B120          181          MOV     @OUTBUF,#20H    ;PUT A SPACE WHERE THE CHARACTER WAS
00AC B4A8          182          JMP     FDCR1           ;LOOP
                   183 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                  184          ;
                  185          ;THIS ROUTINE WAITS FOR THE SENSOR FLAGS TO BE COVERED
                  186          ;WHEN PRINTING RIGHT TO LEFT
                  187          ;
0BAE 340B         188 WATCHD:  CALL    LDBUF            ;GO READ THE LAST CHARACTER
0BB0 89           189          IN      A,P1             ;GET SENSOR INFORMATION
0BB1 D2AE         190          JB6     WATCHD           ;LOOP IF SENSOR IS NOT COVERED
0BB3 FD           191          MOV     A,STATUS         ;GET THE STATUS
0BB4 52BA         192          JB2     OVR              ;SEE IF CONTINUE IS SET
0BB6 94DF         193          CALL    MOTOF            ;TURN THE MOTOR OFF
0BB8 53FD         194          ANL     A,#0FDH          ;RESET BIT 1
0BBA 53F8         195 OVR:     ANL     A,#0F8H          ;RESET BIT 3
0BBC AD           196          MOV     STATUS,A         ;RESTORE STATUS
0BBD FA           197          MOV     A,SAVPNT         ;GET THE SAVED STATUS
0BBE B271         198          JB5     DOLF             ;DO A LINE FEED
0BC0 B48A         199          JMP     PRNT             ;EXIT
                  200          ;
                  201          ;CASE 3, PRINTING LEFT TO RIGHT, LOADING BUFFER FROM
                  202          ;MAX TO FIRST
                  203          ;
0BC2 F1           204 CASE3:   MOV     A,@OUTBUF        ;GET A CHARACTER
0BC3 3491         205          CALL    FXPRNT           ;FIX FOR PRINTING
0BC5 AF           206          MOV     JUNK1,A          ;SAVE CHARACTER
0BC6 B120         207          MOV     @OUTBUF,#20H     ;PUT A SPACE IN THE BUFFER
0BC8 F2D2         208          JB7     CRFND            ;LEAVE IF A CR IS FOUND
0BCA 9463         209          CALL    GTPRNT           ;GO PRINT THE CHARACTER
0BCC 9472         210          CALL    DECTST           ;CHECK THE BUFFER
0BCE C675         211          JZ      WATCH            ;LEAVE IF DONE
0BD0 84C2         212          JMP     CASE3            ;LOOP
0BD2 B120         213 CRFND:   MOV     @OUTBUF,#20H     ;PUT A SPACE IN THE BUFFER RAM
0BD4 BF20         214          MOV     JUNK1,#20H       ;GET A SPACE
0BD6 9463         215          CALL    GTPRNT           ;PRINT A SPACE
0BD8 9472         216          CALL    DECTST           ;CHECK THE BUFFER
0BDA C675         217          JZ      WATCH            ;LEAVE IF DONE
0BDC F1           218          MOV     A,@OUTBUF        ;GET NEXT CHARACTER
0BDD 3491         219          CALL    FXPRNT           ;ADJUST IT
0BDF 84D2         220          JMP     CRFND            ;LOOP
                  221 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

0100                222          ORG     100H
                    223          ;
0100 09             224 LDBUF:   IN      A,P1            ;READ PORT 1
0101 B21C           225          JB5     LNMODE          ;BIT 5 = H = LINE MODE
0103 1207           226          JB0     ARND            ;JUMP AROUND IF MOTOR IS ON
0105 8901           227          ORL     P1,#01H         ;TURN THE MOTOR OFF
0107 920F           228 ARND:    JB4     NOFF            ;NO FORM FEED
0109 FE             229          MOV     A,LINCNT        ;GET THE LINE COUNTER
010A 4380           230          ORL     A,#80H          ;SET MSB
010C AE             231          MOV     LINCNT,A        ;RESTORE THE LINE COUNTER
010D 23FF           232          MOV     A,#0FFH         ;SET ACC
010F 721A           233 NOFF:    JB3     NOLF            ;JUMP IF NO LINE FEED
0111 9478           234          CALL    LINEFD          ;GO DO A LF OR FF
0113 09             235 BUTLOP:  IN      A,P1            ;READ THE PORT
0114 721A           236          JB3     NOLF            ;WAIT FOR SWITCH TO BE RELEASED
0116 921A           237          JB4     NOLF            ;WAIT FOR SWITCH TO BE RELEASED
0118 2413           238          JMP     BUTLOP          ;LOOP
011A 2400           239 NOLF:    JMP     LDBUF           ;LOOP
                    240          ;
                    241          ;FIRST SEE IF A CHARACTER IS PRESENT IN THE BUFFER
                    242          ;
011C 261F           243 LNMODE:  JNTB    CHAR            ;IF CHARACTER PRESENT, READ IT
011E 83             244          RET                     ;IF NOT, EXIT ROUTINE
                    245          ;
                    246          ;IF THERE IS A CHARACTER, READ IT
                    247          ;
011F FD             248 CHAR:    MOV     A,STATUS        ;GET THE STATUS
0120 5249           249          JB2     ARNDJP          ;IF CONTINUE IS SET, DON'T LOAD
0122 9249           250          JB4     ARNDJP          ;IF LF IS SET, DON'T LOAD
0124 724A           251          JB3     LFCRCK          ;WAS CR SET, SEE IF NEXT CHAR IS LF
0126 94D6           252          CALL    GTCAR           ;GO READ A CHARACTER
0128 3461           253 GOOD:    CALL    FXCHAR          ;MAKE SURE IT IS OK
012A A8             254          MOV     @INBUF,A        ;SAVE CHARACTER IN BUFFER MEMORY
012B FD             255          MOV     A,STATUS        ;GET THE STATUS
012C F239           256          JB7     SUB1            ;IF BIT 7 IS SET DECREMENT BUFFER
012E 18             257          INC     INBUF           ;UPDATE INBUF
012F 2378           258          MOV     A,#MAX+1        ;GET TOP
0131 D8             259          XRL     A,INBUF         ;ARE WE AT THE TOP?
0132 9649           260          JNZ     ARNDJP          ;IF NOT GET THE STATUS
0134 F8             261          MOV     A,INBUF         ;GET INBUF
0135 07             262          DEC     A               ;CHANGE BY ONE
0136 A8             263          MOV     INBUF,A         ;PUT IT BACK
0137 2449           264          JMP     ARNDJP          ;GET THE STATUS
0139 F8             265 SUB1:    MOV     A,INBUF         ;GET INBUF
013A 07             266          DEC     A               ;CHANGE BY ONE
013B A8             267          MOV     INBUF,A         ;PUT INBUF BACK
013C 231F           268          MOV     A,#FIRST-1      ;GET THE BOTTOM OF THE BUFFER
013E D8             269          XRL     A,INBUF         ;TEST THE BUFFER
013F 9649           270          JNZ     ARNDJP          ;IF NOT ZERO READ THE STATUS
0141 18             271          INC     INBUF           ;MOVE INBUF BACK
0142 2449           272          JMP     ARNDJP          ;GO GET STATUS
0144 FD             273 GETSTA:  MOV     A,STATUS        ;GET THE STATUS
0145 1249           274          JB0     ARNDJP          ;IF BIT 0 SET, BYPASS
0147 9258           275          JB4     STBIT1          ;IF LF IS FOUND, SET THE STATUS
0149 83             276 ARNDJP:  RET                     ;EXIT
                    277          ;
                    278          ;THIS ROUTINE "FORCES" A LF AFTER A CR
                    279          ;
014A 94D6           280 LFCRCK:  CALL    GTCAR           ;READ A CHARACTER
014C 238A           281          MOV     A,#8AH          ;GET A LINE FEED
014E 2428           282          JMP     GOOD            ;JUMP BACK
                    283          ;
                    284          ;THIS ROUTINE SETS THE STATUS BITS
                    285          ;
0150 FD             286 STBIT1:  MOV     A,STATUS        ;LOAD THE STATUS
0151 3259           287          JB1     STPRNT          ;IF STILL PRINTING, LEAVE
0153 4302           288          ORL     A,#02H          ;SET PRINT BIT
0155 0348           289          ADD     A,#48H          ;UPDATE POSITION COUNTER
0157 AD             290          MOV     STATUS,A        ;PUT STATUS BACK
0158 83             291          RET                     ;EXIT ROUTINE
0159 5268           292 STPRNT:  JB2     BYEBYE          ;CHECK CONTINUE BIT
015B 4304           293          ORL     A,#04H          ;SET CONTINUE BIT
015D 0348           294          ADD     A,#48H          ;UPDATE PRINT DIRECTION
015F AD             295          MOV     STATUS,A        ;PUT THE STATUS BACK
0160 83             296 BYEBYE:  RET                     ;EXIT
                    297          ;
```

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LOC  OBJ          SEQ          SOURCE STATEMENT

                   298          ;THIS ROUTINE "CONVERTS" LOWER CASE LETTERS TO
                   299          ;UPPER CASE
                   300          ;
0161 97            301 FXCHAR:  CLR     C                ;CLEAR THE CARRY
0162 537F          302          ANL     A,#7FH           ;STRIP MSB
0164 AF            303          MOV     JUNK1,A          ;SAVE ACC
0165 03AB          304          ADD     A,#0ABH          ;SEE IF NUMBER IS 60H
0167 E678          305          JNC     FINE             ;IF CARRY ISN'T SET, JUMP
0169 FF            306          MOV     A,JUNK1          ;GET ACC BACK
016A 37            307          CPL     A                ;SUBTRACT 20H FROM THE ACC
016B 0320          308          ADD     A,#20H
016D 37            309          CPL     A
016E 2474          310          JMP     FIXDUN           ;JUMP TO TEST CR LF
0170 37            311 FINE:    CPL     A                ;NOW SUBTRACT A0H FROM ACC
0171 03A0          312          ADD     A,#0A0H
0173 37            313          CPL     A
0174 AF            314 FIXDUN:  MOV     JUNK1,A          ;SAVE A
0175 D30D          315          XRL     A,#0DH           ;IS CHARACTER A CR
0177 967F          316          JNZ     LFTEST           ;IF IT IS NOT TEST LF
0179 FD            317          MOV     A,STATUS         ;GET THE STATUS
017A 4308          318          ORL     A,#08H           ;SET BIT 3
017C AD            319          MOV     STATUS,A         ;RESTORE THE STATUS
017D 248F          320          JMP     FIXFIN           ;LEAVE
017F FF            321 LFTEST:  MOV     A,JUNK1          ;GET CHARACTER BACK
0180 D30A          322          XRL     A,#0AH           ;IS IT A LF
0182 C689          323          JZ      FIXUP            ;IF ITS NOT, WE ARE DONE
0184 FF            324          MOV     A,JUNK1          ;GET THE CHARACTER BACK
0185 D30C          325          XRL     A,#0CH           ;IS IT A FORM FEED
0187 968F          326          JNZ     FIXFIN           ;IF NOT FORM FEED, JUMP
0189 FD            327 FIXUP:   MOV     A,STATUS         ;GET THE STATUS
018A 4310          328          ORL     A,#10H           ;SET BIT 4
018C AD            329          MOV     STATUS,A         ;RETURN THE STATUS
018D 3458          330          CALL    STBIT1           ;SET THE STATUS
018F FF            331 FIXFIN:  MOV     A,JUNK1          ;GET THE CHARACTER
LOC  OBJ          SEQ          SOURCE STATEMENT

0190 83            332          RET                      ;EXIT FIXCHAR
                   333          ;
                   334          ;THIS ROUTINE RECOGNIZES A LF, FF, AND CR
                   335          ;DURING THE PRINT OPERATION
                   336          ;IT ALSO FORCES A SPACE IF A CHARACTER FOUND
                   337          ;IN THE BUFFER IS NOT IN THE LOOKUP TABLE
                   338          ;
0191 AF            339 FXPRNT:  MOV     JUNK1,A          ;SAVE ACC
0192 D30C          340          XRL     A,#0CH           ;FORM FEED
0194 C682          341          JZ      FFFIX            ;GO SET FORM FEED
0196 FF            342          MOV     A,JUNK1          ;RESTORE CHARACTER
0197 D30D          343          XRL     A,#0DH           ;SEE IF IT IS A CR
0199 C6A8          344          JZ      CRFIX            ;LEAVE IF IT IS
019B FF            345          MOV     A,JUNK1          ;GET ACC BACK
019C D30A          346          XRL     A,#0AH           ;SEE IF IT IS A LF
019E C6AB          347          JZ      LFFIX            ;LEAVE IF IT IS
01A0 FF            348          MOV     A,JUNK1          ;GET CHARACTER BACK
01A1 53E0          349          ANL     A,#0E0H          ;SEE IF IT IS A CHARACTER
01A3 96BD          350          JNZ     ISCHAR           ;IF IT IS JUMP
01A5 2320          351          MOV     A,#20H           ;PUT A SPACE IN ACC
01A7 83            352          RET                      ;EXIT
01A8 4380          353 CRFIX:   ORL     A,#80H           ;SET BIT 7
01AA 83            354          RET                      ;EXIT
01AB FD            355 LFFIX:   MOV     A,STATUS         ;GET THE STATUS
01AC 4320          356          ORL     A,#20H           ;SET LF BIT IN STATUS
01AE AD            357          MOV     STATUS,A         ;PUT THE STATUS BACK
01AF 2320          358          MOV     A,#20H           ;GET A SPACE
01B1 83            359          RET                      ;EXIT
01B2 FD            360 FFFIX:   MOV     A,STATUS         ;GET THE STATUS
01B3 4320          361          ORL     A,#20H           ;SET LINE FEED BIT
01B5 AD            362          MOV     STATUS,A         ;PUT THE STATUS BACK
01B6 FE            363          MOV     A,LINCNT         ;GET THE LINE COUNT
01B7 4380          364          ORL     A,#80H           ;SET BIT 7
01B9 AE            365          MOV     LINCNT,A         ;PUT LINE COUNT BACK
01BA 2320          366          MOV     A,#20H           ;GET A SPACE
01BC 83            367          RET                      ;EXIT
01BD FF            368 ISCHAR:  MOV     A,JUNK1          ;GET CHARACTER BACK
01BE 533F          369          ANL     A,#3FH           ;STRIP THE TWO MSB
01C0 83            370          RET                      ;EXIT
```

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LOC  OBJ          SEQ          SOURCE STATEMENT

                  371          ;
                  372          ;THIS ROUTINE PRINTS THE CHARACTER IN THE ACC
                  373          ;
01C1 AC           374 PRNTIT:  MOV      TEMP1,A          ;SAVE CHARACTER
01C2 E7           375          RL       A                ;MULTIPLY BY TWO
01C3 E7           376          RL       A                ;MULTIPLY BY FOUR
01C4 6C           377          ADD      A,TEMP1          ;ADD ONCE TO MULTIPLY BY 5
                  378          ;
                  379          ;NOW SEE WHAT PART OF THE LOOKUP TABLE TO USE
                  380          ;
01C5 2C           381          XCH      A,TEMP1          ;PUT CHARACTER IN A, TARGET IN TEMP1
01C6 B2CA         382          JB5      SHORT            ;JUMP TO HIGH ADDRESS IF BIT 5 SET
01C8 44AB         383          JMP      PAGE1            ;GO TO FIRST PART OF LOOKUP TABLE
01CA 64AB         384 SHORT:   JMP      PAGE2            ;GO TO SECOND PAGE OF LOOKUP TABLE
                  385          ;
                  386          ;THIS ROUTINE TRIGGERS THE SOLENOIDS FOR 600 MICROSECONDS
                  387          ;AFTER WAITING FOR THE TRIGGER SIGNAL FROM THE PRINTER
                  388          ;*
01CC AF           389 FIRE:    MOV      JUNK1,A          ;SAVE THE ACC
01CD FD           390          MOV      A,STATUS         ;GET THE STATUS
01CE D2D4         391          JB6      NT1              ;SEE IF FORWARD OR BACKWARDS
01D0 56D0         392 FIREX:   JT1      FIREX            ;WAIT FOR T1
01D2 24D6         393          JMP      FIREY            ;LEAVE
01D4 46D4         394 NT1:     JNT1     NT1              ;LOOP
01D6 FF           395 FIREY:   MOV      A,JUNK1          ;GET ACC BACK
01D7 90           396          MOVX     @R0,A            ;TRIGGER THE SOLENOID
                  397          ;
                  398          ;NOW KILL 600 MICROSECONDS
                  399          ;
01D8 23F3         400          MOV      A,#0F3H          ;LOAD DELAY NUMBER
01DA 62           401          MOV      T,A              ;PUT IT IN TIMER
01DB 55           402          STRT     T                ;START THE TIMER
01DC 16E0         403 TSJTF:   JTF      KTDUN            ;LOOP ON TIMER FLAG
01DE 24DC         404          JMP      TSJTF            ;
01E0 27           405 KTDUN:   CLR      A                ;ZERO ACC
01E1 90           406          MOVX     @R0,A            ;TURN OFF SOLENOIDS
01E2 65           407          STOP     TCNT             ;STOP THE TIMER
01E3 83           408          RET                       ;EXIT FIRE ROUTINE
                  409 $EJECT
```

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LOC  OBJ          SEQ          SOURCE STATEMENT

                   410          ;
                   411          ;*****************************************************************
                   412          ;
                   413          ;THIS IS THE LOOKUP TABLE. THE MSB IS NOT USED, THE MSB - 1
                   414          ;IS THE DOT THAT IS THE TOP OF ANY GIVEN CHARACTER AND THE
                   415          ;LSB IS THE DOT THAT IS THE BOTTOM OF ANY GIVEN CHARACTER
                   416          ;
                   417          ;*****************************************************************
                   418          ;
0200               419          ORG     200H
                   420          ;*
0200 3E            421 TABLE1:  DB      3EH            ;  *****
0201 41            422          DB      41H            ; *     *
0202 5D            423          DB      5DH            ; * *** *
0203 59            424          DB      59H            ; * **  *
0204 4E            425          DB      4EH            ; *  ***
                   426
0205 7C            427          DB      7CH            ; *****
0206 12            428          DB      12H            ;   *  *
0207 11            429          DB      11H            ;    *   *
0208 12            430          DB      12H            ;   *  *
0209 7C            431          DB      7CH            ; *****
                   432
020A 7F            433          DB      7FH            ; *******
020B 49            434          DB      49H            ; *  *  *
020C 49            435          DB      49H            ; *  *  *
020D 49            436          DB      49H            ; *  *  *
020E 36            437          DB      36H            ;  ** **
                   438
020F 3E            439          DB      3EH            ;  *****
0210 41            440          DB      41H            ; *     *
0211 41            441          DB      41H            ; *     *
0212 41            442          DB      41H            ; *     *
0213 22            443          DB      22H            ;  *   *
                   444
0214 7F            445          DB      7FH            ; *******
0215 41            446          DB      41H            ; *     *
0216 41            447          DB      41H            ; *     *
0217 41            448          DB      41H            ; *     *
0218 3E            449          DB      3EH            ;  *****
                   450
0219 7F            451          DB      7FH            ; *******
021A 49            452          DB      49H            ; *  *  *
021B 49            453          DB      49H            ; *  *  *
021C 49            454          DB      49H            ; *  *  *
021D 41            455          DB      41H            ; *     *
                   456 $EJECT
```

```
LOC   OBJ          SEQ          SOURCE STATEMENT

                   457
021E  7F           458           DB       7FH           ;*******
021F  09           459           DB       09H           ;   *  *
0220  09           460           DB       09H           ;   *  *
0221  09           461           DB       09H           ;   *  *
0222  01           462           DB       01H           ;      *
                   463
0223  3E           464           DB       3EH           ; *****
0224  41           465           DB       41H           ;*     *
0225  41           466           DB       41H           ;*     *
0226  51           467           DB       51H           ;* *   *
0227  71           468           DB       71H           ;***   *
                   469
0228  7F           470           DB       7FH           ;*******
0229  08           471           DB       08H           ;   *
022A  08           472           DB       08H           ;   *
022B  08           473           DB       08H           ;   *
022C  7F           474           DB       7FH           ;*******
                   475
022D  00           476           DB       00H           ;
022E  41           477           DB       41H           ;*     *
022F  7F           478           DB       7FH           ;*******
0230  41           479           DB       41H           ;*     *
0231  00           480           DB       00H           ;
                   481
0232  20           482           DB       20H           ; *
0233  40           483           DB       40H           ;*
0234  40           484           DB       40H           ;*
0235  40           485           DB       40H           ;*
0236  3F           486           DB       3FH           ; ******
                   487
0237  7F           488           DB       7FH           ;*******
0238  08           489           DB       08H           ;   *
0239  14           490           DB       14H           ;  * *
023A  22           491           DB       22H           ; *   *
023B  41           492           DB       41H           ;*     *
                   493
023C  7F           494           DB       7FH           ;*******
023D  40           495           DB       40H           ;*
023E  40           496           DB       40H           ;*
023F  40           497           DB       40H           ;*
0240  40           498           DB       40H           ;*
                   499
0241  7F           500           DB       7FH           ;*******
0242  02           501           DB       02H           ;     *
0243  0C           502           DB       0CH           ;   **
0244  02           503           DB       02H           ;     *
0245  7F           504           DB       7FH           ;*******
                   505
0246  7F           506           DB       7FH           ;*******
0247  04           507           DB       04H           ;    *
0248  08           508           DB       08H           ;   *
0249  10           509           DB       10H           ;  *
024A  7F           510           DB       7FH           ;*******
                   511 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                  512
824B 3E           513          DB      3EH          ;  *****
824C 41           514          DB      41H          ; *     *
824D 41           515          DB      41H          ; *     *
824E 41           516          DB      41H          ; *     *
824F 3E           517          DB      3EH          ;  *****
                  518
8250 7F           519          DB      7FH          ; *******
8251 09           520          DB      09H          ;    *  *
8252 09           521          DB      09H          ;    *  *
8253 09           522          DB      09H          ;    *  *
8254 06           523          DB      06H          ;     **
                  524
8255 3E           525          DB      3EH          ;  *****
8256 41           526          DB      41H          ; *     *
8257 51           527          DB      51H          ; * *   *
8258 21           528          DB      21H          ;  *    *
8259 5E           529          DB      5EH          ; * ****
                  530
825A 7F           531          DB      7FH          ; *******
825B 09           532          DB      09H          ;    *  *
825C 19           533          DB      19H          ;   **  *
825D 29           534          DB      29H          ;  * * *
825E 46           535          DB      46H          ; *   **
                  536
825F 26           537          DB      26H          ;  *  **
8260 49           538          DB      49H          ; *  *  *
8261 49           539          DB      49H          ; *  *  *
8262 49           540          DB      49H          ; *  *  *
8263 32           541          DB      32H          ;  **  *
                  542
8264 01           543          DB      01H          ;       *
8265 01           544          DB      01H          ;       *
8266 7F           545          DB      7FH          ; *******
8267 01           546          DB      01H          ;       *
8268 01           547          DB      01H          ;       *
                  548
8269 3F           549          DB      3FH          ;  ******
826A 40           550          DB      40H          ; *
826B 40           551          DB      40H          ; *
826C 40           552          DB      40H          ; *
826D 3F           553          DB      3FH          ;  ******
                  554
826E 1F           555          DB      1FH          ;   *****
826F 20           556          DB      20H          ;  *
8270 40           557          DB      40H          ; *
8271 20           558          DB      20H          ;  *
8272 1F           559          DB      1FH          ;   *****
                  560
8273 7F           561          DB      7FH          ; *******
8274 20           562          DB      20H          ;  *
8275 18           563          DB      18H          ;   **
8276 20           564          DB      20H          ;  *
8277 7F           565          DB      7FH          ; *******
                  566 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                    567
0278 63             568          DB      63H             ; **   **
0279 14             569          DB      14H             ;   * *
027A 08             570          DB      08H             ;    *
027B 14             571          DB      14H             ;   * *
027C 63             572          DB      63H             ; **   **
                    573
027D 03             574          DB      03H             ;       **
027E 04             575          DB      04H             ;      *
027F 78             576          DB      78H             ; ****
0280 04             577          DB      04H             ;      *
0281 03             578          DB      03H             ;       **
                    579
0282 61             580          DB      61H             ; **    *
0283 51             581          DB      51H             ; * *   *
0284 49             582          DB      49H             ; *  *  *
0285 45             583          DB      45H             ; *   * *
0286 43             584          DB      43H             ; *    **
                    585
0287 7F             586          DB      7FH             ; *******
0288 7F             587          DB      7FH             ; *******
0289 41             588          DB      41H             ; *     *
028A 41             589          DB      41H             ; *     *
028B 41             590          DB      41H             ; *     *
                    591
028C 02             592          DB      02H             ;      *
028D 04             593          DB      04H             ;     *
028E 08             594          DB      08H             ;    *
028F 10             595          DB      10H             ;   *
0290 20             596          DB      20H             ;  *
                    597
0291 41             598          DB      41H             ; *     *
0292 41             599          DB      41H             ; *     *
0293 41             600          DB      41H             ; *     *
0294 7F             601          DB      7FH             ; *******
0295 7F             602          DB      7FH             ; *******
                    603
0296 10             604          DB      10H             ;   *
0297 08             605          DB      08H             ;    *
0298 04             606          DB      04H             ;     *
0299 08             607          DB      08H             ;    *
029A 10             608          DB      10H             ;   *
                    609
029B 40             610          DB      40H             ; *
029C 40             611          DB      40H             ; *
029D 40             612          DB      40H             ; *
029E 40             613          DB      40H             ; *
029F 40             614          DB      40H             ; *
                    615 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                  616          ;
02A0 B000         617 PAGE1:   MOV     STBCNT,#00H      ;ZERO STROBE COUNTER
02A2 FA           618          MOV     A,SAVPNT         ;GET DIRECTION
02A3 37           619          CPL     A                ;FLIP BITS
02A4 D2B3         620          JB6     BAKWRD           ;IF BACKWARD JUMP OUT
02A6 FC           621 LKLO:    MOV     A,TEMP1          ;GET THE TARGET
02A7 A3           622          MOVP    A,@A             ;GET THE DATA
02A8 34CC         623          CALL    FIRE             ;STROBE THE SOLENOIDS
02AA 1C           624          INC     TEMP1            ;INCREMENT THE POINTER
02AB 1B           625          INC     STBCNT           ;INCREMENT THE STROBE COUNTER
02AC FB           626          MOV     A,STBCNT         ;GET THE STROBE COUNTER
02AD D385         627          XRL     A,#85H           ;IS IT FIVE
02AF 96A6         628          JNZ     LKLO             ;REPEAT IF NOT FIVE
02B1 84AE         629          JMP     SETTIM           ;GO BACK
02B3 FC           630 BAKWRD:  MOV     A,TEMP1          ;GET THE TARGET
02B4 0304         631          ADD     A,#04H           ;COMPENSATE FOR GOING BACKWARDS
02B6 AC           632          MOV     TEMP1,A          ;SAVE IT
02B7 FC           633 LKLO1:   MOV     A,TEMP1          ;GET THE TARGET
02B8 A3           634          MOVP    A,@A             ;GET THE DATA
02B9 34CC         635          CALL    FIRE             ;STROBE THE SOLENOIDS
02BB FC           636          MOV     A,TEMP1          ;GET TEMP1
02BC 07           637          DEC     A                ;DECREASE BY ONE
02BD AC           638          MOV     TEMP1,A          ;PUT IT BACK
02BE 1B           639          INC     STBCNT           ;INCREMENT THE STROBE COUNTER
02BF FB           640          MOV     A,STBCNT         ;GET THE STROBE COUNTER
02C0 D385         641          XRL     A,#85H           ;IS IT FIVE
02C2 96B7         642          JNZ     LKLO1            ;REPEAT IF NOT FIVE
02C4 84AE         643          JMP     SETTIM           ;GO BACK, CHARACTER IS DONE
                  644 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                   645          ;*
0300               646          ORG     300H
                   647          ;*
                   648
0300 00            649          DB      00H             ;
0301 00            650          DB      00H             ;
0302 00            651          DB      00H             ;
0303 00            652          DB      00H             ;
0304 00            653          DB      00H             ;
                   654
0305 00            655          DB      00H             ;
0306 00            656          DB      00H             ;
0307 5F            657          DB      5FH             ; * *****
0308 00            658          DB      00H             ;
0309 00            659          DB      00H             ;
                   660
030A 00            661          DB      00H             ;
030B 07            662          DB      07H             ;      ***
030C 00            663          DB      00H             ;
030D 07            664          DB      07H             ;      ***
030E 00            665          DB      00H             ;
                   666
030F 14            667          DB      14H             ;    * *
0310 7F            668          DB      7FH             ; *******
0311 14            669          DB      14H             ;    * *
0312 7F            670          DB      7FH             ; *******
0313 14            671          DB      14H             ;    * *
                   672
0314 24            673          DB      24H             ;   *  *
0315 2A            674          DB      2AH             ;   * * *
0316 7F            675          DB      7FH             ; *******
0317 2A            676          DB      2AH             ;   * * *
0318 12            677          DB      12H             ;    *  *
                   678
0319 23            679          DB      23H             ;   *   **
031A 13            680          DB      13H             ;    *  **
031B 08            681          DB      08H             ;     *
031C 64            682          DB      64H             ; **  *
031D 62            683          DB      62H             ; **   *
                   684
031E 36            685          DB      36H             ;  ** **
031F 49            686          DB      49H             ; *  *  *
0320 56            687          DB      56H             ; * * **
0321 20            688          DB      20H             ;  *
0322 50            689          DB      50H             ; * *
                   690 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                   691
0323 00            692          DB      00H             ;
0324 00            693          DB      00H             ;
0325 07            694          DB      07H             ;     ***
0326 00            695          DB      00H             ;
0327 00            696          DB      00H             ;
                   697
0328 1C            698          DB      1CH             ;    ***
0329 22            699          DB      22H             ;   *   *
032A 41            700          DB      41H             ; *       *
032B 00            701          DB      00H             ;
032C 00            702          DB      00H             ;
                   703
032D 00            704          DB      00H             ;
032E 00            705          DB      00H             ;
032F 41            706          DB      41H             ; *       *
0330 22            707          DB      22H             ;   *   *
0331 1C            708          DB      1CH             ;    ***
                   709
0332 22            710          DB      22H             ;   *   *
0333 14            711          DB      14H             ;    * *
0334 7F            712          DB      7FH             ; *******
0335 14            713          DB      14H             ;    * *
0336 22            714          DB      22H             ;   *   *
                   715
0337 08            716          DB      08H             ;     *
0338 08            717          DB      08H             ;     *
0339 7F            718          DB      7FH             ; *******
033A 08            719          DB      08H             ;     *
033B 08            720          DB      08H             ;     *
                   721
033C 00            722          DB      00H             ;
033D 40            723          DB      40H             ; *
033E 30            724          DB      30H             ;  **
033F 00            725          DB      00H             ;
0340 00            726          DB      00H             ;
                   727
0341 08            728          DB      08H             ;     *
0342 08            729          DB      08H             ;     *
0343 08            730          DB      08H             ;     *
0344 08            731          DB      08H             ;     *
0345 08            732          DB      08H             ;     *
                   733
0346 00            734          DB      00H             ;
0347 00            735          DB      00H             ;
0348 40            736          DB      40H             ; *
0349 00            737          DB      00H             ;
034A 00            738          DB      00H             ;
                   739
034B 20            740          DB      20H             ;  *
034C 10            741          DB      10H             ;   *
034D 08            742          DB      08H             ;    *
034E 04            743          DB      04H             ;     *
034F 02            744          DB      02H             ;      *
                   745
0350 3E            746          DB      3EH             ;  *****
0351 51            747          DB      51H             ; * *   *
0352 49            748          DB      49H             ; *  *  *
0353 45            749          DB      45H             ; *   * *
0354 3E            750          DB      3EH             ;  *****
                   751
0355 00            752          DB      00H             ;
0356 42            753          DB      42H             ; *    *
0357 7F            754          DB      7FH             ; *******
0358 40            755          DB      40H             ; *
0359 00            756          DB      00H             ;
                   757
035A 62            758          DB      62H             ; **   *
035B 51            759          DB      51H             ; * *   *
035C 49            760          DB      49H             ; *  *  *
035D 49            761          DB      49H             ; *  *  *
035E 46            762          DB      46H             ; *   **
                   763
035F 21            764          DB      21H             ;  *    *
0360 41            765          DB      41H             ; *      *
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

0361 49           766          DB      49H             ; *  *  *
0362 4D           767          DB      4DH             ; *  ** *
0363 33           768          DB      33H             ;  **  **
                  769
0364 1B           770          DB      1BH             ;   **
0365 14           771          DB      14H             ;   * *
0366 12           772          DB      12H             ;   *  *
0367 7F           773          DB      7FH             ; *******
0368 1B           774          DB      1BH             ;   *
                  775
0369 27           776          DB      27H             ;  *  ***
036A 45           777          DB      45H             ; *   * *
036B 45           778          DB      45H             ; *   * *
036C 45           779          DB      45H             ; *   * *
036D 39           780          DB      39H             ;  ***  *
                  781
036E 3C           782          DB      3CH             ;  ****
036F 4A           783          DB      4AH             ; *  * *
0370 49           784          DB      49H             ; *  *  *
0371 49           785          DB      49H             ; *  *  *
0372 31           786          DB      31H             ;  **   *
                  787
0373 01           788          DB      01H             ;       *
0374 71           789          DB      71H             ; ***   *
0375 09           790          DB      09H             ;    *  *
0376 05           791          DB      05H             ;     * *
0377 03           792          DB      03H             ;      **
                  793
0378 36           794          DB      36H             ;  ** **
0379 49           795          DB      49H             ; *  *  *
037A 49           796          DB      49H             ; *  *  *
037B 49           797          DB      49H             ; *  *  *
037C 36           798          DB      36H             ;  ** **
                  799 $EJECT
```

```
LOC  OBJ         SEQ       SOURCE STATEMENT

                 800
037D 46          801        DB      46H          ; *   **
037E 49          802        DB      49H          ; *  *  *
037F 49          803        DB      49H          ; *  *  *
0380 29          804        DB      29H          ;  * *  *
0381 1E          805        DB      1EH          ;   ****
                 806
0382 00          807        DB      00H          ;
0383 00          808        DB      00H          ;
0384 14          809        DB      14H          ;   * *
0385 00          810        DB      00H          ;
0386 00          811        DB      00H          ;
                 812
0387 00          813        DB      00H          ;
0388 40          814        DB      40H          ; *
0389 34          815        DB      34H          ;  ** *
038A 00          816        DB      00H          ;
038B 00          817        DB      00H          ;
                 818
038C 08          819        DB      08H          ;    *
038D 14          820        DB      14H          ;   * *
038E 22          821        DB      22H          ;  *   *
038F 41          822        DB      41H          ; *     *
0390 00          823        DB      00H          ;
                 824
0391 14          825        DB      14H          ;   * *
0392 14          826        DB      14H          ;   * *
0393 14          827        DB      14H          ;   * *
0394 14          828        DB      14H          ;   * *
0395 14          829        DB      14H          ;   * *
                 830
0396 00          831        DB      00H          ;
0397 41          832        DB      41H          ; *     *
0398 22          833        DB      22H          ;  *   *
0399 14          834        DB      14H          ;   * *
039A 08          835        DB      08H          ;    *
                 836
039B 02          837        DB      02H          ;      *
039C 01          838        DB      01H          ;       *
039D 59          839        DB      59H          ; * **  *
039E 05          840        DB      05H          ;     * *
039F 02          841        DB      02H          ;      *
                 842 $EJECT
```

```
LOC  OBJ        SEQ          SOURCE STATEMENT

03A8 8808         843 PAGE2:  MOV     STBCNT,#80H     ;ZERO STROBE COUNTER
03A2 FA           844         MOV     A,SAVPNT        ;GET DIRECTION
03A3 37           845         CPL     A               ;FLIP BITS
03A4 D2B5         846         JB6     BKWRD           ;IF BACKWARD JUMP OUT
03A6 FC           847 LKHI:   MOV     A,TEMP1         ;GET THE TARGET
03A7 8368         848         ADD     A,#68H          ;ADJUST THE TARGET
03A9 A3           849         MOVP    A,@A            ;GET THE DATA
03AA 34CC         850         CALL    FIRE            ;STROBE THE SOLENOIDS
03AC 1C           851         INC     TEMP1           ;INCREMENT THE POINTER
03AD 1B           852         INC     STBCNT          ;INCREMENT THE STROBE COUNTER
03AE FB           853         MOV     A,STBCNT        ;GET THE STROBE COUNTER
03AF D385         854         XRL     A,#85H          ;IS IT FIVE
03B1 96A6         855         JNZ     LKHI            ;REPEAT IF NOT FIVE
03B3 84AE         856         JMP     SETTIM          ;GO BACK
03B5 FC           857 BKWRD:  MOV     A,TEMP1         ;GET THE TARGET
03B6 8364         858         ADD     A,#64H          ;COMPENSATE FOR GOING BACKWARDS
03B8 AC           859         MOV     TEMP1,A         ;SAVE IT
03B9 FC           860 LKHI1:  MOV     A,TEMP1         ;GET THE TARGET
03BA A3           861         MOVP    A,@A            ;GET THE DATA
03BB 34CC         862         CALL    FIRE            ;STROBE THE SOLENOIDS
03BD FC           863         MOV     A,TEMP1         ;GET TEMP1
03BE 07           864         DEC     A               ;DECREASE BY ONE
03BF AC           865         MOV     TEMP1,A         ;PUT IT BACK
03C0 1B           866         INC     STBCNT          ;INCREMENT THE STROBE COUNTER
03C1 FB           867         MOV     A,STBCNT        ;GET THE STROBE COUNTER
03C2 D385         868         XRL     A,#85H          ;IS IT FIVE
03C4 96B9         869         JNZ     LKHI1           ;REPEAT IF NOT FIVE
03C6 84AE         870         JMP     SETTIM          ;GO BACK, CHARACTER IS DONE
                  871 $EJECT
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

                  872          ;
0400              873          ORG     400H
                  874          ;
0400 27           875 BGIN:    CLR     A                ;ZERO ACC
0401 90           876          MOVX    @R0,A            ;TURN OFF THE SOLENOIDS
0402 9408         877          CALL    SETUP            ;SET UP THE PRINTER
0404 943F         878          CALL    VARSET           ;SET UP THE SOFTWARE
0406 040A         879          JMP     PRNT             ;GO START
                  880          ;
0408 23FE         881 SETUP:   MOV     A,#0FEH          ;LOAD ACC WITH VALUE TO TURN ON MOTOR
040A 39           882          OUTL    P1,A             ;TURN ON MOTOR
                  883          ;
                  884          ;NOW DELAY 3.2 SECONDS WHILE CHECKING RIGHT SENSOR
                  885          ;
040B BC05         886          MOV     TEMP1,#05H       ;LOAD DELAY VALUE ONE
040D BFFF         887 SELFC:   MOV     JUNK1,#0FFH      ;LOAD DELAY VALUE TWO
040F BEFF         888 SELFB:   MOV     LINCNT,#0FFH     ;LOAD DELAY VALUE THREE
0411 09           889 SELFA:   IN      A,P1             ;READ PORT ONE
0412 37           890          CPL     A                ;MAKE THINGS RIGHT
0413 F21D         891          JB7     DONER            ;IS BIT 7 SET?
0415 EE11         892          DJNZ    LINCNT,SELFA     ;SMALL LOOP
0417 EFBF         893          DJNZ    JUNK1,SELFB      ;BIGGER LOOP
0419 ECBD         894          DJNZ    TEMP1,SELFC      ;BIGGEST LOOP
041B 845A         895          JMP     ERROR            ;SOMETHING IS WRONG
                  896          ;
                  897          ;NOW MAKE SURE THE RIGHT SENSOR IS CLEARED
                  898          ;
041D BFFF         899 DONER:   MOV     JUNK1,#0FFH      ;SET UP DELAY
041F BEFF         900 SELF:    MOV     LINCNT,#0FFH     ;SOME MORE DELAY
0421 09           901 SELF1:   IN      A,P1             ;GET THE FLAG INFORMATION
0422 F22A         902          JB7     DONEF            ;IS FLAG CLEARED?
0424 EE21         903          DJNZ    LINCNT,SELF1     ;IF NOT LOOP
0426 EF1F         904          DJNZ    JUNK1,SELF       ;LOOP SOME MORE
0428 845A         905          JMP     ERROR            ;LEAVE IF FLAG IS NOT UNCOVERED
                  906          ;
                  907          ;NOW CHECK THE LEFT SENSOR IN THE SAME MANNER AS THE
                  908          ;RIGHT SENSOR.  EXCEPT DELAY ONLY 2.5 SECONDS
                  909          ;
042A BC04         910 DONEF:   MOV     TEMP1,#04H       ;LOAD DELAY 1
042C BFFF         911 SELFCC:  MOV     JUNK1,#0FFH      ;LOAD DELAY 2
042E BEFF         912 SELFBB:  MOV     LINCNT,#0FFH     ;LOAD DELAY 3
0430 09           913 SELFAA:  IN      A,P1             ;READ THE PORT
0431 37           914          CPL     A                ;CHANGE THINGS AROUND
0432 D23C         915          JB6     DONEL            ;OK IF BIT 6 IS A ZERO
0434 EE30         916          DJNZ    LINCNT,SELFAA    ;SMALL LOOP
0436 EF2E         917          DJNZ    JUNK1,SELFBB     ;BIGGER LOOP
0438 EC2C         918          DJNZ    TEMP1,SELFCC     ;BIGGEST LOOP
043A 845A         919          JMP     ERROR            ;SOMETHING IS WRONG
043C 8901         920 DONEL:   ORL     P1,#01H          ;TURN MOTOR OFF
043E 83           921          RET                      ;GO BACK
                  922          ;
                  923          ;NOW SET UP THE VARIABLES
                  924          ;
043F 23FE         925 VARSET:  MOV     A,#0FEH          ;LOAD THE TIMER
0441 62           926          MOV     T,A
0442 55           927          STRT    T                ;START THE TIMER
0443 B820         928          MOV     INBUF,#FIRST     ;LOAD INPUT BUFFER
0445 BE08         929          MOV     LINCNT,#08H      ;SET LINE COUNT
0447 BD08         930          MOV     STATUS,#08H      ;SET FORWARD BIT
                  931          ;
                  932          ;NOW CLEAR THE RAM AREA BY WRITING SPACE CODES
                  933          ;
0449 B920         934          MOV     OUTBUF,#FIRST    ;LOAD OUTBUF
044B 2320         935 CLRMEM:  MOV     A,#20H           ;PUT SPACE CODE IN ACC
044D A1           936          MOV     @OUTBUF,A        ;PUT SPACE CODE IN DATA MEMORY
044E 19           937          INC     OUTBUF           ;UPDATE THE POINTER
044F F9           938          MOV     A,OUTBUF         ;MOVE THE POINTER INTO ACC
0450 D378         939          XRL     A,#MAX+1         ;SEE IF DONE
0452 964B         940          JNZ     CLRMEM           ;LOOP IF NOT CLEARED
                  941          ;
                  942          ;NOW CLEAR THE 8212
                  943          ;
0454 99EF         944          ANL     P1,#0EFH         ;SET ENABLE BIT
0456 80           945          MOVX    A,@INBUF         ;CLEAR THE 8212 INPUT BUFFER
0457 8910         946          ORL     P1,#10H          ;RESET ENABLE BIT
                  947          ;
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT
                   948          ;NOW EXIT VARSET
                   949          ;
0459 83            950          RET                     ;LEAVE INITIALIZATION
                   951          ;
                   952          ;THIS ROUTINE TURNS THE MOTOR OFF AND LOOPS
                   953          ;
045A 89FF          954 ERROR:   ORL     P1,#0FFH        ;TURN OFF MOTOR
045C 845C          955 DEAD:    JMP     DEAD            ;LOOP BECAUSE SOMETHING IS WRONG
                   956          ;
                   957          ;THESE ARE ALL SUBROUTINES THAT ARE CALLED
                   958          ;
045E 19            959 INCTST:  INC     OUTBUF          ;UPDATE THE POINTER
045F 237B          960          MOV     A,#MAX+1        ;GET THE VALUE FOR THE LAST CHARACTER
0461 D9            961          XRL     A,OUTBUF        ;DO THE TEST
0462 83            962          RET                     ;EXIT
0463 B9            963 GTPRNT:  IN      A,P1            ;READ PORT ONE
0464 37            964          CPL     A               ;FLIP BITS
0465 D263          965          JB6     GTPRNT          ;LOOP UNTIL SENSOR IS UNCOVERED
0467 166B          966 TSTJTF:  JTF     PIT             ;SEE IF TIMER FLAG IS SET
0469 8467          967          JMP     TSTJTF          ;TEST FLAG
046B 65            968 PIT:     STOP    TCNT            ;STOP THE TIMER
046C FF            969          MOV     A,JUNK1         ;GET THE CHARACTER
046D 34C1          970          CALL    PRNTIT          ;PRINT THE CHARACTER
046F 341C          971          CALL    LNMODE          ;GET ANOTHER CHARACTER
0471 83            972          RET                     ;EXIT
0472 F9            973 DECTST:  MOV     A,OUTBUF        ;GET OUTBUF
0473 B7            974          DEC     A               ;REDUCE BY ONE
0474 A9            975          MOV     OUTBUF,A        ;PUT BACK IN OUTBUF
0475 D31F          976          XRL     A,#FIRST-1      ;SEE IF IT IS ALL THE WAY DOWN
0477 83            977          RET                     ;EXIT
                   978          ;
                   979          ;THIS ROUTINE DOES A LINE FEED
                   980          ;
0478 FE            981 LINEFD:  MOV     A,LINCNT        ;GET THE LINE COUNT
0479 F298          982          JB7     DOFF            ;IF BIT 7 IS SET, DO A FORMFEED
047B 99FD          983 LFDO:    ANL     P1,#0FDH        ;TURN ON THE SOLENOID
047D BC4D          984          MOV     TEMP1,#4DH      ;LOAD ONE DELAY
047F BF93          985 LFLP1:   MOV     JUNK1,#93H      ;LOAD ANOTHER DELAY
0481 EF81          986 LFLP2:   DJNZ    JUNK1,LFLP2     ;LOOP
0483 EC7F          987          DJNZ    TEMP1,LFLP1     ;LOOP SOME MORE
0485 8982          988          ORL     P1,#02H         ;TURN OFF LF SOLENOID
0487 1E            989          INC     LINCNT          ;UPDATE THE LINE COUNTER
0488 FE            990          MOV     A,LINCNT        ;GET THE LINE COUNT
0489 D328          991          XRL     A,#28H          ;IS PAGE DONE
048B 968F          992          JNZ     NOTDON          ;SKIP OVER
048D BE00          993          MOV     LINCNT,#00H     ;ZERO LINE COUNTER
                   994          ;
                   995          ;NOW DELAY 90 MILLISECONDS
                   996          ;
048F BC0B          997 NOTDON:  MOV     TEMP1,#0BH      ;LOAD DELAY VALUES
0491 BFFF          998 LOP1:    MOV     JUNK1,#0FFH     ;
0493 EF93          999 LOP2:    DJNZ    JUNK1,LOP2      ;GENERATE DELAY
0495 EC91         1000          DJNZ    TEMP1,LOP1      ;
0497 83           1001          RET                     ;LINE FEED IS DONE
                  1002          ;
                  1003          ;THIS ROUTINE DOES A FORM FEED
                  1004          ;
0498 B9           1005 DOFF:    IN      A,P1            ;GET THE STATUS
0499 37           1006          CPL     A               ;FLIP ACC
049A 53C0         1007          ANL     A,#0C0H         ;LEAVE ONLY TWO MSB'S
049C C698         1008          JZ      DOFF            ;IF A FLAG ISN'T COVERED, LOOP
049E 8981         1009          ORL     P1,#81H         ;TURN THE MOTOR OFF
04A0 9478         1010          CALL    LFDO            ;GO DO ONE LINE FEED
04A2 FE           1011 FFCK:    MOV     A,LINCNT        ;GET THE LINE COUNT
04A3 537F         1012          ANL     A,#7FH          ;STRIP BIT SEVEN
04A5 D300         1013          XRL     A,#00H          ;IS IT DONE
04A7 C6AD         1014          JZ      FFDONE          ;LEAVE IF IT IS
04A9 9478         1015          CALL    LFDO            ;STROBE THE SOLENOIDS
04AB 04A2         1016          JMP     FFCK            ;CHECK THE FORM FEED OUT
04AD 83           1017 FFDONE:  RET                     ;EXIT FORM FEED
                  1018          ;
04AE 23E8         1019 SETTIM:  MOV     A,#0E8H         ;GET DELAY VALUE
04B0 62           1020          MOV     T,A             ;PUT IN TIMER
04B1 55           1021          STRT    T               ;START THE TIMER
04B2 83           1022          RET                     ;EXIT
                  1023
```

```
LOC  OBJ          SEQ          SOURCE STATEMENT

04B3 42           1824 PRNTBK: MOV      A,T              ;GET THE TIMER
04B4 37           1825         CPL      A                ;TWOS COMPLEMENT ACC
04B5 17           1826         INC      A
04B6 17           1827         INC      A
04B7 17           1828         INC      A
04B8 17           1829         INC      A
04B9 17           1830         INC      A                ;ADJUST TIMER
04BA 62           1831         MOV      T,A              ;PUT IT BACK IN THE TIMER
04BB B9           1832 INLOOP: IN       A,P1             ;READ PORT 1
04BC F2C8         1833         JB7      CONPBK           ;IF SENSOR IN NOT COVERED, LEAVE
04BE 84BB         1834         JMP      INLOOP           ;OTHERWISE LOOP
04C0 55           1835 CONPBK: STRT     T                ;START THE TIMER
04C1 16C5         1836 CONPB:  JTF      RDTOPT           ;SEE IF READY TO PRINT
04C3 84C1         1837         JMP      CONPB            ;OTHERWISE LOOP
04C5 23FF         1838 RDTOPT: MOV      A,#0FFH          ;LOAD A
04C7 62           1839         MOV      T,A              ;PUT IT IN THE TIMER
04C8 83           1840         RET                       ;EXIT
                  1841         ;
                  1842         ;THIS ROUTINE ADJUSTS AND SAVES THE STATUS DURING PRINTING
                  1843         ;
04C9 FD           1844 STACHK: MOV      A,STATUS         ;GET THE STATUS
04CA 92D2         1845         JB4      LFSET            ;SET LINE FEED BIT
04CC AA           1846 B4RET:  MOV      SAVPNT,A         ;SAVE THE STATUS
04CD 53C2         1847         ANL      A,#0C2H          ;RESET EVERYTHING EXCEPT
                  1848                                   ;DIRECTION AND PRINT
04CF AD           1849         MOV      STATUS,A         ;PUT THE STATUS BACK
04D0 8413         1850         JMP      LPRNT1           ;EXIT
04D2 4320         1851 LFSET:  ORL      A,#20H           ;SET BIT 5
04D4 84CC         1852         JMP      B4RET            ;JUMP BACK
                  1853         ;
                  1854         ;THIS ROUTINE READS A CHARACTER AND PUTS IT IN THE ACC
                  1855         ;
04D6 99EF         1856 GTCAR:  ANL      P1,#0EFH         ;SET ENABLE BIT
04D8 80           1857         MOVX     A,@INBUF         ;READ THE CHARACTER
04D9 8918         1858         ORL      P1,#10H          ;RESET ENABLE BIT
04DB 83           1859         RET                       ;EXIT GTCHAR
                  1860         ;
                  1861         ;THIS ROUTINE TURNS THE MOTOR ON
                  1862         ;
04DC 99FE         1863 MOTON:  ANL      P1,#0FEH         ;TURN MOTOR ON
04DE 83           1864         RET                       ;EXIT
                  1865         ;
                  1866         ;THIS ROUTINE TURNS THE MOTOR OFF
                  1867         ;
04DF 8901         1868 MOTOF:  ORL      P1,#01H          ;TURN MOTOR OFF
04E1 83           1869         RET                       ;EXIT
                  1870         ;
                  1871         END                       ;DONE

USER SYMBOLS
ARND   0107   ARNDJP 0149   B4RET  04CC   BAKWRD 02B3   BGIN   0400   BKWRD  03B5   BUTLOP 0113   BYEBYE 0160
CASE0  0031   CASE01 0017   CASE1  0052   CASE2  0080   CASE23 0024   CASE3  00C2   CHAR   011F   CLRMEM 0448
CONPB  04C1   CONPBK 04C0   CRFIX  01A8   CRFND  00D2   CRFOND 0062   DEAD   045C   DECTST 0472   DOFF   0490
DOLF   0071   DONEF  042A   DONEL  043C   DONER  0410   ERROR  045A   FDC    0042   FDC1   0044   FDCR   009E
FDCR1  00A8   FFCK   04A2   FFDONE 04AD   FFFIX  01B2   FINE   0178   FIRE   01CC   FIREX  01D8   FIREY  01D6
FIRST  0020   FIXDUN 0174   FIXFIN 018F   FIXUP  0189   FXCHAR 0161   FXPRNT 0191   GETSTA 0144   GOOD   0128
GTCAR  04D6   GTPRNT 0463   INBUF  0000   INCTST 045E   INLOOP 04B8   ISCHAR 01BD   JUNK1  0007   KTDUN  01E0
LDBUF  0180   LFCRCK 014A   LFDD   0478   LFFIX  014B   LFLP1  047F   LFLP2  0481   LFSET  04D2   LFTEST 017F
LINCNT 0006   LINEFD 0478   LKHI   03A6   LKHI1  03B9   LKLO   02A6   LKLO1  02B7   LNMODE 011C   LOOPW  007A
LOP1   0491   LOP2   0493   LPRNT  0011   LPRNT1 0013   MAX    006F   MOTOF  04DF   MOTON  04DC   NOFF   018F
NOLF   011A   NOTDON 043F   NT1    01D4   OUTBUF 0001   OVR    00BA   OVR1   0085   PAGE1  0240   PAGE2  0340
PIT    046B   PRNT   0004   PRNTBK 04B3   PRNTIT 01C1   RDTOPT 04C5   SAVPNT 0002   SELF   041F   SELF1  0421
SELFA  0411   SELFAA 0438   SELFB  040F   SELFBB 042E   SELFC  040D   SELFCC 042C   SETTIM 04AE   SETUP  0408
SHORT  01CA   STACHK 04C9   STATUS 0005   STBCNT 0003   STBIT1 0150   STPRNT 0159   SUB1   0139   TABLE1 0200
TEMP1  0004   TSJTF  01DC   TSTJTF 0467   VARSET 043F   WATCH  0075   WATCHD 00AE

ASSEMBLY COMPLETE.  NO ERRORS
```

MCS®-51 Application Notes & Article Reprints

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APPLICATION NOTE

AP-69

May 1980

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An Introduction to the Intel® MCS-51™ Single-Chip Microcomputer Family

John Wharton
Microcontroller Applications

AFN-01502A-01

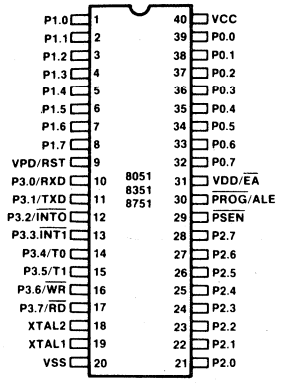

Figure 1a. 8051 Microcomputer Pinout Diagram

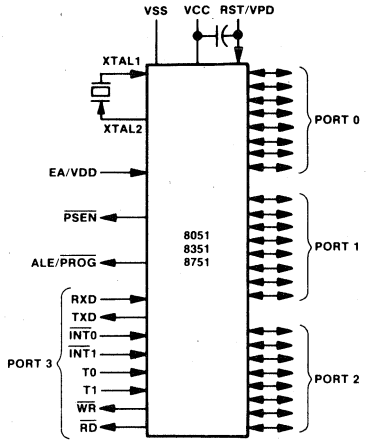

Figure 1b. 8051 Microcomputer Logic Symbol

1. INTRODUCTION

In 1976 Intel introduced the MCS-48™ family, consisting of the 8048, 8748, and 8035 microcomputers. These parts marked the first time a complete microcomputer system, including an eight-bit CPU, 1024 8-bit words of ROM or EPROM program memory, 64 words of data memory, I/O ports and an eight-bit timer/counter could be integrated onto a single silicon chip. Depending only on the program memory contents, one chip could control a limitless variety of products, ranging from appliances or automobile engines to text or data processing equipment. Follow-on products stretched the MCS-48™ architecture in several directions: the 8049 and 8039 doubled the amount of on-chip memory and ran 83% faster; the 8021 reduced costs by executing a subset of the 8048 instructions with a somewhat slower clock; and the 8022 put a unique two-channel 8-bit analog-to-digital converter on the same NMOS chip as the computer, letting the chip interface directly with analog transducers.

Now three new high-performance single-chip microcomputers—the Intel® 8051, 8751, and 8031—extend the advantages of Integrated Electronics to whole new product areas. Thanks to Intel's new HMOS technology, the MCS-51™ family provides four times the program memory and twice the data memory as the 8048 on a single chip. New I/O and peripheral capabilities both increase the range of applicability and reduce total system cost. Depending on the use, processing throughput increases by two and one-half to ten times.

This Application Note is intended to introduce the reader to the MCS-51™ architecture and features. While it does not assume intimacy with the MCS-48™ product line on the part of the reader, he she should be familiar with some microprocessor (preferably Intel's, of course) or have a background in computer programming and digital logic.

Family Overview

Pinout diagrams for the 8051, 8751, and 8031 are shown in Figure 1. The devices include the following features:

- Single-supply 5 volt operation using HMOS technology.
- 4096 bytes program memory on-chip (not on 8031).
- 128 bytes data memory on-chip.
- Four register banks.
- 128 User-defined software flags.
- 64 Kilobytes each program and external RAM addressability.
- One microsecond instruction cycle with 12 MHz crystal.
- 32 bidirectional I/O lines organized as four 8-bit ports (16 lines on 8031).
- Multiple mode, high-speed programmable Serial Port.
- Two multiple mode, 16-bit Timer/Counters.
- Two-level prioritized interrupt structure.
- Full depth stack for subroutine return linkage and data storage.
- Augmented MCS-48™ instruction set.
- Direct Byte and Bit addressability.
- Binary or Decimal arithmetic.
- Signed-overflow detection and parity computation.
- Hardware Multiple and Divide in 4 μsec.
- Integrated Boolean Processor for control applications.
- Upwardly compatible with existing 8048 software.

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All three devices come in a standard 40-pin Dual In-Line Package, with the same pin-out, the same timing, and the same electrical characteristics. The primary difference between the three is the on-chip program memory—different types are offered to satisfy differing user requirements.

The 8751 provides 4K bytes of ultraviolet-Erasable, Programmable Read Only Memory (EPROM) for program development, prototyping, and limited production runs. (By convention, 1K means $2^{10} = 1024$. 1k—with a lower case "k"—equals $10^3 = 1000$.) This part may be individually programmed for a specific application using Intel's Universal PROM Programmer (UPP). If software bugs are detected or design specifications change the same part may be "erased" in a matter of minutes by exposure to ultraviolet light and reprogrammed with the modified code. This cycle may be repeated indefinitely during the design and development phase.

The final version of the software must be programmed into a large number of production parts. The 8051 has 4K bytes of ROM which are mask-programmed with the customer's order when the chip is built. This part is considerably less expensive, but cannot be erased or altered after fabrication.

The 8031 does not have any program memory on-chip, but may be used with up to 64K bytes of external standard or multiplexed ROMs, PROMs, or EPROMs. The 8031 fits well in applications requiring significantly larger or smaller amounts of memory than the 4K bytes provided by its two siblings.

(The 8051 and 8751 automatically access external program memory for all addresses greater than the 4096 bytes on-chip. The External Access input is an override for all internal program memory—the 8051 and 8751 will each emulate an 8031 when pin 31 is low.)

Throughout this Note, "8051" is used as a generic term. Unless specifically stated otherwise, the point applies equally to all three components. Table 1 summarizes the quantitative differences between the members of the MCS-48™ and MCS-51™ families.

The remainder of this Note discusses the various MCS-51™ features and how they can be used. Software and/or hardware application examples illustrate many of the concepts. Several isolated tasks (rather than one complete system design example) are presented in the hope that some of them will apply to the reader's experiences or needs.

A document this short cannot detail all of a computer system's capabilities. By no means will all the 8051 instructions be demonstrated; the intent is to stress new or unique MCS-51™ operations and instructions generally used in conjunction with each other. For additional hardware information refer to the Intel **MCS-51™ Family User's Manual,** publication number 121517. The assembly language and use of ASM51, the MCS-51™ assembler, are further described in the **MCS-51™ Macro Assembler User's Guide,** publication number 9800937.

The next section reviews some of the basic concepts of microcomputer design and use. Readers familiar with the 8048 may wish to skim through this section or skip directly to the next, "ARCHITECTURE AND ORGANIZATION."

2

Microcomputer Background Concepts

Most digital computers use the binary (base 2) number system internally. All variables, constants, alphanumeric characters, program statements, etc., are represented by groups of binary digits ("bits"), each of which has the value 0 or 1. Computers are classified by how many bits they can move or process at a time.

The MCS-51™ microcomputers contain an eight-bit central processing unit (CPU). Most operations process variables eight bits wide. All internal RAM and ROM, and virtually all other registers are also eight bits wide. An eight-bit ("byte") variable (shown in Figure 2) may assume one of $2^8 = 256$ distinct values, which usually represent integers between 0 and 255. Other types of numbers, instructions, and so forth are represented by one or more bytes using certain conventions.

For example, to represent positive and negative values, the most significant bit (D7) indicates the sign of the other seven bits—0 if positive, 1 if negative—allowing integer variables between −128 and +127. For integers with extremely large magnitudes, several bytes are manipulated together as "multiple precision" signed or unsigned integers—16, 24, or more bits wide.

Table 1. Features of Intel's Single-Chip Microcomputers

EPROM Program Memory	ROM Program Memory	External Program Memory	Program Memory (Int/Max)	Data Memory (Bytes)	Instr. Cycle Time	Input/ Output Pins	Interrupt Sources	Reg. Banks
—	8021	—	1K 1K	64	8.4 μSec	21	0	1
—	8022	—	2K 2K	64	8.4 μSec	28	2	1
8748	8048	8035	1K 4K	64	2.5 μSec	27	2	2
—	8049	8039	2K 4K	128	1.36 μSec	27	2	2
8751	8051	8031	4K 64K	128	1.0 μSec	32	5	4

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The letters "MCS" have traditionally indicated a system or family of compatible Intel® microcomputer components, including CPUs, memories, clock generators, I/O expanders, and so forth. The numerical suffix indicates the microprocessor or microcomputer which serves as the cornerstone of the family. Microcomputers in the MCS-48™ family currently include the 8048-series (8035, 8048, & 8748), the 8049-series (8039 & 8049), and the 8021 and 8022; the family also includes the 8243, an I/O expander compatible with each of the microcomputers. Each computer's CPU is derived from the 8048, with essentially the same architecture, addressing modes, and instruction set, and a single assembler (ASM48) serves each.

The first members of the MCS-51™ family are the 8051, 8751, and 8031. The architecture of the 8051-series, while derived from the 8048, is not strictly compatible; there are more addressing modes, more instructions, larger address spaces, and a few other hardware differences. In this Application Note the letters "MCS-51" are used when referring to *architectural* features of the 8051-series—features which would be included on possible future microcomputers based on the 8051 CPU. Such products could have different amounts of memory (as in the 8048/8049) or different peripheral functions (as in the 8021 and 8022) while leaving the CPU and instruction set intact. ASM51 is the assembler used by all microcomputers in the 8051 family.

Two digit decimal numbers may be "packed" in an eight-bit value, using four bits for the binary code of each digit. This is called Binary-Coded Decimal (BCD) representation, and is often used internally in programs which interact heavily with human beings.

Alphanumeric characters (letters, numbers, punctuation marks, etc.) are often represented using the American Standard Code for Information Interchange (ASCII) convention. Each character is associated with a unique seven-bit binary number. Thus one byte may represent a single character, and a word or sequence of letters may be represented by a series (or "string") of bytes. Since the ASCII code only uses 128 characters, the most significant bit of the byte is not needed to distinguish between characters. Often D7 is set to 0 for all characters. In some coding schemes, D7 is used to indicate the "parity" of the other seven bits—set or cleared as necessary to ensure that the total number of "1" bits in the eight-bit code is even ("even parity") or odd ("odd parity"). The 8051 includes hardware to compute parity when it is needed.

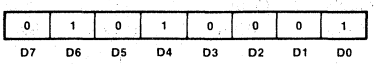

Figure 2. Representation of Bits Within an Eight-Bit "Byte" (Value shown = 01010001 Binary = 81 decimal).

A computer program consists of an ordered sequence of specific, simple steps to be executed by the CPU one-at-a-time. The method or sequence of steps used collectively to solve the user's application is called an "algorithm."

The program is stored inside the computer as a sequence of binary numbers, where each number corresponds to one of the basic operations ("opcodes") which the CPU is capable of executing. In the 8051, each program memory location is one byte. A complete instruction consists of a sequence of one or more bytes, where the first defines the operation to be executed and additional bytes (if needed) hold additional information, such as data values or variable addresses. No instruction is longer than three bytes.

The way in which binary opcodes and modifier bytes are assigned to the CPU's operations is called the computer's "machine language." Writing a program directly in machine language is time-consuming and tedious. Human beings think in words and concepts rather than encoded numbers, so each CPU operation and resource is given a name and standard abbreviation ("mnemonic"). Programs are more easily discussed using these standard mnemonics, or "assembly language," and may be typed into an Intel® Intellec® 800 or Series II® microcomputer development system in this form. The development system can mechanically translate the program from assembly language "source" form to machine language "object" code using a program called an "assembler." The MCS-51™ assembler is called ASM51.

There are several important differences between a computer's machine language and the assembly language used as a tool to represent it. The machine language or instruction set is the set of operations which the CPU can perform while a program is executing ("at run-time"), and is strictly determined by the microcomputer hardware design.

The assembly language is a standard (though more-or-less arbitrary) set of symbols including the instruction set mnemonics, but with additional features which further simplify the program design process. For example, ASM51 has controls for creating and formatting a program listing, and a number of directives for allocating variable storage and inserting arbitrary bytes of data into the object code for creating tables of constants.

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In addition, ASM51 can perform sophisticated mathematical operations, computing addresses or evaluating arithmetic expressions to relieve the programmer from this drudgery. However, these calculations can only use information known at "assembly time."

For example, the 8051 performs arithmetic calculations at run-time, eight bits at a time. ASM51 can do similar operations 16 bits at a time. The 8051 can only do one simple step per instruction, while ASM51 can perform complex calculations in each line of source code. However, the operations performed by the assembler may only use parameter values fixed at assembly-time, not variables whose values are unknown until program execution begins.

For example, when the assembly language source line,

```
ADD     A,#(LOOP_COUNT + 1) * 3
```

is *assembled*, ASM51 will find the value of the previously-defined constant "LOOP_COUNT" in an internal symbol table, increment the value, multiply the sum by three, and (assuming it is between -256 and 255 inclusive) truncate the product to eight bits. When this instruction is *executed*, the 8051 ALU will just add that resulting constant to the accumulator.

Some similar differences exist to distinguish number system ("radix") specifications. The 8051 does all computations in binary (though there are provisions for then converting the result to decimal form). In the course of writing a program, though, it may be more convenient to specify constants using some other radix, such as base 10. On other occasions, it is desirable to specify the ASCII code for some character or string of characters without refering to tables. ASM51 allows several representations for constants, which are converted to binary as each instruction is assembled.

For example, binary numbers are represented in the assembly language by a series of ones and zeros (naturally), followed by the letter "B" (for Binary); octal numbers as a series of octal digits (0-7) followed by the letter "O" (for Octal) or "Q" (which doesn't stand for anything, but *looks* sort of like an "O" and is less likely to be confused with a zero).

Hexadecimal numbers are represented by a series of hexadecimal digits (0-9,A-F), followed by (you guessed it) the letter "H." A "hex" number must begin with a decimal digit; otherwise it would look like a user-defined symbol (to be discussed later). A "dummy" leading zero may be inserted before the first digit to meet this constraint. The character string "BACH" could be a legal label for a Baroque music synthesis routine; the string "0BACH" is the hexadecimal constant BAC_{16}. This is a case where adding 0 makes a big difference.

Decimal numbers are represented by a sequence of decimal digits, optionally followed by a "D." If a number has no suffix, it is assumed to be decimal—so it had better not contain any non-decimal digits. "0BAC" is not a legal representation for anything.

When an ASCII code is needed in a program, enclose the desired character between two apostrophes (as in '#') and the assembler will convert it to the appropriate code (in this case 23H). A string of characters between apostrophes is translated into a series of constants; 'BACH' becomes 42H, 41H, 43H, 48H.

These same conventions are used throughout the associated Intel documentation. Table 2 illustrates some of the different number formats.

2. ARCHITECTURE AND ORGANIZATION

Figure 3 blocks out the MCS-51™ internal organization. Each microcomputer combines a Central Processing Unit, two kinds of memory (data RAM plus program ROM or EPROM), Input/Output ports, and the mode,

Table 2. Notations Used to Represent Numbers

Bit Pattern	Binary	Octal	Hexa-Decimal	Decimal	Signed Decimal
0 0 0 0 0 0 0 0	0B	0Q	00H	0	0
0 0 0 0 0 0 0 1	1B	1Q	01H	1	+1
.....	..	...	...	..	....
0 0 0 0 0 1 1 1	111B	7Q	07H	7	+7
0 0 0 0 1 0 0 0	1000B	10Q	08H	8	+8
0 0 0 0 1 0 0 1	1001B	11Q	09H	9	+9
0 0 0 0 1 0 1 0	1010B	12Q	0AH	10	+10
.....	..	...	...	..	....
0 0 0 0 1 1 1 1	1111B	17Q	0FH	15	+15
0 0 0 1 0 0 0 0	10000B	20Q	10H	16	+16
.....	..	...	...	..	....
0 1 1 1 1 1 1 1	1111111B	177Q	7FH	127	+127
1 0 0 0 0 0 0 0	10000000B	200Q	80H	128	-128
1 0 0 0 0 0 0 1	10000001B	201Q	81H	129	-127
.....	.....	...	...	...	....
1 1 1 1 1 1 1 0	11111110B	376Q	0FEH	254	-2
1 1 1 1 1 1 1 1	11111111B	377Q	0FFH	255	-1

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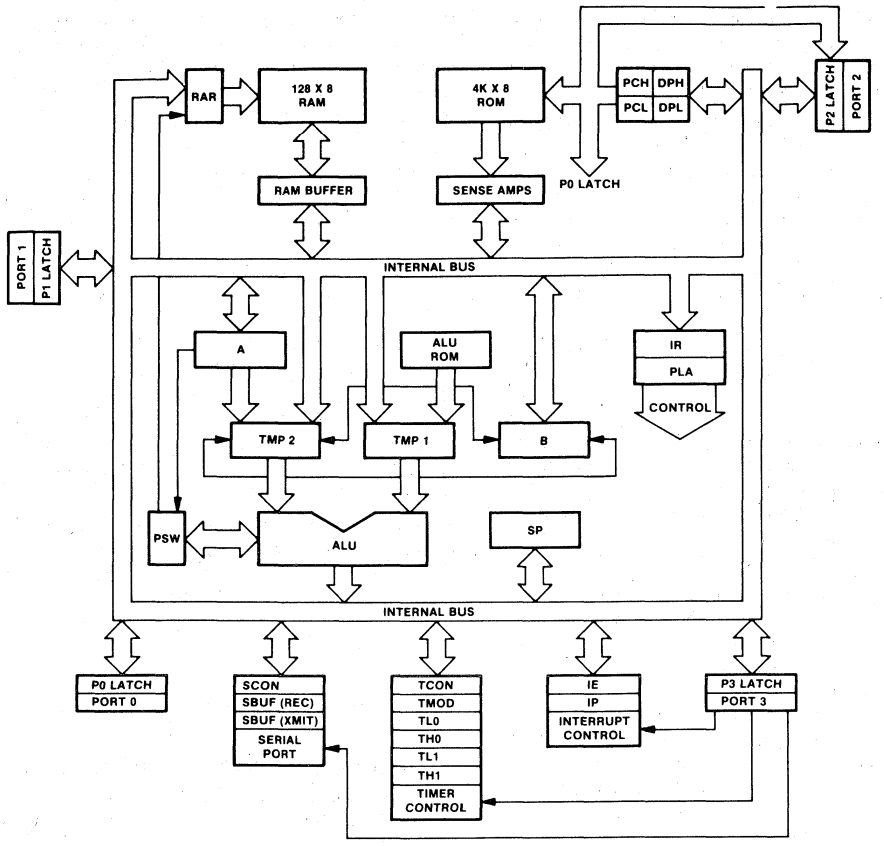


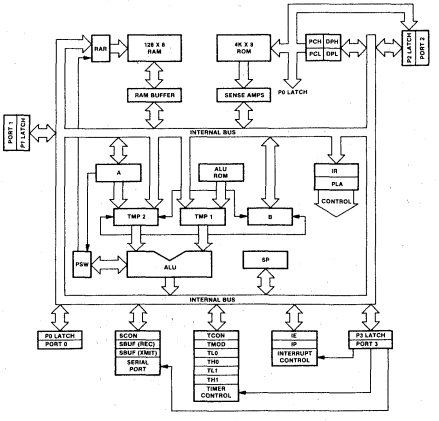
Figure 3. Block Diagram of 8051 Internal Structure

status, and data registers and random logic needed for a variety of peripheral functions. These elements communicate through an eight-bit data bus which runs throughout the chip, somewhat akin to indoor plumbing. This bus is buffered to the outside world through an I/O port when memory or I/O expansion is desired.

Let's summarize what each block does; later chapters dig into the CPU's instruction set and the peripheral registers in much greater detail.

Central Processing Unit

The CPU is the "brains" of the microcomputer, reading the user's program and executing the instructions stored therein. Its primary elements are an eight-bit Arithmetic/Logic Unit with associated registers A, B, PSW, and SP, and the sixteen-bit Program Counter and "Data Pointer" registers.



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Arithmetic Logic Unit

The ALU can perform (as the name implies) arithmetic and logic functions on eight-bit variables. The former include basic addition, subtraction, multiplication, and division; the latter include the logical operations AND, OR, and Exclusive-OR, as well as rotate, clear, complement, and so forth. The ALU also makes conditional branching decisions, and provides data paths and temporary registers used for data transfers within the system. Other instructions are built up from these primitive functions: the addition capability can increment registers or automatically compute program destination addresses; subtraction is also used in decrementing or comparing the magnitude of two variables.

These primitive operations are automatically cascaded and combined with dedicated logic to build complex instructions such as incrementing a sixteen-bit register pair. To execute one form of the compare instruction, for example, the 8051 increments the program counter three times, reads three bytes of program memory, computes a register address with logical operations, reads internal data memory twice, makes an arithmetic comparison of two variables, computes a sixteen-bit destination address, and decides whether or not to make a branch—all in two microseconds!

An important and unique feature of the MCS-51 architecture is that the ALU can also manipulate one-bit as well as eight-bit data types. Individual bits may be set, cleared, or complemented, moved, tested, and used in logic computations. While support for a more primitive data type may initially seem a step backwards in an era of increasing word length, it makes the 8051 especially well suited for controller-type applications. Such algorithms *inherently* involve Boolean (true/false) input and output variables, which were heretofore difficult to implement with standard microprocessors. These features are collectively referred to as the MCS-51™ "Boolean Processor," and are described in the so-named chapter to come.

Thanks to this powerful ALU, the 8051 instruction set fares well at both real-time control and data intensive algorithms. A total of 51 separate operations move and manipulate three data types: Boolean (1-bit), byte (8-bit), and address (16-bit). All told, there are eleven addressing modes—seven for data, four for program sequence control (though only eight are used by more than just a few specialized instructions). Most operations allow several addressing modes, bringing the total number of instructions (operation/addressing mode combinations) to 111, encompassing 255 of the 256 possible eight-bit instruction opcodes.

Instruction Set Overview

Table 4 lists these 111 instructions classified into five groups:

- Arithmetic Operations
- Logical Operations for Byte Variables
- Data Transfer Instructions
- Boolean Variable Manipulation
- Program Branching and Machine Control

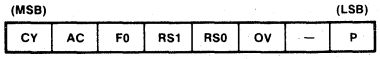
MCS-48™ programmers perusing Table 4 will notice the absence of special categories for Input/Output, Timer/Counter, or Control instructions. These functions are all still provided (and indeed many new functions are added), but as special cases of more generalized operations in other categories. To explicitly list all the useful instructions involving I/O and peripheral registers would require a table approximately four times as long.

Observant readers will also notice that all of the 8048's page-oriented instructions (conditional jumps, JMPP, MOVP, MOVP3) have been replaced with corresponding but non-paged instructions. The 8051 instruction set is entirely *non*-page-oriented. The MCS-48™ "MOVP" instruction replacement and all conditional jump instructions operate relative to the program counter, with the actual jump address computed by the CPU during instruction execution. The "MOVP3" and "JMPP" replacements are now made relative to another sixteen-bit register, which allows the effective destination to be anywhere in the program memory space, regardless of where the instruction itself is located. There are even three-byte jump and call instructions allowing the destination to be *anywhere* in the 64K program address space.

The instruction set is designed to make programs efficient both in terms of code size and execution speed. No instruction requires more than three bytes of program memory, with the majority requiring only one or two bytes. Virtually all instructions execute in either one or two instruction cycles—one or two microseconds with a 12-MHz crystal—with the sole exceptions (multiply and divide) completing in four cycles.

Many instructions such as arithmetic and logical functions or program control, provide both a short and a long form for the same operation, allowing the programmer to optimize the code produced for a specific application. The 8051 usually fetches two instruction bytes per instruction cycle, so using a shorter form can lead to faster execution as well.

For example, any byte of RAM may be loaded with a constant with a three-byte, two-cycle instruction, but the commonly used "working registers" in RAM may be initialized in one cycle with a two-byte form. Any bit anywhere on the chip may be set, cleared, or complemented by a single three-byte logical instruction using two cycles. But critical control bits, I/O pins, and software flags may be controlled by two-byte, single cycle instructions. While three-byte jumps and calls can "go anywhere" in program memory, nearby sections of code may be reached by shorter relative or absolute versions.



Symbol	Position	Name and Significance
CY	PSW.7	Carry flag. Set/cleared by hardware or software during certain arithmetic and logical instructions.
AC	PSW.6	Auxiliary Carry flag. Set/cleared by hardware during addition or subtraction instructions to indicate carry or borrow out of bit 3.
F0	PSW.5	Flag 0 Set/cleared/tested by software as a user-defined status flag.
RS1	PSW.4	Register bank Select control bits 1 & 0. Set/cleared by software to determine working register bank (see Note).
RS	PSW.3	
OV	PSW.2	Overflow flag. Set/cleared by hardware during arithmetic instructions to indicate overflow conditions.
–	PSW.1	(reserved)
P	PSW.0	Parity flag. Set/cleared by hardware each instruction cycle to indicate an odd/even number of "one" bits in the accumulator, i.e., even parity.

Note— the contents of (RS1, RS0) enable the working register banks as follows:

(0,0) – Bank 0 (00H-07H)
(0,1) – Bank 1 (08H-0FH)
(1,0) – Bank 2 (10H-17H)
(1,1) – Bank 3 (18H-1FH)

Figure 4. PSW—Program Status Word Organization

A significant side benefit of an instruction set more powerful than those of previous single-chip microcomputers is that it is easier to generate applications-oriented software. Generalized addressing modes for byte and bit instructions reduce the number of source code lines written and debugged for a given application. This leads in turn to proportionately lower software costs, greater reliability, and faster design cycles.

Accumulator and PSW

The 8051, like its 8048 predecessor, is primarily an accumulator-based architecture: an eight-bit register called the accumulator ("A") holds a source operand and receives the result of the arithmetic instructions (addition, subtraction, multiplication, and division). The accumulator can be the source or destination for logical operations and a number of special data movement instructions, including table look-ups and external RAM expansion. Several functions apply exclusively to the accumulator: rotates, parity computation, testing for zero, and so on.

Many instructions implicitly or explicitly affect (or are affected by) several status flags, which are grouped together to form the Program Status Word shown in Figure 4.

(The period within entries under the Position column is called the "dot operator," and indicates a particular bit position within an eight-bit byte. "PSW.5" specifies bit 5 of the PSW. Both the documentation and ASM51 use this notation.)

The most "active" status bit is called the carry flag (abbreviated "C"). This bit makes possible multiple precision arithmetic operations including addition, subtraction, and rotates. The carry also serves as a "Boolean accumulator" for one-bit logical operations and bit manipulation instructions. The overflow flag (OV) detects when arithmetic overflow occurs on signed integer operands, making two's complement arithmetic possible. The parity flag (P) is updated after every instruction cycle with the even-parity of the accumulator contents.

The CPU does not control the two register-bank select bits, RS1 and RS0. Rather, they are manipulated by software to enable one of the four register banks. The usage of the PSW flags is demonstrated in the Instruction Set chapter of this Note.

Even though the architecture is accumulator-based, provisions have been made to bypass the accumulator in common instruction situations. Data may be moved from any location on-chip to any register, address, or indirect address (and vice versa), any register may be loaded with a constant, etc., all without affecting the accumulator. Logical operations may be performed against registers or variables to alter fields of bits—without using or affecting the accumulator. Variables may be incremented, decremented, or tested without using the accumulator. Flags and control bits may be manipulated and tested without affecting anything else.

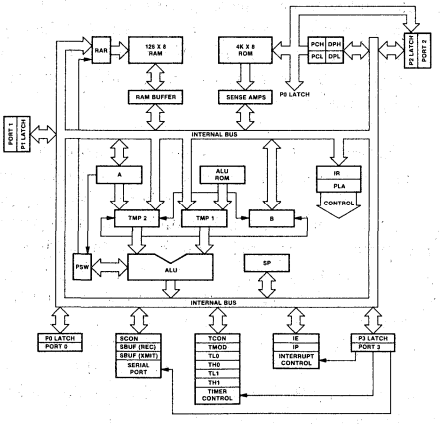
Other CPU Registers

A special eight-bit register ("B") serves in the execution of the multiply and divide instructions. This register is used in conjunction with the accumulator as the second input operand and to return eight-bits of the result.

The MCS-51 family processors include a hardware stack within internal RAM, useful for subroutine linkage,

passing parameters between routines, temporary variable storage, or saving status during interrupt service routines. The Stack Pointer (SP) is an eight-bit pointer register which indicates the address of the last byte pushed onto the stack. The stack pointer is automatically incremented or decremented on all push or pop instructions and all subroutine calls and returns. In theory, the stack in the 8051 may be up to a full 128 bytes deep. (In practice, even simple programs would use a handful of RAM locations for pointers, variables, and so forth—reducing the stack depth by that number.) The stack pointer defaults to 7 on reset, so that the stack will start growing up from location 8, just like in the 8048. By altering the pointer contents the stack may be relocated anywhere within internal RAM.

Finally, a 16-bit register called the data pointer (DPTR) serves as a base register in indirect jumps, table look-up instructions, and external data transfers. The high- and low-order halves of the data pointer may be manipulated as separate registers (DPH and DPL, respectively) or together using special instructions to load or increment all sixteen bits. Unlike the 8048, look-up tables can therefore start anywhere in program memory and be of arbitrary length.



Memory Spaces

Program memory is separate and distinct from data memory. Each memory type has a different addressing mechanism, different control signals, and a different function.

The program memory array (ROM or EPROM), like an elephant, is extremely large and never forgets information, even when power is removed. Program memory is used for information needed each time power is applied: initialization values, calibration constants, keyboard layout tables, etc., as well as the program itself. The program memory has a sixteen-bit address bus; its elements are addressed using the Program Counter or instructions which generate a sixteen-bit address.

To stretch our analogy just a bit, data memory is like a mouse: it is smaller and therefore quicker than program memory, and it goes into a random state when electrical power is applied. On-chip data RAM is used for variables which are determined or may change while the program is running.

A computer spends most of its time manipulating variables, not constants, and a relatively small number of variables at that. Since eight-bits is more than sufficient to uniquely address 128 RAM locations, the on-chip RAM address register is only one byte wide. In contrast to the program memory, data memory accesses need a single eight-bit value—a constant or another variable—to specify a unique location. Since this is the basic width of the ALU and the different memory types, those resources can be used by the addressing mechanisms, contributing greatly to the computer's operating efficiency.

The partitioning of program and data memory is extended to off-chip memory expansion. Each may be added independently, and each uses the same address and data busses, but with different control signals. External program memory is gated onto the external data bus by the $\overline{\text{PSEN}}$ (Program Store Enable) control output, pin 29. External data memory is read onto the bus by the $\overline{\text{RD}}$ output, pin 17, and written with data supplied from the microcomputer by the $\overline{\text{WR}}$ output, pin 16. (There is no control pin to write external program ROM, which is by definition Read Only.) While both types may be expanded to up to 64K bytes, the external data memory may optionally be expanded in 256 byte "pages" to preserve the use of P2 as an I/O port. This is useful with a relatively small expansion RAM (such as the Intel® 8155) or for addressing external peripherals.

Single-chip controller programs are finalized during the project design cycle, and are not modified after production. Intel's single-chip microcomputers are not "von Neumann" architectures common among main-frame and mini-computer systems: the MCS-51™ processor *data* memory—on-chip and external—may *not* be used for program code. Just as there is no write-control signal for program memory, there is no way for the CPU to execute instructions out of RAM. In return, this concession allows an architecture optimized for efficient controller applications: a large, fixed program located in ROM, a hundred or so variables in RAM, and different methods for efficiently addressing each.

(Von Neumann machines are helpful for software development and debug. An 8051 system could be modified to have a single off-chip memory space by gating together the two memory-read controls ($\overline{\text{PSEN}}$ and $\overline{\text{RD}}$) with a two-input AND gate (Figure 5). The CPU could then write data into the common memory array using $\overline{\text{WR}}$ and

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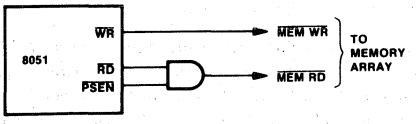


Figure 5. Combining External Program and Data Memory Arrays

external data transfer instructions, and read instructions or data with the AND gate output and data transfer or program memory look-up instructions.)

In addition to the memory arrays, there is (yet) another (albeit sparsely populated) physical address space. Connected to the internal data bus are a score of special-purpose eight-bit registers scattered throughout the chip. Some of these—B, SP, PSW, DPH, and DPL—have been discussed above. Others—I/O ports and peripheral function registers—will be introduced in the following sections. Collectively, these registers are designated as the "special-function register" address space. Even the accumulator is assigned a spot in the special-function register address space for additional flexibility and uniformity.

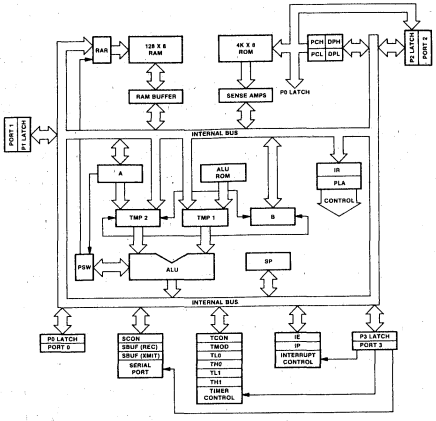
Thus, the MCS-51™ architecture supports several distinct "physical" address spaces, functionally separated at the hardware level by different addressing mechanisms, read and write control signals, or both:

- On-chip program memory;
- On-chip data memory;
- Off-chip program memory;
- Off-chip data memory;
- On-chip special-function registers.

What the *programmer sees,* though, are "logical" address spaces. For example, as far as the programmer is concerned, there is only one type of program memory, 64K bytes in length. The fact that it is formed by combining on- and off-chip arrays (split 4K/60K on the 8051 and 8751) is "invisible" to the programmer; the CPU automatically fetches each byte from the appropriate array, based on its address.

(Presumably, future microcomputers based on the MCS-51™ architecture may have a different physical split, with more or less of the 64K total implemented on-chip. Using the MCS-48™ family as a precedent, the 8048's 4K potential program address space was split 1K/3K between on- and off-chip arrays; the 8049's was split 2K/2K.)

Why go into such tedious details about address spaces? The logical addressing modes are described in the Instruction Set chapter in terms of physical address spaces. Understanding their differences now will pay off in understanding and using the chips later.



Input/Output Ports

The MCS-51™ I/O port structure is extremely versatile. The 8051 and 8751 each have 32 I/O pins configured as four eight-bit parallel ports (P0, P1, P2, and P3). Each pin will input or output data (or both) under software control, and each may be referenced by a wide repertoire of byte and bit operations.

In various operating or expansion modes, some of these I/O pins are also used for special input or output functions. Instructions which access external memory use Port 0 as a multiplexed address/data bus: at the beginning of an external memory cycle eight bits of the address are output on P0; later data is transferred on the same eight pins. External data transfer instructions which supply a sixteen-bit address, and any instruction accessing external program memory, output the high-order eight bits on P2 during the access cycle. (The 8031 *always* uses the pins of P0 and P2 for external addressing, but P1 and P3 are available for standard I/O.)

The eight pins of Port 3 (P3) each have a special function. Two external interrupts, two counter inputs, two serial data lines, and two timing control strobes use pins of P3 as described in Figure 6. Port 3 pins corresponding to functions not used are available for conventional I/O.

Even within a single port, I/O functions may be combined in many ways: input and output may be performed using different pins at the same time, or the same pins at different times; in parallel in some cases, and in serial in others; as test pins, or (in the case of Port 3) as additional special functions.

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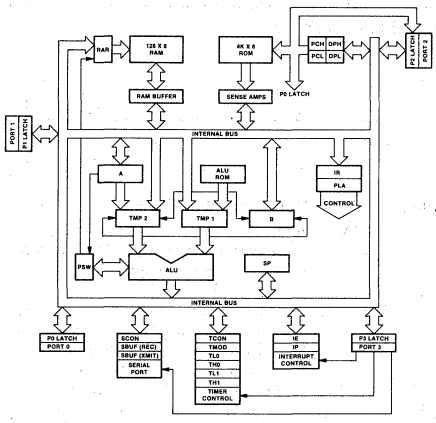
(MSB)							(LSB)
RD	WR	T1	T0	INT1	INT0	TXD	RXD

Symbol	Position	Name and Significance
RD	P3.7	Read data control output. Active low pulse generated by hardware when external data memory is read.
WR	P3.6	Write data control output. Active low pulse generated by hardware when external data memory is written.
T1	P3.5	Timer/counter 1 external input or test pin.
T0	P3.4	Timer/counter 0 external input or test pin.
INT1	P3.3	Interrupt 1 input pin. Low-level or falling-edge triggered.
INT0	P3.2	Interrupt 0 input pin. Low-level or falling-edge triggered.
TXD	P3.1	Transmit Data pin for serial port in UART mode. Clock output in shift register mode.
RXD	P3.0	Receive Data pin for serial port in UART mode. Data I/O pin in shift register mode.

Figure 6. P3—Alternate Special Functions of Port 3



Special Peripheral Functions

There are a few special needs common among control-oriented computer systems:

- keeping track of elapsed real-time;
- maintaining a count of signal transitions;
- measuring the precise width of input pulses;
- communicating with other systems or people;
- closely monitoring asynchronous external events.

Until now, microprocessor systems needed peripheral chips such as timer/counters, USARTs, or interrupt controllers to meet these needs. The 8051 integrates all of these capabilities on-chip!

Timer/Counters

There are two sixteen-bit multiple-mode Timer/Counters on the 8051, each consisting of a "High" byte (corresponding to the 8048 "T" register) and a low byte (similar to the 8048 prescaler, with the additional flexibility of being software-accessible). These registers are called, naturally enough, TH0, TL0, TH1, and TL1. Each pair may be independently software programmed to any of a dozen modes with a mode register designated TMOD (Figure 7), and controlled with register TCON (Figure 8).

The timer modes can be used to measure time intervals, determine pulse widths, or initiate events, with one-microsecond resolution, up to a maximum interval of 65,536 instruction cycles (over 65 milliseconds). Longer delays may easily be accumulated through software. Configured as a counter, the same hardware will accumulate external events at frequencies from D.C. to 500 KHz, with up to sixteen bits of precision.

Serial Port Interface

Each microcomputer contains a high-speed, full-duplex, serial port which is software programmable to function in four basic modes: shift-register I/O expander, 8-bit UART, 9-bit UART, or interprocessor communications link. The UART modes will interface with standard I/O devices (e.g. CRTs, teletypewriters, or modems) at data rates from 122 baud to 31 kilobaud. Replacing the standard 12 MHz crystal with a 10.7 MHz crystal allows 110 baud. Even or odd parity (if desired) can be included with simple bit-handling software routines. Inter-processor communications in distributed systems takes place at 187 kilobaud with hardware for automatic address/data message recognition. Simple TTL or CMOS shift registers provide low-cost I/O expansion at a super-fast 1 Megabaud. The serial port operating modes are controlled by the contents of register SCON (Figure 9).

Interrupt Capability and Control

(Interrupt capability is generally considered a CPU function. It is being introduced here since, from an applications point of view, interrupts relate more closely to peripheral and system interfacing.)

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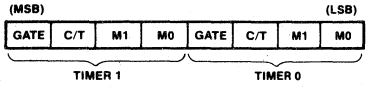
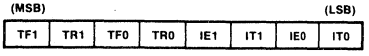


GATE — Gating control. When set, Timer/counter "x" is enabled only while "INTx" pin is high and "TRx" control bit is set. When cleared, timer/counter is enabled whenever "TRx" control bit is set.

C/T — Timer or Counter Selector. Cleared for Timer operation (input from internal system clock). Set for Counter operation (input from "Tx" input pin).

M1	M0	Operating Mode
0	0	MCS-48 Timer. "TLx" serves as five-bit prescaler.
0	1	16-bit timer/counter. "THx" and "TLx" are cascaded; there is no prescaler.
1	0	8-bit auto-reload timer counter. "THx" holds a value which is to be reloaded into "TLx" each time it overflows.
1	1	(Timer 0) TL0 is an eight-bit timer counter controlled by the standard Timer 0 control bits. TH0 is an eight-bit timer only controlled by Timer 1 control bits.
1	1	(Timer 1) Timer/counter 1 stopped.

Figure 7. TMOD—Timer/Counter Mode Register



Symbol	Position	Name and Significance
TF1	TCON.7	Timer 1 overflow Flag. Set by hardware on timer/counter overflow. Cleared when interrupt processed.
TR1	TCON.6	Timer 1 Run control bit. Set/cleared by software to turn timer/counter on/off.
TF0	TCON.5	Timer 0 overflow Flag. Set by hardware on timer/counter overflow. Cleared when interrupt processed.
TR0	TCON.4	Timer 0 Run control bit. Set/cleared by software to turn timer/counter on/off.
IE1	TCON.3	Interrupt 1 Edge flag. Set by hardware when external interrupt edge detected. Cleared when interrupt processed.
IT1	TCON.2	Interrupt 1 Type control bit. Set cleared by software to specify falling edge low level triggered external interrupts.
IE0	TCON.1	Interrupt 0 Edge flag. Set by hardware when external interrupt edge detected. Cleared when interrupt processed.
IT0	TCON.0	Interrupt 0 Type control bit. Set/cleared by software to specify falling edge low level triggered external interrupts.

Figure 8. TCON—Timer/Counter Control/Status Register

(MSB)							(LSB)
SM0	SM1	SM2	REN	TB8	RB8	TI	RI

Symbol	Position	Name and Significance
SM0	SCON.7	Serial port Mode control bit 0. Set/cleared by software (see note).
SM1	SCON.6	Serial port Mode control bit 1. Set/cleared by software (see note).
SM2	SCON.5	Serial port Mode control bit 2. Set by software to disable reception of frames for which bit 8 is zero.
REN	SCON.4	Receiver Enable control bit. Set/cleared by software to enable/disable serial data reception.
TB8	SCON.3	Transmit Bit 8. Set/cleared by hardware to determine state of ninth data bit transmitted in 9-bit UART mode.
RB8	SCON.2	Receive Bit 8. Set/cleared by hardware to indicate state of ninth data bit received.
TI	SCON.1	Transmit Interrupt flag. Set by hardware when byte transmitted. Cleared by software after servicing.
RI	SCON.0	Received Interrupt flag. Set by hardware when byte received. Cleared by software after servicing.

Note— the state of (SM0,SM1) selects:
(0,0)—Shift register I/O expansion.
(0,1)—8 bit UART, variable data rate.
(1,0)—9 bit UART, fixed data rate.
(1,1)—9 bit UART, variable data rate.

Figure 9. SCON—Serial Port Control/Status Register

These peripheral functions allow special hardware to monitor real-time signal interfacing without bothering the CPU. For example, imagine serial data is arriving from one CRT while being transmitted to another, and one timer/counter is tallying high-speed input transitions while the other measures input pulse widths. During all of this the CPU is thinking about something else.

But how does the CPU know when a reception, transmission, count, or pulse is finished? The 8051 programmer can choose from three approaches.

TCON and SCON contain status bits set by the hardware when a timer overflows or a serial port operation is completed. The first technique reads the control register into the accumulator, tests the appropriate bit, and does a conditional branch based on the result. This "polling" scheme (typically a three-instruction sequence though additional instructions to save and restore the accumulator may sometimes be needed) will surely be familiar to programmers used to multi-chip microcomputer systems and peripheral controller chips. This process is rather cumbersome, especially when monitoring multiple peripherals.

As a second approach, the 8051 can perform a conditional branch based on the state of any control or status bit or input pin in a single instruction; a four instruction sequence could poll the four simultaneous happenings mentioned above in just eight microseconds.

Unfortunately, the CPU must still drop what it's doing to test these bits. A manager cannot do his own work well if he is continuously monitoring his subordinates; they should interrupt him (or her) only when they need attention or guidance. So it is with machines: ideally, the CPU would not have to worry about the peripherals until they require servicing. At that time, it would postpone the background task long enough to handle the appropriate device, then return to the point where it left off.

This is the basis of the third and generally optimal solution, hardware interrupts. The 8051 has five interrupt sources: one from the serial port when a transmission or reception is complete, two from the timers when overflows occur, and two from input pins INT0 and INT1. Each source may be independently enabled or disabled to allow polling on some sources or at some times, and each may be classified as high or low priority. A high priority source can interrupt a low priority service routine; the manager's boss can interrupt conferences with subordinates. These options are selected by the interrupt enable and priority control registers, IE and IP (Figures 10 and 11).

Each source has a particular program memory address associated with it (Table 3), starting at 0003H (as in the 8048) and continuing at eight-byte intervals. When an event enabled for interrupts occurs the CPU automatically executes an internal subroutine call to the corresponding address. A user subroutine starting at this location (or jumped to from this location) then performs the instructions to service that particular source. After completing the interrupt service routine, execution returns to the background program.

Table 3. 8051 Interrupt Sources and Service Vectors

Interrupt Source	Service Routine Starting Address
(Reset)	0000H
External 0	0003H
Timer/Counter 0	000BH
External 1	0013H
Timer/Counter 1	001BH
Serial Port	0023H

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(MSB)							(LSB)
EA	–	–	ES	ET1	EX1	ET0	EX0

Symbol	Position	Name and Significance
EA	IE.7	Enable All control bit. Cleared by software to disable all interrupts, independent of the state of IE.4-IE.0.
—	IE.6	(reserved)
—	IE.5	(reserved)
ES	IE.4	Enable Serial port control bit. Set/cleared by software to enable disable interrupts from TI or RI flags.
ET1	IE.3	Enable Timer 1 control bit. Set/cleared by software to enable/disable interrupts from timer/counter 1.
EX1	IE.2	Enable External interrupt 1 control bit. Set cleared by software to enable disable interrupts from INT1.
ET0	IE.1	Enable Timer 0 control bit. Set cleared by software to enable disable interrupts from timer counter 0
EX0	IE.0	Enable External interrupt 0 control bit. Set cleared by software to enable disable interrupts from INT0.

Figure 10. IE—Interrupt Enable Register

(MSB)							(LSB)
–	–	-	PS	PT1	PX1	PT0	PX0

Symbol	Position	Name and Significance
—	IP.7	(reserved)
—	IP.6	(reserved)
—	IP.5	(reserved)
PS	IP.4	Serial port Priority control bit. Set/cleared by software to specify high/low priority interrupts for Serial port.
PT1	IP.3	Timer 1 Priority control bit. Set/cleared by software to specify high/low priority interrupts for timer/counter 1.
PX1	IP.2	External interrupt 1 Priority control bit. Set cleared by software to specify high low priority interrupts for INT1.
PT0	IP.1	Timer 0 Priority control bit. Set cleared by software to specify high low priority interrupts for timer counter 0.
PX0	IP.0	External interrupt 0 Priority control bit. Set cleared by software to specify high low priority interrupts for INT0.

Figure 11. IP—Interrupt Priority Control Register

Table 4. MCS-51™ Instruction Set Description

ARITHMETIC OPERATIONS

Mnemonic		Description	Byte	Cyc
ADD	A,Rn	Add register to Accumulator	1	1
ADD	A,direct	Add direct byte to Accumulator	2	1
ADD	A,@Ri	Add indirect RAM to Accumulator	1	1
ADD	A,#data	Add immediate data to Accumulator	2	1
ADDC	A,Rn	Add register to Accumulator with Carry	1	1
ADDC	A,direct	Add direct byte to A with Carry flag	2	1
ADDC	A,@Ri	Add indirect RAM to A with Carry flag	1	1
ADDC	A,#data	Add immediate data to A with Carry flag	2	1
SUBB	A,Rn	Subtract register from A with Borrow	1	1
SUBB	A,direct	Subtract direct byte from A with Borrow	2	1
SUBB	A,@Ri	Subtract indirect RAM from A w Borrow	1	1
SUBB	A,#data	Subtract immed. data from A w Borrow	2	1
INC	A	Increment Accumulator	1	1
INC	Rn	Increment register	1	1
INC	direct	Increment direct byte	2	1
INC	@Ri	Increment indirect RAM	1	1
DEC	A	Decrement Accumulator	1	1
DEC	Rn	Decrement register	1	1
DEC	direct	Decrement direct byte	2	1
DEC	@Ri	Decrement indirect RAM	1	1
INC	DPTR	Increment Data Pointer	1	2
MUL	AB	Multiply A & B	1	4
DIV	AB	Divide A by B	1	4
DA	A	Decimal Adjust Accumulator	1	1

LOGICAL OPERATIONS

Mnemonic		Destination	Byte	Cyc
ANL	A,Rn	AND register to Accumulator	1	1
ANL	A,direct	AND direct byte to Accumulator	2	1
ANL	A,@Ri	AND indirect RAM to Accumulator	1	1
ANL	A,#data	AND immediate data to Accumulator	2	1
ANL	direct,A	AND Accumulator to direct byte	2	1
ANL	direct,#data	AND immediate data to direct byte	3	2
ORL	A,Rn	OR register to Accumulator	1	1
ORL	A,direct	OR direct byte to Accumulator	2	1
ORL	A,@Ri	OR indirect RAM to Accumulator	1	1
ORL	A,#data	OR immediate data to Accumulator	2	1
ORL	direct,A	OR Accumulator to direct byte	2	1
ORL	direct,#data	OR immediate data to direct byte	3	2
XRL	A,Rn	Exclusive-OR register to Accumulator	1	1
XRL	A,direct	Exclusive-OR direct byte to Accumulator	2	1
XRL	A,@Ri	Exclusive-OR indirect RAM to A	1	1
XRL	A,#data	Exclusive-OR immediate data to A	2	1
XRL	direct,A	Exclusive-OR Accumulator to direct byte	2	1
XRL	direct,#data	Exclusive-OR immediate data to direct	3	2
CLR	A	Clear Accumulator	1	1
CPL	A	Complement Accumulator	1	1
RL	A	Rotate Accumulator Left	1	1
RLC	A	Rotate A Left through the Carry flag	1	1
RR	A	Rotate Accumulator Right	1	1
RRC	A	Rotate A Right through Carry flag	1	1
SWAP	A	Swap nibbles within the Accumulator	1	1

DATA TRANSFER

Mnemonic		Description	Byte	Cyc
MOV	A,Rn	Move register to Accumulator	1	1
MOV	A,direct	Move direct byte to Accumulator	2	1
MOV	A,@Ri	Move indirect RAM to Accumulator	1	1
MOV	A,#data	Move immediate data to Accumulator	2	1
MOV	Rn,A	Move Accumulator to register	1	1
MOV	Rn,direct	Move direct byte to register	2	2
MOV	Rn,#data	Move immediate data to register	2	1
MOV	direct,A	Move Accumulator to direct byte	2	1
MOV	direct,Rn	Move register to direct byte	2	2
MOV	direct,direct	Move direct byte to direct	3	2
MOV	direct,@Ri	Move indirect RAM to direct byte	2	2
MOV	direct,#data	Move immediate data to direct byte	3	2
MOV	@Ri,A	Move Accumulator to indirect RAM	1	1
MOV	@Ri,direct	Move direct byte to indirect RAM	2	2
MOV	@Ri,#data	Move immediate data to indirect RAM	2	1
MOV	DPTR,#data16	Load Data Pointer with a 16-bit constant	3	2

DATA TRANSFER (cont.)

Mnemonic		Description	Byte	Cyc
MOVC	A,@A+DPTR	Move Code byte relative to DPTR to A	1	2
MOVC	A,@A+PC	Move Code byte relative to PC to A	1	2
MOVX	A,@Ri	Move External RAM (8-bit addr) to A	1	2
MOVX	A,@DPTR	Move External RAM (16-bit addr) to A	1	2
MOVX	@Ri,A	Move A to External RAM (8-bit addr)	1	2
MOVX	@DPTR,A	Move A to External RAM (16-bit addr)	1	2
PUSH	direct	Push direct byte onto stack	2	2
POP	direct	Pop direct byte from stack	2	2
XCH	A,Rn	Exchange register with Accumulator	1	1
XCH	A,direct	Exchange direct byte with Accumulator	2	1
XCH	A,@Ri	Exchange indirect RAM with A	1	1
XCHD	A,@Ri	Exchange low-order Digit ind. RAM w A	1	1

BOOLEAN VARIABLE MANIPULATION

Mnemonic		Description	Byte	Cyc
CLR	C	Clear Carry flag	1	1
CLR	bit	Clear direct bit	2	1
SETB	C	Set Carry flag	1	1
SETB	bit	Set direct Bit	2	1
CPL	C	Complement Carry flag	1	1
CPL	bit	Complement direct bit	2	1
ANL	C,bit	AND direct bit to Carry flag	2	2
ANL	C, bit	AND complement of direct bit to Carry	2	2
ORL	C,bit	OR direct bit to Carry flag	2	2
ORL	C, bit	OR complement of direct bit to Carry	2	2
MOV	C,bit	Move direct bit to Carry flag	2	1
MOV	bit,C	Move Carry flag to direct bit	2	2

PROGRAM AND MACHINE CONTROL

Mnemonic		Description	Byte	Cyc
ACALL	addr11	Absolute Subroutine Call	2	2
LCALL	addr16	Long Subroutine Call	3	2
RET		Return from subroutine	1	2
RETI		Return from interrupt	1	2
AJMP	addr11	Absolute Jump	2	2
LJMP	addr16	Long Jump	3	2
SJMP	rel	Short Jump (relative addr)	2	2
JMP	@A+DPTR	Jump indirect relative to the DPTR	1	2
JZ	rel	Jump if Accumulator is Zero	2	2
JNZ	rel	Jump if Accumulator is Not Zero	2	2
JC	rel	Jump if Carry flag is set	2	2
JNC	rel	Jump if No Carry flag	2	2
JB	bit,rel	Jump if direct Bit set	3	2
JNB	bit,rel	Jump if direct Bit Not set	3	2
JBC	bit,rel	Jump if direct Bit is set & Clear bit	3	2
CJNE	A,direct,rel	Compare direct to A & Jump if Not Equal	3	2
CJNE	A,#data,rel	Comp. immed. to A & Jump if Not Equal	3	2
CJNE	Rn,#data,rel	Comp. immed. to reg. & Jump if Not Equal	3	2
CJNE	@Ri,#data,rel	Comp. immed. to ind. & Jump if Not Equal	3	2
DJNZ	Rn,rel	Decrement register & Jump if Not Zero	2	2
DJNZ	direct,rel	Decrement direct & Jump if Not Zero	3	2
NOP		No operation	1	1

Notes on data addressing modes:

Rn	Working register R0-R7
direct	128 internal RAM locations, any I/O port, control or status register
@Ri	Indirect internal RAM location addressed by register R0 or R1
#data	8-bit constant included in instruction
#data16	16-bit constant included as bytes 2 & 3 of instruction
bit	128 software flags, any I/O pin, control or status bit

Notes on program addressing modes:

addr16	Destination address for LCALL & LJMP may be anywhere within the 64-Kilobyte program memory address space.
addr11	Destination address for ACALL & AJMP will be within the same 2-Kilobyte page of program memory as the first byte of the following instruction.
rel	SJMP and all conditional jumps include an 8-bit offset byte. Range is +127 -128 bytes relative to first byte of the following instruction.

3. INSTRUCTION SET AND ADDRESSING MODES

The 8051 instruction set is extremely regular, in the sense that most instructions can operate with variables from several different physical or logical address spaces. Before getting deeply enmeshed in the instruction set proper, it is important to understand the details of the most common data addressing modes. Whereas Table 4 summarizes the instructions set broken down by functional group, this chapter starts with the addressing mode classes and builds to include the related instructions.

Data Addressing Modes

MCS-51 assembly language instructions consist of an operation mnemonic and zero to three operands separated by commas. In two operand instructions the destination is specified first, then the source. Many byte-wide data

operations (such as ADD or MOV) inherently use the accumulator as a source operand and/or to receive the result. For the sake of clarity the letter "A" is specified in the source or destination field in all such instructions. For example, the instruction,

ADD A,<source>

will add the variable<source>to the accumulator, leaving the sum in the accumulator.

The operand designated "<source>" above may use any of four common logical addressing modes:

- Register—one of the working registers in the currently enabled bank.
- Direct—an internal RAM location, I/O port, or special-function register.
- Register-indirect—an internal RAM location, pointed to by a working register.
- Immediate data—an eight-bit constant incorporated into the instruction.

The first three modes provide access to the internal RAM and Hardware Register address spaces, and may therefore be used as source or destination operands; the last mode accesses program memory and may be a source operand only.

(It is hard to show a "typical application" of any instruction without involving instructions not yet described. The following descriptions use only the self-explanatory ADD and MOV instructions to demonstrate how the four addressing modes are specified and used. Subsequent examples will become increasingly complex.)

Register Addressing

The 8051 programmer has access to eight "working registers," numbered R0-R7. The least-significant three-bits of the instruction opcode indicate one register within this logical address space. Thus, a function code and operand address can be combined to form a short (one byte) instruction (Figure 12.a).

The 8051 assembly language indicates register addressing with the symbol Rn (where n is from 0 to 7) or with a symbolic name previously defined as a register by the EQUate or SET directives. (For more information on assembler directives see the Macro Assembler Reference Manual.)

Example 1—Adding Two Registers Together

```
;REGADR ADD CONTENTS OF REGISTER 1
;       TO CONTENTS OF REGISTER 0
;
REGADR: MOV     A,R0
        ADD     A,R1
        MOV     R0,A
```

There are four such banks of working registers, only one of which is active at a time. Physically, they occupy the first 32 bytes of on-chip data RAM (addresses 0-1FH). PSW bits 4 and 3 determine which bank is active. A hardware reset enables register bank 0; to select a different bank the programmer modifies PSW bits 4 and 3 accordingly.

Example 2—Selecting Alternate Memory Banks

```
        MOV     PSW.#00010000B  ;SELECT BANK 2
```

Register addressing in the 8051 is the same as in the 8048 family, with two enhancements: there are four banks rather than one or two, and 16 instructions (rather than 12) can access them.

Direct Byte Addressing

Direct addressing can access any on-chip variable or hardware register. An additional byte appended to the opcode specifies the location to be used (Figure 12.b).

Depending on the highest order bit of the direct address byte, one of two physical memory spaces is selected. When the direct address is between 0 and 127 (00H-7FH) one of the 128 low-order on-chip RAM locations is used. (Future microcomputers based on the MCS-51™ architecture may incorporate more than 128 bytes of on-chip RAM. Even if this is the case, only the low-order 128 bytes will be directly addressable. The remainder would be accessed indirectly or via the stack pointer.)

Example 3—Adding RAM Location Contents

```
;DIRADR ADD CONTENTS OF RAM LOCATION 41H
;       TO CONTENTS OF RAM LOCATION 40H
;
DIRADR: MOV     A,40H
        ADD     A,41H
        MOV     40H,A
```

All I/O ports and special function, control, or status registers are assigned addresses between 128 and 255 (80H-0FFH). When the direct address byte is between these limits the corresponding hardware register is accessed. For example, Ports 0 and 1 are assigned direct addresses 80H and 90H, respectively. A complete list is presented in Table 5. Don't waste your time trying to memorize the addresses in Table 5. Since programs using absolute addresses for function registers would be difficult to write or understand, ASM51 allows and understands the abbreviations listed instead.

Example 4—Adding Input Port Data to Output Port Data

```
;PRTADR ADD DATA INPUT ON PORT 1
;       TO DATA PREVIOUSLY OUTPUT
;       ON PORT 0
;
PRTADR: MOV     A,P0
        ADD     A,P1
        MOV     P0,A
```

Direct addressing allows all special-function registers in the 8051 to be read, written, or used as instruction operands. In general, this is the *only* method used for accessing I/O ports and special-function registers. If direct addressing is used with special-function register addresses other than those listed, the result of the instruction is undefined.

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The 8048 does not have or need any generalized direct addressing mode, since there are only five special registers (BUS, P1, P2, PSW, & T) rather than twenty. Instead, 16 special 8048 opcodes control output bits or read or write each register to the accumulator. These functions are all subsumed by four of the 27 direct addressing instructions of the 8051.

Table 5. 8051 Hardware Register Direct Addresses

Register	Address	Function
P0	80H*	Port 0
SP	81H	Stack Pointer
DPL	82H	Data Pointer (Low)
DPH	83H	Data Pointer (High)
TCON	88H*	Timer register
TMOD	89H	Timer Mode register
TL0	8AH	Timer 0 Low byte
TL1	8BH	Timer 1 Low byte
TH0	8CH	Timer 0 High byte
TH1	8DH	Timer 1 High byte
P1	90H*	Port 1
SCON	98H*	Serial Port Control register
SBUF	99H	Serial Port data Buffer
P2	0A0H*	Port 2
IE	0A8H*	Interrupt Enable register
P3	0B0H*	Port 3
IP	0B8H*	Interrupt Priority register
PSW	0D0H*	Program Status Word
ACC	0E0H*	Accumulator (direct address)
B	0F0H*	B register

* = bit addressable register.

Register-Indirect Addressing

How can you handle variables whose locations in RAM are determined, computed, or modified while the program is running? This situation arises when manipulating sequential memory locations, indexed entries within tables in RAM, and multiple precision or string operations. Register or Direct addressing cannot be used, since their operand addresses are fixed at assembly time.

The 8051 solution is "register-indirect RAM addressing." R0 and R1 of each register bank may operate as index or pointer registers, their contents indicating an address into RAM. The internal RAM location so addressed is the actual operand used. The least significant bit of the instruction opcode determines which register is used as the "pointer" (Figure 12.c).

In the 8051 assembly language, register-indirect addressing is represented by a commercial "at" sign ("@") preceding R0, R1, or a symbol defined by the user to be equal to R0 or R1.

Example 5—Indirect Addressing

```
;INDADR ADD CONTENTS OF MEMORY LOCATION
;       ADDRESSED BY REGISTER 1
;       TO CONTENTS OF RAM LOCATION
;       ADDRESSED BY REGISTER 0
;
INDADR  MOV     A,@R0
        ADD     A,@R1
        MOV     @R0,A
```

Indirect addressing on the 8051 is the same as in the 8048 family, except that all eight bits of the pointer register contents are significant; if the contents point to a non-existent memory location (i.e., an address greater than 7FH on the 8051) the result of the instruction is undefined. (Future microcomputers based on the MCS-51™ architecture could implement additional memory in the on-chip RAM logical address space at locations above 7FH.) The 8051 uses register-indirect addressing for five new instructions plus the 13 on the 8048.

Immediate Addressing

When a source operand is a constant rather than a variable (i.e.—the instruction uses a value known at assembly time), then the constant can be incorporated into the instruction. An additional instruction byte specifies the value used (Figure 12.d).

The value used is fixed at the time of ROM manufacture or EPROM programming and may not be altered during program execution. In the assembly language immediate operands are preceded by a number sign ("#"). The operand may be either a numeric string, a symbolic variable, or an arithmetic expression using constants.

Example 6—Adding Constants Using Immediate Addressing

```
;IMMADR ADD THE CONSTANT 12 (DECIMAL)
;       TO THE CONSTANT 34 (DECIMAL)
;       LEAVE SUM IN ACCUMULATOR.
;
IMMADR  MOV     A,#12
        ADD     A,#34
```

The preceding example was included for consistency; it has little practical value. Instead, ASM51 could compute the sum of two constants at assembly time.

Example 7—Adding Constants Using ASM51 Capabilities

```
;ASMSUM LOAD ACC WITH THE SUM OF
;       THE CONSTANT 12 (DECIMAL) AND
;       THE CONSTANT 34 (DECIMAL).
;
ASMSUM  MOV     A,#(12+34)
```

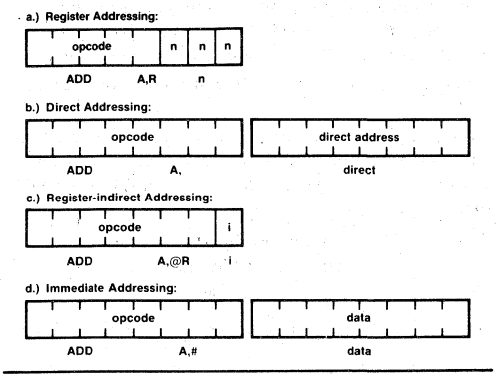

Figure 12. Data Addressing Machine Code Formats

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Addressing Mode Combinations

The above examples all demonstrated the use of the four data-addressing modes in two-operand instructions (MOV, ADD) which use the accumulator as one operand. The operations ADDC, SUBB, ANL, ORL, and XRL (all to be discussed later) could be substituted for ADD in each example. The first three modes may be also be used for the XCH operation or, in combination with the Immediate Addressing mode (and an additional byte), loaded with a constant. The one-operand instructions INC and DEC, DJNZ, and CJNE may all operate on the accumulator, or may specify the Register, Direct, and Register-indirect addressing modes. Exception: as in the 8048, DJNZ cannot use the accumulator or indirect addressing. (The PUSH and POP operations cannot inherently address the accumulator as a special register either. However, all three can *directly* address the accumulator as one of the twenty special-function registers by putting the symbol "ACC" in the operand field.)

Advantages of Symbolic Addressing

Like most assembly or higher-level programming languages, ASM51 allows instructions or variables to be given appropriate, user-defined symbolic names. This is done for instruction lines by putting a label followed by a colon (":") before the instruction proper, as in the above examples. Such symbols must start with an alphabetic character (remember what distinguished BACH from 0BACH?), and may include any combination of letters, numbers, question marks ("?") and underscores ("_"). For **very** long names only the first 31 characters are relevant.

Assembly language programs may intermix upper- and lower-case letters arbitrarily, but ASM51 converts both to upper-case. For example, ASM51 will internally process an "I" for an "i" and, of course, "A_TOOTH" for "a_tooth."

The underscore character makes symbols easier to read and can eliminate potential ambiguity (as in the label for a subroutine to switch two entires on a stack, "S_EXCHANGE"). The underscore is significant, and would distinguish between otherwise-identical character strings.

ASM51 allows *all* variables (registers, ports, internal or external RAM addresses, constants, etc.) to be assigned labels according to these rules with the EQUate or SET directives.

Example 8 — Symbolic Addressing of Variables Defined as RAM Locations

```
VAR_0   SET     20H
VAR_1   SET     21H
;
;SYMB_1 ADD CONTENTS OF VAR_1
;       TO CONTENTS OF VAR_0
;
SYMB_1  MOV     A,VAR_0
        ADD     A,VAR_1
        MOV     VAR_0,A
```

Notice from Table 4 that the MCS-51™ instruction set has relatively few instruction mnemonics (abbreviations) for the programmer to memorize. Different data types or addressing modes are determined by the operands specified, rather than variations on the mnemonic. For example, the mnemonic "MOV" is used by 18 different instructions to operate on three data types (bit, byte, and address). The fifteen versions which move byte variables between the logical address spaces are diagrammed in Figure 13. Each arrow shows the direction of transfer from source to destination.

Notice also that for most instructions allowing register addressing there is a corresponding direct addressing instruction and vice versa. This lets the programmer begin writing 8051 programs as if (s)he has access to 128 different registers. When the program has evolved to the point where the programmer has a fairly accurate idea how often each variable is used, he she may allocate the working registers in each bank to the most "popular" variables. (The assembly cross-reference option will show exactly how often and where each symbol is referenced.) If symbolic addressing is used in writing the source program only the lines containing the symbol definition will need to be changed; the assembler will produce the appropriate instructions even though the rest of the program is left untouched. Editing only the first two lines of Example 8 will shrink the six-byte code segment produced in half.

How are instruction sets "counted"? There is no standard practice; different people assessing the same CPU using different conventions may arrive at different totals.

Each operation is then broken down according to the different addressing modes (or combinations of addressing modes) it can accommodate. The "CLR" mnemonic is used by two instructions with respect to bit variables ("CLR C" and "CLR bit") and once ("CLR A") with regards to bytes. This expansion yields the 111 separate instructions of Table 4.

The method used for the MCS-51® instruction set first breaks it down into "operations": a basic function applied to a single data type. For example, the four versions of the ADD instruction are grouped to form one operation — addition of eight-bit variables. The six forms of the ANL instruction for *byte* variables make up a different operation; the two forms of ANL which operate on *bits* are considered still another. The MOV mnemonic is used by three different operation classes, depending on whether bit, byte, or 16-bit values are affected. Using this terminology the 8051 can perform 51 different operations.

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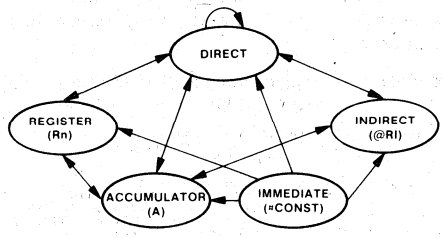

Figure 13. Road map for moving data bytes

Example 9—Redeclaring Example 8 Symbols as Registers

```
VAR_0   SET     R0
VAR_1   SET     R1
;
;SYMB_2 ADD CONTENTS OF VAR_1
;       TO CONTENTS OF VAR_0
;
SYMB_2: MOV     A,VAR_0
        ADD     A,VAR_1
        MOV     VAR_0,A
```

Arithmetic Instruction Usage — ADD, ADDC, SUBB and DA

The ADD instruction adds a byte variable with the accumulator, leaving the result in the accumulator. The carry flag is set if there is an overflow from bit 7 and cleared otherwise. The AC flag is set to the carry-out from bit 3 for use by the DA instruction described later. ADDC adds the previous contents of the carry flag with the two byte variables, but otherwise is the same as ADD.

The SUBB (subtract with borrow) instruction subtracts the byte variable indicated and the contents of the carry flag together from the accumulator, and puts the result back in the accumulator. The carry flag serves as a "Borrow Required" flag during subtraction operations; when a greater value is subtracted from a lesser value (as in subtracting 5 from 1) requiring a borrow into the highest order bit, the carry flag is set; otherwise it is cleared.

When performing signed binary arithmetic, certain combinations of input variables can produce results which seem to violate the Laws of Mathematics. For example, adding 7FH (127) to itself produces a sum of 0FEH, which is the two's complement representation of -2 (refer back to Table 2)! In "normal" arithmetic, two positive values can't have a negative sum. Similarly, it is normally impossible to subtract a positive value from a negative value and leave a positive result — but in two's complement there are instances where this too may happen. Fundamentally, such anomolies occur when the magnitude of the resulting value is too great to "fit" into the seven bits allowed for it; there is no one-byte two's complement representation for 254, the true sum of 127 and 127.

The MCS-51™ processors detect whether these situations occur and indicate such errors with the OV flag. (OV may be tested with the conditional jump instructions JB and JNB, described under the Boolean Processor chapter.)

At a hardware level, OV is set if there is a carry out of bit 6 but not out of bit 7, or a carry out of bit 7 but not out of bit 6. When adding signed integers this indicates a negative number produced as the sum of two positive operands, or a positive sum from two negative operands; on SUBB this indicates a negative result after subtracting a negative number from a positive number, or a positive result when a positive number is subtracted from a negative number.

The ADDC and SUBB instructions incorporate the previous state of the carry (borrow) flag to allow multiple precision calculations by repeating the operation with successively higher-order operand bytes. In either case, the carry must be cleared before the first iteration.

If the input data for a multiple precision operation is an unsigned string of integers, upon completion the carry flag will be set if an overflow (for ADDC) or underflow (for SUBB) occurs. With two's complement signed data (i.e., if the most significant bit of the original input data indicates the sign of the string), the overflow flag will be set if overflow or underflow occurred.

Example 10—String Subtraction with Signed Overflow Detection

```
;SUBSTR SUBTRACT STRING INDICATED BY R1
;       FROM STRING INDICATED BY R0 TO
;       PRECISION INDICATED BY R2.
;       CHECK FOR SIGNED UNDERFLOW WHEN DONE.
;
SUBSTR: CLR     C           ;BORROW= 0
SUBS1:  MOV     A,@R0
        SUBB    A,@R1       ;SUBTRACT NEXT PLACE
        MOV     @R0,A
        INC     R0          ;BUMP POINTERS
        INC     R1
        DJNZ    R2,SUBS1            ;LOOP AS NEEDED
;               WHEN DONE, TEST IF OVERFLOW OCCURED
;               ON LAST ITERATION OF LOOP
        JNB     OV,OV_OK
;                           (OVERFLOW RECOVERY ROUTINE)
OV_OK:  RET                 ;RETURN
```

Decimal addition is possible by using the DA instruction in conjunction with ADD and/or ADDC. The eight-bit binary value in the accumulator resulting from an earlier addition of two variables (each a packed BCD digit-pair) is adjusted to form two BCD digits of four bits each. If the contents of accumulator bits 3-0 are greater than nine (xxxx1010-xxxx1111), or if the AC flag had been set, six is added to the accumulator producing the proper BCD digit in the low-order nibble. (This addition might itself set — but would not clear — the carry flag.) If the carry flag is set, or if the four high-order bits now exceed nine (1010xxxx-1111xxxx), these bits are incremented by six. The carry flag is left set if originally set or if either addition of six produces a carry out of the highest-order bit, indicating the sum of the original two BCD variables is greater than or equal to decimal 100.

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Example 11 — Two Byte Decimal Add with Registers and Constants

```
;BCDADD ADD THE CONSTANT 1,234 (DECIMAL) TO THE
;       CONTENTS OF REGISTER PAIR <R3><R2>
;       (ALREADY A 4 BCD-DIGIT VARIABLE)
;
BCDADD  MOV     A,R2
        ADD     A,#34H
        DA      A
        MOV     R2,A
        MOV     A,R3
        ADDC    A,#12H
        DA      A
        MOV     R3,A
        RET
```

Multiplication and Division

The instruction "MUL AB" multiplies the unsigned eight-bit integer values held in the accumulator and B-registers. The low-order byte of the sixteen-bit product is left in the accumulator, the higher-order byte in B. If the high-order eight-bits of the product are all zero the overflow flag is cleared; otherwise it is set. The programmer can poll OV to determine when the B register is non-zero and must be processed.

"DIV AB" divides the unsigned eight-bit integer in the accumulator by the unsigned eight-bit integer in the B-register. The integer part of the quotient is returned in the accumulator; the remainder in the B-register. If the B-register originally contained 00H then the overflow flag will be set to indicate a division error, and the values returned will be undefined. Otherwise OV is cleared.

The divide instruction is also useful for purposes such as radix conversion or separating bit fields of the accumulator. A short subroutine can convert an eight-bit unsigned binary integer in the accumulator (between 0 & 255) to a three-digit (two byte) BCD representation. The hundred's digit is returned in one register (HUND) and the ten's and one's digits returned as packed BCD in another (TENONE).

Example 12 — Use of DIV Instruction for Radix Conversion

```
;BINBCD CONVERT 8-BIT BINARY VARIABLE IN ACC
;       TO 3-DIGIT PACKED BCD FORMAT
;       HUNDREDS' PLACE LEFT IN VARIABLE 'HUND',
;       TENS' AND ONES' PLACES IN 'TENONE'.
;
HUND    EQU     21H
TENONE  EQU     22H
;
BINBCD  MOV     B,#100  ;DIVIDE BY 100 TO
        DIV     AB      ;DETERMINE NUMBER OF HUNDREDS
        MOV     HUND,A
        MOV     A,#10   ;DIVIDE REMAINDER BY 10 TO
        XCH     A,B     ;DETERMINE # OF TENS LEFT
        DIV     AB      ;TENS DIGIT IN ACC, REMAINDER IS ONES
                        ;DIGIT
        SWAP    A
        ADD     A,B     ;PACK BCD DIGITS IN ACC
        MOV     TENONE,A
        RET
```

The divide instruction can also separate eight bits of data in the accumulator into sub-fields. For example, packed BCD data may be separated into two nibbles by dividing the data by 16, leaving the high-nibble in the accumulator and the low-order nibble (remainder) in B. The two digits may then be operated on individually or in conjunction with each other. This example receives two packed BCD digits in the accumulator and returns the product of the two individual digits in packed BCD format in the accumulator.

Example 13 — Implementing a BCD Multiply Using MPY and DIV

```
;MULBCD UNPACK TWO BCD DIGITS RECEIVED IN ACC,
;       FIND THEIR PRODUCT, AND RETURN PRODUCT
;       IN PACKED BCD FORMAT IN ACC
;
MULBCD  MOV     B,#10H  ;DIVIDE INPUT BY 16
        DIV     AB      ;A & B HOLD SEPARATED DIGITS
                        ;(EACH RIGHT JUSTIFIED IN REGISTER)
        MUL     AB      ;A HOLDS PRODUCT IN BINARY FORMAT (0 -
                        ;99(DECIMAL) = 0 - 63H)
        MOV     B,#10   ;DIVIDE PRODUCT BY 10
        DIV     AB      ;A HOLDS # OF TENS, B HOLDS REMAINDER
        SWAP    A
        ORL     A,B     ;PACK DIGITS
        RET
```

Logical Byte Operations — ANL, ORL, XRL

The instructions ANL, ORL, and XRL perform the logical functions AND, OR, and/or Exclusive-OR on the two byte variables indicated, leaving the results in the first. No flags are affected. (A word to the wise — do not vocalize the first two mnemonics in mixed company.)

These operations may use all the same addressing modes as the arithmetics (ADD, etc.) but unlike the arithmetics, they are not restricted to operating on the accumulator. Directly addressed bytes may be used as the destination with either the accumulator or a constant as the source. These instructions are useful for clearing (ANL), setting (ORL), or complementing (XRL) one or more bits in a RAM, output ports, or control registers. The pattern of bits to be affected is indicated by a suitable mask byte. Use immediate addressing when the pattern to be affected is known at assembly time (Figure 14); use the accumulator versions when the pattern is computed at run-time.

I/O ports are often used for parallel data in formats other than simple eight-bit bytes. For example, the low-order five bits of port 1 may output an alphabetic character code (hopefully) without disturbing bits 7-5. This can be a simple two-step process. First, clear the low-order five pins with an ANL instruction; then set those pins corresponding to ones in the accumulator. (This example assumes the three high-order bits of the accumulator are originally zero.)

Example 14 — Reconfiguring Port Size with Logical Byte Instructions

```
OUT_PX: ANL   P1,#11100000B ;CLEAR BITS P1.4 - P1.0
        ORL   P1,A          ;SET P1 PINS CORRESONDING TO SET ACC
                            ; BITS.
        RET
```

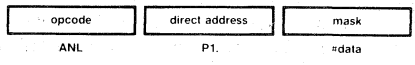

Figure 14. Instruction Pattern for Logical Operation Special Addressing Modes

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In this example, low-order bits remaining high may "glitch" low for one machine cycle. If this is undesirable, use a slightly different approach. First, set all pins corresponding to accumulator one bits, then clear the pins corresponding to zeroes in low-order accumulator bits. Not all bits will change from original to final state at the same instant, but no bit makes an intermediate transition.

Example 15 — Reconfiguring I/O Port Size without Glitching

```
ALT_PX: ORL     P1,A
        ORL     A,#11100000B
        ANL     P1,A
        RET
```

Program Control — Jumps, Calls, Returns

Whereas the 8048 only has a single form of the simple jump instruction, the 8051 has three. Each causes the program to unconditionally jump to some other address. They differ in how the machine code represents the destination address.

LJMP (Long Jump) encodes a sixteen-bit address in the second and third instruction bytes (Figure 15.a); the destination may be anywhere in the 64 Kilobyte program memory address space.

The two-byte AJMP (Absolute Jump) instruction encodes its destination using the same format as the 8048: address bits 10 through 8 form a three bit field in the opcode and address bits 7 through 0 form the second byte (Figure 15.b). Address bits 15-12 are unchanged from the (incremented) contents of the P.C., so AJMP can only be used when the destination is known to be within the same 2K memory block. (Otherwise ASM51 will point out the error.)

A different two-byte jump instruction is legal with any nearby destination, regardless of memory block boundaries or "pages." SJMP (Short Jump) encodes the destination with a program counter-relative address in the second byte (Figure 15.c). The CPU calculates the destination at run-time by adding the signed eight-bit displacement value to the incremented P.C. Negative offset values will cause jumps up to 128 bytes backwards; positive values up to 127 bytes forwards. (SJMP with 00H in the machine code offset byte will proceed with the following instruction).

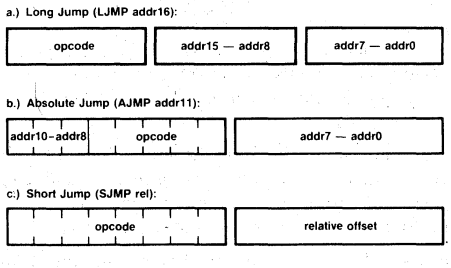

Figure 15. Jump Instruction Machine Code Formats

In keeping with the 8051 assembly language goal of minimizing the number of instruction mnemonics, there is a "generic" form of the three jump instructions. ASM51 recognizes the mnemonic JMP as a "pseudo-instruction," translating it into the machine instructions LJMP, AJMP, or SJMP, depending on the destination address.

Like SJMP, all conditional jump instructions use relative addressing. JZ (Jump if Zero) and JNZ (Jump if Not Zero) monitor the state of the accumulator as implied by their names, while JC (Jump on Carry) and JNC (Jump on No Carry) test whether or not the carry flag is set. All four are two-byte instructions, with the same format as Figure 15.c. JB (Jump on Bit), JNB (Jump on No Bit) and JBC (Jump on Bit then Clear Bit) can test any status bit or input pin with a three byte instruction; the second byte specifies which bit to test and the third gives the relative offset value.

There are two subroutine-call instructions, LCALL (Long Call) and ACALL (Absolute Call). Each increments the P.C. to the first byte of the following instruction, then pushes it onto the stack (low byte first). Saving both bytes increments the stack pointer by two. The subroutine's starting address is encoded in the same ways as LJMP and AJMP. The generic form of the call operation is the mnemonic CALL, which ASM51 will translate into LCALL or ACALL as appropriate.

The return instruction RET pops the high- and low-order bytes of the program counter successively from the stack, decrementing the stack pointer by two. Program execution continues at the address previously pushed; the first byte of the instruction immediately following the call.

When an interrupt request is recognized by the 8051 hardware, two things happen. Program control is automatically "vectored" to one of the interrupt service routine starting addresses by, in effect, forcing the CPU to process an LCALL instead of the next instruction. This automatically stores the return address on the stack. (Unlike the 8048, no status information is automatically saved.)

Secondly, the interrupt logic is disabled from accepting any other interrupts from the same or lower priority. After completing the interrupt service routine, executing an RETI (Return from Interrupt) instruction will return execution to the point where the background program was interrupted — just like RET — while restoring the interrupt logic to its previous state.

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Operate-and-branch instructions — CJNE, DJNZ

Two groups of instructions combine a byte operation with a conditional jump based on the results.

CJNE (Compare and Jump if Not Equal) compares two byte operands and executes a jump if they disagree. The carry flag is set following the rules for subtraction: if the unsigned integer value of the first operand is less than that of the second it is set; otherwise, it is cleared. However, neither operand is modified.

The CJNE instruction provides, in effect, a one-instruction "case" statement. This instruction may be executed repeatedly, comparing the code variable to a list of "special case" value: the code segment following the instruction (up to the destination label) will be executed only if the operands match. Comparing the accumulator or a register to a series of constants is a convenient way to check for special handling or error conditions; if none of the cases match the program will continue with "normal" processing.

A typical example might be a word processing device which receives ASCII characters through the serial port and drives a thermal hard-copy printer. A standard routine translates "printing" characters to bit patterns, but control characters (<DEL>, <CR>, <LF>, <BEL>, <ESC> or <SP>) must invoke corresponding special routines. Any other character with an ASCII code less than 20H should be translated into the <NUL> value, 00H, and processed with the printing characters.

Example 16 — Case Statements Using CJNE

```
CHAR    EQU     R7          ;CHARACTER CODE VARIABLE
;
INTERP: CJNE    CHAR,#7FH,INTP_1
;                           (SPECIAL ROUTINE FOR RUBOUT CODE)
        RET
INTP_1: CJNE    CHAR,#07H,INTP_2
;                           (SPECIAL ROUTINE FOR BELL CODE)
        RET
INTP_2: CJNE    CHAR,#0AH,INTP_3
;                           (SPECIAL ROUTINE FOR LFEED CODE)
        RET
INTP_3: CJNE    CHAR,#0DH,INTP_4
;                           (SPECIAL ROUTINE FOR RETURN CODE)
        RET
INTP_4: CJNE    CHAR,#1BH,INTP_5
;                           (SPECIAL ROUTINE FOR ESCAPE CODE)
        RET
INTP_5: CJNE    CHAR,#20H,INTP_6
;                           (SPECIAL ROUTINE FOR SPACE CODE)
        RET
INTP_6: JC      PRINTC      ;JUMP IF CODE > 20H
        MOV     CHAR,#0     ;REPLACE CONTROL CHARACTERS WITH
                            ;  NULL CODE
PRINTC:                     ;PROCESS STANDARD PRINTING
;                           ;  CHARACTER
        RET
```

DJNZ (Decrement and Jump if Not Zero) decrements the register or direct address indicated and jumps if the result is not zero, without affecting any flags. This provides a simple means for executing a program loop a given number of times, or for adding a moderate time delay (from 2 to 512 machine cycles) with a single instruction. For example, a 99-usec. software delay loop can be added to code forcing an I/O pin low with only two instructions.

Example 17 — Inserting a Software Delay with DJNZ

```
        CLR     WR
        MOV     R2,#49
        DJNZ    R2,$
        SETB    WR
```

The dollar sign in this example is a special character meaning "the address of this instruction." It is useful in eliminating instruction labels on the same or adjacent source lines. CJNE and DJNZ (like all conditional jumps) use program-counter relative addressing for the destination address.

Stack Operations — PUSH, POP

The PUSH instruction increments the stack pointer by one, then transfers the contents of the single byte variable indicated (direct addressing only) into the internal RAM location addressed by the stack pointer. Conversely, POP copies the contents of the internal RAM location addressed by the stack pointer to the byte variable indicated, then decrements the stack pointer by one.

(Stack Addressing follows the same rules, and addresses the same locations as Register-indirect. Future microcomputers based on the MCS-51™ CPU could have up to 256 bytes of RAM for the stack.)

Interrupt service routines must not change any variable or hardware registers modified by the main program, or else the program may not resume correctly. (Such a change might look like a spontaneous random error.) Resources used or altered by the service routine (Accumulator, PSW, etc.) must be saved and restored to their previous value before returning from the service routine. PUSH and POP provide an efficient and convenient way to save register states on the stack.

Example 18 — Use of the Stack for Status Saving on Interrupts

```
LOC_TMP EQU             ;REMEMBER LOCATION COUNTER
;
        ORG     0003H   ;STARTING ADDRESS FOR INTERRUPT ROUTINE
        LJMP    SERVER  ;JUMP TO ACTUAL SERVICE ROUTINE LOCATED
                        ;  ELSEWHERE
;
        ORG     LOC_TMP ;RESTORE LOCATION COUNTER
SERVER  PUSH    PSW
        PUSH    ACC     ;SAVE ACCUMULATOR (NOTE DIRECT ADDRESSING
                        ;  NOTATION)
        PUSH    B       ;SAVE B REGISTER
        PUSH    DPL     ;SAVE DATA POINTER
        PUSH    DPH
        MOV     PSW,#00001000B  ;SELECT REGISTER BANK 1
;
;
        POP     DPH     ;RESTORE REGISTERS IN REVERSE ORDER
        POP     DPL
        POP     B
        POP     ACC
        POP     PSW     ;RESTORE PSW AND RE-SELECT ORIGINAL
                        ;  REGISTER BANK
        RETI            ;RETURN TO MAIN PROGRAM AND RESTORE
                        ;  INTERRUPT LOGIC
```

If the SP register held 1FH when the interrupt was detected, then while the service routine was in progress the stack would hold the registers shown in Figure 16; SP would contain 26H.

The example shows the most general situation; if the service routine doesn't alter the B-register and data pointer, for example, the instructions saving and restoring those registers would not be necessary.

The stack may also pass parameters to and from subroutines. The subroutine can indirectly address the parameters derived from the contents of the stack pointer.

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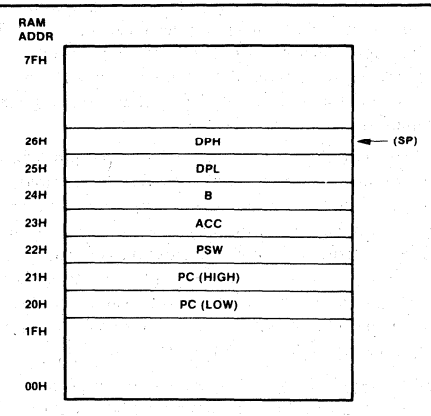

Figure 16. Stack contents during interrupt

One advantage here is simplicity. Variables need not be allocated for specific parameters, a potentially large number of parameters may be passed, and different calling programs may use different techniques for determining or handling the variables.

For example, the following subroutine reads out a parameter stored on the stack by the calling program, uses the low order bits to access a local look-up table holding bit patterns for driving the coils of a four phase stepper motor, and stores the appropriate bit pattern back in the same position on the stack before returning. The accumulator contents are left unchanged.

Example 19—Passing Variable Parameters to Subroutines Using the Stack

```
NXTPOS: MOV     R0, SP
        DEC     R0          ;ACCESS LOCATION PARAMETER PUSHED INTO
        DEC     R0
        XCH     A, @R0      ;READ INPUT PARAMETER AND SAVE
                            ; ACCUMULATOR
        ANL     A, #03H     ;MASK ALL BUT LOW-ORDER TWO BITS
        ADD     A, #2       ;ALLOW FOR OFFSET FROM MOVC TO TABLE
        MOVC    A, @A+PC    ;READ LOOK-UP TABLE ENTRY
        XCH     A, @R0      ;PASS BACK TRANSLATED VALUE AND RESTORE
                            ; ACC
        RET                 ;RETURN TO BACKGROUND PROGRAM
STPTBL: DB      01101111B           ;POSITION 0
        DB      01011111B           ;POSITION 1
        DB      10011111B           ;POSITION 2
        DB      10101111B           ;POSITION 3
```

The background program may reach this subroutine with several different calling sequences, all of which PUSH a value before calling the routine and POP the result after. A motor on Port 1 may be initialized by placing the desired position (zero) on the stack before calling the subroutine and outputing the results directly to a port afterwards.

Example 20—Sending and Receiving Data Parameters Via the Stack

```
        CLR     A
        PUSH    ACC
        CALL    NXTPOS
        POP     P1
```

If the position of the motor is determined by the contents of variable POSM1 (a byte in internal RAM) and the position of a second motor on Port 2 is determined by the data input to the low-order nibble of Port 2, a six-instruction sequence could update them both.

Example 21—Loading and Unloading Stack Direct from I/O Ports

```
POSM1   EQU     51

        PUSH    POSM1
        CALL    NXTPOS
        POP     P1
        PUSH    P2
        CALL    NXTPOS
        POP     P2
```

Data Pointer and Table Look-up instructions — MOV, INC, MOVC, JMP

The data pointer can be loaded with a 16-bit value using the instruction MOV DPTR, #data16. The data used is stored in the second and third instruction bytes, high-order byte first. The data pointer is incremented by INC DPTR. A 16-bit increment is performed; an overflow from the low byte will carry into the high-order byte. Neither instruction affects any flags.

The MOVC (Move Constant) instructions (MOVC A,@A+DPTR and MOVC A,@A+PC) read into the accumulator bytes of data from the program memory logical address space. Both use a form of indexed addressing: the former adds the unsigned eight-bit accumulator contents with the sixteen-bit data pointer register, and uses the resulting sum as the address from which the byte is fetched. A sixteen-bit addition is performed; a carry-out from the low-order eight bits may propagate through higher-order bits, but the contents of the DPTR are not altered. The latter form uses the incremented program counter as the "base" value instead of the DPTR (figure 17). Again, neither version affects the flags.

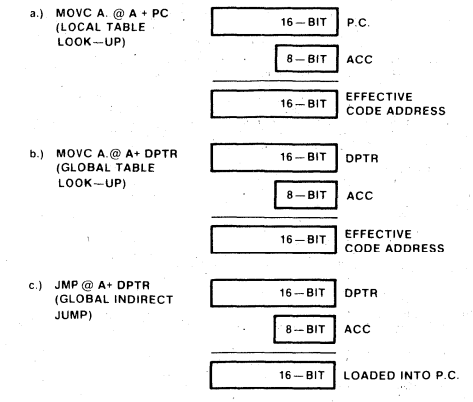

Figure 17. Operation of MOVC instructions

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Each can be part of a three step sequence to access look-up tables in ROM. To use the DPTR-relative version, load the Data Pointer with the starting address of a look-up table; load the accumulator with (or compute) the index of the entry desired; and execute MOVC A,@A+DPTR. Unlike the similar MOVP3 instructions in the 8048, the table may be located anywhere in program memory. The data pointer may be loaded with a constant for short tables. Or to allow more complicated data structures, or tables with more than 256 entries, the values for DPH and DPL may be computed or modified with the standard arithmetic instruction set.

The PC-relative version has the advantage of not affecting the data pointer. Again, a look-up sequence takes three steps: load the accumulator with the index; compensate for the offset from the look-up instruction to the start of the table by adding the number of bytes separating them to the accumulator; then execute the MOVC A,@A+PC instruction.

Let's look at a non-trivial situation where this instruction would be used. Some applications store large multi-dimensional look-up tables of dot matrix patterns, non-linear calibration parameters, and so on in a linear (one-dimensional) vector in program memory. To retrieve data from the tables, variables representing matrix indices must be converted to the desired entry's memory address. For a matrix of dimensions (MDIMEN x NDIMEN) starting at address BASE and respective indices INDEXI and INDEXJ, the address of element (INDEXI, INDEXJ) is determined by the formula,

Entry Address = BASE + (NDIMEN x INDEXI) + INDEXJ

The code shown below can access any array with less than 255 entries (i.e., an 11x21 array with 231 elements). The table entries are defined using the Data Byte ("DB") directive, and will be contained in the assembly object code as part of the accessing subroutine itself.

Example 22 — Use of MPY and Data Pointer Instructions to Access Entries from a Multi-dimensional Look-Up Table in ROM

```
;MATRX1 LOAD CONSTANT READ FROM TWO DIMENSIONAL LOOK-UP
;       TABLE IN PROGRAM MEMORY INTO ACCUMULATOR
;       USING LOCAL TABLE LOOK-UP INSTRUCTION.  'MOVC    A,@A+PC
;       THE TOTAL NUMBER OF TABLE ENTRIES IS ASSUMED TO
;       BE SMALL, I.E. LESS THAN ABOUT 250 ENTRIES )
;       TABLE USED IN THIS EXAMPLE IS ( 11 X 21 )
;       DESIRED ENTRY ADDRESS IS GIVEN BY THE FORMULA,
;       [ (BASE ADDRESS) + (21 X INDEXI) + (INDEXJ) ]
;
INDEXI  EQU     R6      ;FIRST COORDINATE OF ENTRY (0-10)
INDEXJ  EQU     23H     ;SECOND COORDINATE OF ENTRY (0-20)
;
MATRX1  MOV     A,INDEXI
        MOV     B,#21
        MUL     AB
        ADD     A,INDEXJ
;       ALLOW FOR INSTRUCTION BYTE BETWEEN "MOVC" AND
;       ENTRY (0,0)
        INC     A
        MOVC    A,@A+PC
        RET
BASE1   DB      1       ;(entry 0,0)
        DB      2       ;(entry 0,1)
;
        DB      21      ;(entry 0,20)
        DB      22      ;(entry 1,0)
;
        DB      42      ;(entry 1,20)
;
;
        DB      231     ;(entry 10,20)
```

There are several different means for branching to sections of code determined or selected at run time. (The single destination addresses incorporated into conditional and unconditional jumps are, of course, determined at assembly time). Each has advantages for different applications.

The most common is an N-way conditional jump based on some variable, with all of the potential destinations known at assembly time. One of a number of small routines is selected according to the value of an index variable determined while the program is running. The most efficient way to solve this problem is with the MOVC and an indirect jump instruction, using a short table of one byte offset values in ROM to indicate the relative starting addresses of the several routines.

JMP @A+DPTR is an instruction which performs an indirect jump to an address determined during program execution. The instruction adds the eight-bit unsigned accumulator contents with the contents of the sixteen-bit data pointer, just like MOVC A,@A+DPTR. The resulting sum is loaded into the program counter and is used as the address for subsequent instruction fetches. Again, a sixteen-bit addition is performed; a carry out from the low-order eight bits may propagate through the higher-order bits. In this case, neither the accumulator contents nor the data pointer is altered.

The example subroutine below reads a byte of RAM into the accumulator from one of four alternate address spaces, as selected by the contents of the variable MEMSEL. The address of the byte to be read is determined by the contents of R0 (and optionally R1). It might find use in a printing terminal application, where four different model printers all use the same ROM code but use different types and sizes of buffer memory for different speeds and options.

Example 23 — N-Way Branch and Computed Jump Instructions via JMP @ ADPTR

```
MEMSEL  EQU     R3
;
JUMP_4  MOV     A,MEMSEL
        MOV     DPTR,#JMPTBL
        MOVC    A,@A+DPTR
        JMP     @A+DPTR
JMPTBL  DB      MEMSP0-JMPTBL
        DB      MEMSP1-JMPTBL
        DB      MEMSP2-JMPTBL
        DB      MEMSP3-JMPTBL
MEMSP0  MOV     A,@R0   ;READ FROM INTERNAL RAM
        RET
MEMSP1  MOVX    A,@R0   ;READ FROM 256 BYTES OF EXTERNAL RAM
        RET
MEMSP2  MOV     DPL,R0
        MOV     DPH,R1
        MOVX    A,@DPTR ;READ FROM 64K BYTES OF EXTERNAL RAM
        RET
MEMSP3  MOV     A,R1
        ANL     A,#07H
        ANL     P1,#11111000B
        ORL     P1,A
        MOVX    A,@R0   ;READ FROM 4K BYTES OF EXTERNAL RAM
        RET
```

Note that this approach is suitable whenever the size of jump table plus the length of the alternate routines is less than 256 bytes. The jump table and routines may be located anywhere in program memory, independent of 256-byte program memory pages.

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For applications where up to 128 destinations must be selected, all of which reside in the same 2K page of program memory which may be reached by the two-byte absolute jump instructions, the following technique may be used. In the above mentioned printing terminal example, this sequence could "parse" 128 different codes for ASCII characters arriving via the 8051 serial port.

Example 24 — N-Way Branch with 128 Optional Destinations

```
OPTION  EQU     R3
;
JMP128  MOV     A,OPTION
        RL      A               ;MULTIPLY BY 2 FOR 2 BYTE JUMP TABLE
        MOV     DPTR,#INSTBL    ;FIRST ENTRY IN JUMP TABLE
        JMP     @A+DPTR         ;JUMP INTO JUMP TABLE
;
INSTBL  AJMP    PROC00  ;128 CONSECUTIVE
        AJMP    PROC01  ;AJMP INSTRUCTIONS
        AJMP    PROC02
;
;
        AJMP    PROC7E
        AJMP    PROC7F
```

The destinations in the jump table (PROC00-PROC7F) are not all necessarily unique routines. A large number of special control codes could each be processed with their own unique routine, with the remaining printing characters all causing a branch to a common routine for entering the character into the output queue.

In those rare situations where even 128 options are insufficient, or where the destination routines may cross a 2K page boundary, the above approach may be modified slightly as shown below.

Example 25 — 256-Way Branch Using Address Look-Up Tables

```
RTEMP   EQU     R7
;
JMP256  MOV     DPTR,#ADRTBL    ;FIRST ENTRY IN TABLE OF ADDRESSES
        MOV     A,OPTION
        CLR     C
        RLC     A               ;MULTIPLY BY 2 FOR 2 BYTE JUMP TABLE
        JNC     LOW128
        INC     DPH
LOW128  MOV     RTEMP,A         ;SAVE ACC FOR HIGH BYTE READ
        MOVC    A,@A+DPTR       ;READ LOW BYTE FROM JUMP TABLE
        XCH     A,RTEMP
        INC     A
        MOVC    A,@A+DPTR       ;GET LOW-ORDER BYTE FROM TABLE
        PUSH    ACC
        MOV     A,RTEMP
        MOVC    A,@A+DPTR       ;GET HIGH-ORDER BYTE FROM TABLE
        PUSH    ACC
;       THE TWO ACC PUSHES HAVE PRODUCED
;       A "RETURN ADDRESS" ON THE STACK WHICH CORRESPONDS
;       TO THE DESIRED STARTING ADDRESS
;       IT MAY BE REACHED BY POPPING THE STACK
;       INTO THE PC
        RET
;
ADRTBL  DW      PROC00  ;UP TO 256 CONSECUTIVE DATA
        DW      PROC01  ;WORDS INDICATING STARTING ADDRESSES
;
        DW      PROCFF
;
;
;       DUMMY CODE ADDRESS DEFINITIONS NEEDED BY ABOVE
;       TWO EXAMPLES
;
PROC00  NOP
PROC01  NOP
PROC02  NOP
PROC7E  NOP
PROC7F  NOP
PROCFF  NOP
```

4. BOOLEAN PROCESSING INSTRUCTIONS

The commonly accepted terms for tasks at either end of the computational vs. control application spectrum are, respectively, "number-crunching" and "bit-banging". Prior to the introduction of the MCS-51™ family, nice number-crunchers made bad bit-bangers and vice versa. The 8051 is the industry's first single-chip microcomputer designed to crunch **and** bang. (In some circles, the latter technique is also referred to as "bit-twiddling". Either is correct.)

Direct Bit Addressing

A number of instructions operate on Boolean (one-bit) variables, using a direct bit addressing mode comparable to direct byte addressing. An additional byte appended to the opcode specifies the Boolean variable, I/O pin, or control bit used. The state of any of these bits may be tested for "true" or "false" with the conditional branch instructions JB (Jump on Bit) and JNB (Jump on Not Bit). The JBC (Jump on Bit and Clear) instruction combines a test-for-true with an unconditional clear.

As in direct byte addressing, bit 7 of the address byte switches between two physical address spaces. Values between 0 and 127 (00H-7FH) define bits in internal RAM locations 20H to 2FH (Figure 18a); address bytes between 128 and 255 (80H-0FFH) define bits in the 2 x "special-function" register address space (Figure 18b). If no 2 x "special-function" register corresponds to the direct bit address used the result of the instruction is undefined.

Bits so addressed have many wondrous properties. They may be set, cleared, or complemented with the two byte instructions SETB, CLR, or CPL. Bits may be moved to and from the carry flag with MOV. The logical ANL and ORL functions may be performed between the carry and either the addressed bit or its complement.

Bit Manipulation Instructions — MOV

The "MOV" mnemonic can be used to load an addressable bit into the carry flag ("MOV C, bit") or to copy the state of the carry to such a bit ("MOV bit, C"). These instructions are often used for implementing serial I/O algorithms via software or to adapt the standard I/O port structure.

It is sometimes desirable to "re-arrange" the order of I/O pins because of considerations in laying out printed circuit boards. When interfacing the 8051 to an immediately adjacent device with "weighted" input pins, such as keyboard column decoder, the corresponding pins are likely to be not aligned (Figure 19).

There is a trade-off in "scrambling" the interconnections with either interwoven circuit board traces or through software. This is extremely cumbersome (if not impossible) to do with byte-oriented computer architectures. The 8051's unique set of Boolean instructions makes it simple to move individual bits between arbitrary locations.

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a.) RAM Bit Addresses.

RAM BYTE	(MSB)							(LSB)
7FH								
2FH	7F	7E	7D	7C	7B	7A	79	78
2EH	77	76	75	74	73	72	71	70
2DH	6F	6E	6D	6C	6B	6A	69	68
2CH	67	66	65	64	63	62	61	60
2BH	5F	5E	5D	5C	5B	5A	59	58
2AH	57	56	55	54	53	52	51	50
29H	4F	4E	4D	4C	4B	4A	49	48
28H	47	46	45	44	43	42	41	40
27H	3F	3E	3D	3C	3B	3A	39	38
26H	37	36	35	34	33	32	31	30
25H	2F	2E	2D	2C	2B	2A	29	28
24H	27	26	25	24	23	22	21	20
23H	1F	1E	1D	1C	1B	1A	19	18
22H	17	16	15	14	13	12	11	10
21H	0F	0E	0D	0C	0B	0A	09	08
20H	07	06	05	04	03	02	01	00
1FH	Bank 3							
18H								
17H	Bank 2							
10H								
0FH	Bank 1							
08H								
07H	Bank 0							
00H								

b.) Hardware Register Bit Addresses.

Direct Byte Address	(MSB) Bit Addresses (LSB)								Hardware Register Symbol
0FFH									
0F0H	F7	F6	F5	F4	F3	F2	F1	F0	B
0E0H	E7	E6	E5	E4	E3	E2	E1	E0	ACC
0D0H	D7	D6	D5	D4	D3	D2	D1	D0	PSW
0B8H	—	—	—	BC	BB	BA	B9	B8	IP
0B0H	B7	B6	B5	B4	B3	B2	B1	B0	P3
0A8H	AF	—	—	AC	AB	AA	A9	A8	IE
0A0H	A7	A6	A5	A4	A3	A2	A1	A0	P2
98H	9F	9E	9D	9C	9B	9A	99	98	SCON
90H	97	96	95	94	93	92	91	90	P1
88H	8F	8E	8D	8C	8B	8A	89	88	TCON
80H	87	86	85	84	83	82	81	80	P0

Figure 18. Bit Address Maps

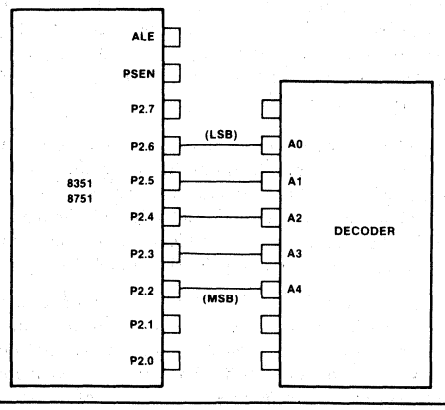

Figure 19. "Mismatch" Between I/O port and Decoder

Example 26 — Re-ordering I/O Port Configuration

```
OUT_P2: RRC     A       ;MOVE ORIGINAL ACC.0 INTO CY
        MOV     P2.6,C  ;STORE CARRY TO PIN P26
        RRC     A       ;MOVE ORIGINAL ACC.1 INTO CY
        MOV     P2.5,C  ;STORE CARRY TO PIN P25
        RRC     A       ;MOVE ORIGINAL ACC.2 INTO CY
        MOV     P2.4,C  ;STORE CARRY TO PIN P24
        RRC     A       ;MOVE ORIGINAL ACC.3 INTO CY
        MOV     P2.3,C  ;STORE CARRY TO PIN P23
        RRC     A       ;MOVE ORIGINAL ACC.4 INTO CY
        MOV     P2.2,C  ;STORE CARRY TO PIN P22
        RET
```

Solving Combinatorial Logic Equations — ANL, ORL

Virtually all hardware designers are familiar with the problem of solving complex functions using combinatorial logic. The technologies involved may vary greatly, from multiple contact relay logic, vacuum tubes, TTL, or CMOS to more esoteric approaches like fluidics, but in each case the goal is the same: a Boolean (true false) function is computed on a number of Boolean variables.

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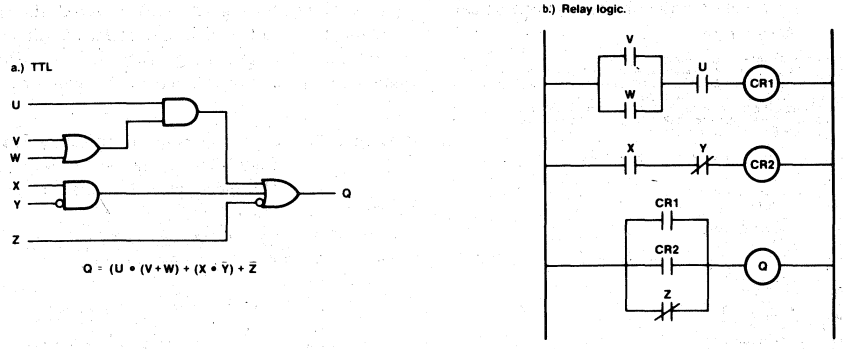

Figure 20. Implementations of Boolean functions

Figure 20 shows the logic diagram for an arbitrary function of six variables named U through Z using standard logic and relay logic symbols. Each is a solution of the equation,

$$Q = (U \cdot (V + W)) + (X \cdot \overline{Y}) + \overline{Z}$$

(While this equation could be reduced using Karnaugh Maps or algebraic techniques, that is not the purpose of this example. Even a minor change to the function equation would require re-reducing from scratch.)

Most digital computers can solve equations of this type with standard word-wide logical instructions and conditional jumps. Still, such software solutions seem somewhat sloppy because of the many paths through the program the computation can take.

Assume U and V are input pins being read by different input ports, W and X are status bits for two peripheral controllers (read as I O ports), and Y and Z are software flags set or cleared earlier in the program. The end result must be written to an output pin on some third port.

For the sake of comparison we will implement this function with software drawn from three proper subsets of the MCS-51™ instruction set. The first two implementations follow the flow chart shown in Figure 21. Program flow would embark on a route down a test-and-branch tree and leaves either the "True" or "Not True" exit ASAP. These exits then write the output port with the data previously written to the same port with the result bit respectively one or zero.

In the first case, we assume there are no instructions for addressing individual bits other than special flags like the carry. This is typical of many older microprocessors and mainframe computers designed for number-crunching. MCS-51™ mnemonics are used here, though for most other machines the issue would be even further clouded by their use of operation-specific mnemonics like INPUT, OUTPUT, LOAD, STORE, etc., instead of the universal MOV.

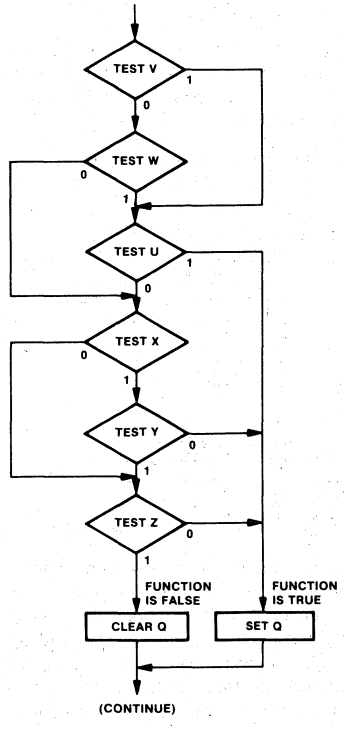

Figure 21. Flow chart for tree-branching logic implementation

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Example 27—Software Solution to Logic Function of Figure 20, Using only Byte-Wide Logical Instructions

```
;BFUNC1 SOLVE A RANDOM LOGIC FUNCTION OF 6
;       VARIABLES BY LOADING AND MASKING THE APPROPRIATE
;       BITS IN THE ACCUMULATOR, THEN EXECUTING CONDITIONAL
;       JUMPS BASED ON ZERO CONDITION.
;       (APPROACH USED BY BYTE-ORIENTED ARCHITECTURES.)
;       BYTE AND MASK VALUES CORRESPOND TO RESPECTIVE
;       BYTE ADDRESS AND BIT POSITION.
;
OUTBUF  EQU     22H     ;OUTPUT PIN STATE MAP
;
TESTV:  MOV     A,P2
        ANL     A,#00000100B
        JNZ     TESTU
        MOV     A,TCON
        ANL     A,#00100000B
        JZ      TESTX
TESTU:  MOV     A,P1
        ANL     A,#00000010B
        JNZ     SETQ
TESTX:  MOV     A,TCON
        ANL     A,#00001000B
        JZ      TESTZ
        MOV     A,20H
        ANL     A,#00000001B
        JZ      SETQ
TESTZ:  MOV     A,21H
        ANL     A,#00000010B
        JZ      SETQ
CLRQ:   MOV     A,OUTBUF
        ANL     A,#11110111B
        JMP     OUTQ
SETQ:   MOV     A,OUTBUF
        ORL     A,#00001000B
OUTQ:   MOV     OUTBUF,A
        MOV     P3,A
```

Cumbersome, to say the least, and error prone. It would be hard to prove the above example worked in all cases without an exhaustive test.

Each move/mask/conditional jump instruction sequence may be replaced by a single bit-test instruction thanks to direct bit addressing. But the algorithm would be equally convoluted.

Example 28—Software Solution to Logic Function of Figure 20, Using only Bit-Test Instructions

```
;BFUNC2 SOLVE A RANDOM LOGIC FUNCTION OF 6
;       VARIABLES BY DIRECTLY POLLING EACH BIT.
;       (APPROACH USING MCS-51 UNIQUE BIT-TEST
;       INSTRUCTION CAPABILITY.)
;       SYMBOLS USED IN LOGIC DIAGRAM ASSIGNED TO
;       CORRESPONDING 8051 BIT ADDRESSES.
;
U       BIT     P1.1
V       BIT     P2.2
W       BIT     TF0
X       BIT     IE1
Y       BIT     20H.0
Z       BIT     21H.1
Q       BIT     P3.3
;
TEST_V: JB      V,TEST_U
        JNB     W,TEST_X
TEST_U: JB      U,SET_Q
TEST_X: JNB     X,TEST_Z
        JNB     Y,SET_Q
TEST_Z: JNB     Z,SET_Q
CLR_Q:  CLR     Q
        JMP     NXTTST
SET_Q:  SETB    Q
NXTTST:                 ;(CONTINUATION OF PROGRAM)
```

A more elegant and efficient 8051 implementation uses the Boolean ANL and ORL functions to generate the output function using straight-line code. These instructions perform the corresponding logical operations between the carry flag ("Boolean Accumulator") and the addressed bit, leaving the result in the carry. Alternate forms of each instruction (specified in the assembly language by placing a slash before the bit name) use the complement of the bit's state as the input operand.

These instructions may be "strung together" to simulate a multiple input logic gate. When finished, the carry flag contains the result, which may be moved directly to the destination or output pin. No flow chart is needed — it is simple to code directly from the logic diagrams in Figure 20.

Example 29—Software Solution to Logic Function of Figure 20, Using the MCS-51 (TM) Unique Logical Instructions on Boolean Variables

```
;BFUNC3 SOLVE A RANDOM LOGIC FUNCTION OF 6
;       VARIABLES USING STRAIGHT-LINE LOGICAL INSTRUCTIONS
;       ON MCS-51 BOOLEAN VARIABLES.
;
        MOV     C,V
        ORL     C,W     ;OUTPUT OF OR GATE
        ANL     C,U     ;OUTPUT OF TOP AND GATE
        MOV     F0,C    ;SAVE INTERMEDIATE STATE
        MOV     C,X
        ANL     C,/Y    ;OUTPUT OF BOTTOM AND GATE
        ORL     C,F0    ;INCLUDE VALUE SAVED ABOVE
        ORL     C,/Z    ;INCLUDE LAST INPUT VARIABLE
        MOV     Q,C     ;OUTPUT COMPUTED RESULT
```

Simplicity itself. Fast, flexible, reliable, easy to design, and easy to debug.

The Boolean features are useful and unique enough to warrant a complete Application Note of their own. Additional uses and ideas are presented in Application Note AP-70, **Using the Intel® MCS-51® Boolean Processing Capabilities,** publication number 121519.

5. ON-CHIP PERIPHERAL FUNCTION OPERATION AND INTERFACING

I/O Ports

The I/O port versatility results from the "quasi-bidirectional" output structure depicted in Figure 22. (This is effectively the structure of ports 1, 2, and 3 for normal I/O operations. On port 0 resistor R2 is disabled except during multiplexed bus operations, providing

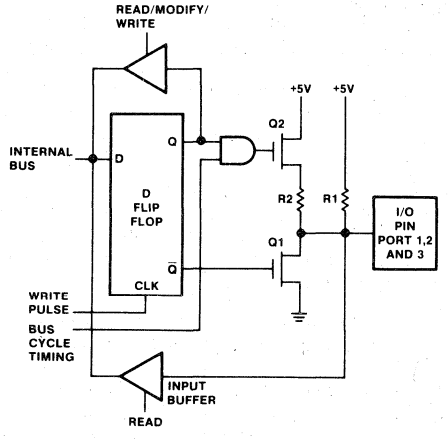

Figure 22. Pseudo-bidirectional I/O port circuitry

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essentially open-collector outputs. For full electrical characteristics see the User's Manual.)

An output latch bit associated with each pin is updated by direct addressing instructions when that port is the destination. The latch state is buffered to the outside world by R1 and Q1, which may drive a standard TTL input. (In TTL terms, Q1 and R1 resemble an open-collector output with a pull-up resistor to Vcc.)

R2 and Q2 represent an "active pull-up" device enabled momentarily when a 0 previously output changes to a 1. This "jerks" the output pin to a 1 level more quickly than the passive pull-up, improving rise-time significantly if the pin is driving a capacitive load. Note that the active pull-up is **only** activated on 0-to-1 transitions at the output latch (unlike the 8048, in which Q2 is activated whenever a 1 is written out).

Operations using an input port or pin as the source operand use the logic level of the pin itself, rather than the output latch contents. This level is affected by both the microcomputer itself and whatever device the pin is connected to externally. The value read is essentially the "OR-tied" function of Q1 and the external device. If the external device is high-impedence, such as a logic gate input or a three state output in the third state, then reading a pin will reflect the logic level previously output. To use a pin for input, the corresponding output latch must be set. The external device may then drive the pin with either a high or low logic signal. Thus the same port may be used as both input and output by writing ones to all pins used as inputs on output operations, and ignoring all pins used as output on an input operation.

In one operand instructions (INC, DEC, DJNZ and the Boolean CPL) the output latch rather than the input pin level is used as the source data. Similarly, two operand instructions using the port as both one source and the destination (ANL, ORL, XRL) use the output latches. This ensures that latch bits corresponding to pins used as inputs will not be cleared in the process of executing these instructions.

The Boolean operation JBC tests the output latch bit, rather than the input pin, in deciding whether or not to jump. Like the byte-wise logical operations, Boolean operations which modify individual pins of a port leave the other bits of the output latch unchanged.

A good example of how these modes may play together may be taken from the host-processor interface expected by an 8243 I/O expander. Even though the 8051 does not include 8048-type instructions for interfacing with an 8243, the parts can be interconnected (Figure 23) and the protocol may be emulated with simple software.

Example 30 — Mixing Parallel Output, Input, and Control Strobes on Port 2

```
IN8243: INPUT DATA FROM AN 8243 I/O EXPANDER
        CONNECTED TO P23-P20
        P25 & P24 MIMIC CS & PROG
        P27-P26 USED AS INPUTS
        PORT TO BE READ IN ACC

IN8243: SP      A,#11010000B
        MOV     P2,A      ;OUTPUT INSTRUCTION CODE
        CLR     P2.4      ;FALLING EDGE OF PROG
        ORL     P2,#00001111B   ;SET FOR INPUT
        MOV     A,P2      ;READ INPUT DATA
        SETB    P2.4      ;RETURN PROG HIGH
        SETB    P2.5      ;DE-SELECT CHIP
```

Serial Port and Timer applications

Configuring the 8051's Serial Port for a given data rate and protocol requires essentially three short sections of software. On power-up or hardware reset the serial port and timer control words must be initialized to the appropriate values. Additional software is also needed in the transmit routine to load the serial port data register and in the receive routine to unload the data as it arrives.

This is best illustrated through an arbitrary example. Assume the 8051 will communicate with a CRT operating at 2400 baud (bits per second). Each character is transmitted as seven data bits, odd parity, and one stop bit. This results in a character rate of 2400 10=240 characters per second.

For the sake of clarity, the transmit and receive subroutines are driven by simple-minded software status polling code rather than interrupts. (It might help to refer back to Figures 7-9 showing the control word formats.) The serial port must be initialized to 8-bit UART mode (M0, M1=01), enabled to receive all messages (M2=0, REN=1). The flag indicating that the transmit register is free for more data will be artificially set in order to let the output software know the output register is available. This can all be set up with one instruction.

Example 31 — Serial Port Mode and Control Bits

```
;SPINIT INITIALIZE SERIAL PORT
;       FOR 8-BIT UART MODE
;       & SET TRANSMIT READY FLAG
;
SPINIT: MOV     SCON,#01010010B
```

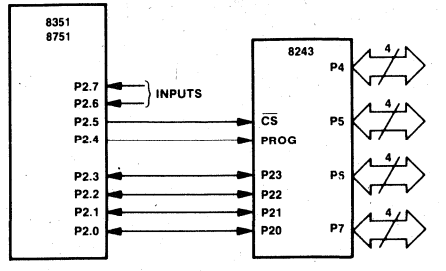

Figure 23. Connecting an 8051 with an 8243 I/O Expander

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Timer 1 will be used in auto-reload mode as a data rate generator. To achieve a data rate of 2400 baud, the timer must divide the 1 MHz internal clock by 32 x (desired data rate):

$$\frac{1 \times 10^6}{(32)\ (2400)}$$

which equals 13.02 rounded down to 13 instruction cycles. The timer must reload the value -13, or 0F3H. (ASM51 will accept both the signed decimal or hexadecimal representations.)

Example 32—Initializing Timer Mode and Control Bits

```
;T1INIT INITIALIZE TIMER 1 FOR
;       AUTO-RELOAD AT 32*2400 HZ
;       (TO USED AS GATED 16-BIT COUNTER )
;
T1INIT  MOV     TCON,#11010010B
        MOV     TH1,#-13
        SETB    TR1
```

A simple subroutine to transmit the character passed to it in the accumulator must first compute the parity bit, insert it into the data byte, wait until the transmitter is available, output the character, and return. This is nearly as easy said as done.

Example 33—Code for UART Output, Adding Parity, Transmitter Loading

```
;SP_OUT ADD ODD PARITY TO ACC AND
;       TRANSMIT WHEN SERIAL PORT READY
;
SP_OUT  MOV     C,P
        CPL     C
        MOV     ACC.7,C
        JNB     TI,$
        CLR     TI
        MOV     SBUF,A
        RET
```

A simple minded routine to wait until a character is received, set the carry flag if there is an odd-parity error, and return the masked seven-bit code in the accumulator is equally short.

Example 34—Code for UART Reception and Parity Verification

```
;SP_IN   INPUT NEXT CHARACTER FROM SERIAL PORT
;        SET CARRY IFF ODD-PARITY ERROR
;
SP_IN:  JNB     RI,$
        CLR     RI
        MOV     A,SBUF
        MOV     C,P
        CPL     C
        ANL     A,#7FH
        RET
```

6. SUMMARY

This Application Note has described the architecture, instruction set, and on-chip peripheral features of the first three members of the MCS-51™ microcomputer family. The examples used throughout were admittedly (and necessarily) very simple. Additional examples and techniques may be found in the MCS-51™ User's Manual and other application notes written for the MCS-48™ and MCS-51™ families.

Since its introduction in 1977, the MCS-48™ family has become the industry standard single-chip microcomputer. The MCS-51™ architecture expands the addressing capabilities and instruction set of its predecessor while ensuring flexibility for the future, and maintaining basic software compatability with the past.

Designers already familiar with the 8048 or 8049 will be able to take with them the education and experience gained from past designs as ever-increasing system performance demands force them to move on to state-of-the-art products. Newcomers will find the power and regularity of the 8051 instruction set an advantage in streamlining both the learning and design processes.

Microcomputer system designers will appreciate the 8051 as basically a single-chip solution to many problems which previously required board-level computers. Designers of real-time control systems will find the high execution speed, on-chip peripherals, and interrupt capabilities vital in meeting the timing constraints of products previously requiring discrete logic designs. And designers of industrial controllers will be able to convert ladder diagrams directly from tested-and-true TTL or relay-logic designs to microcomputer software, thanks to the unique Boolean processing capabilities.

It has not been the intent of this note to gloss over the difficulty of designing microcomputer-based systems. To be sure, the hardware and software design aspects of any new computer system are nontrivial tasks. However, the system speed and level of integration of the MCS-51™ microcomputers, the power and flexibility of the instruction set, and the sophisticated assembler and other support products combine to give both the hardware and software designer as much of a head start on the problem as possible.

April 1980

2

Using the Intel MCS®-51 Boolean Processing Capabilities

JOHN WHARTON
MICROCONTROLLER APPLICATIONS

Order Number: 203830-001

USING THE INTEL MCS®-51 BOOLEAN PROCESSING CAPABILITIES

CONTENTS

1.0 INTRODUCTION

The Intel microcontroller family now has three new members: the Intel® 8031, 8051, and 8751 single-chip microcomputers. These devices, shown in Figure 1, will allow whole new classes of products to benefit from recent advances in Integrated Electronics. Thanks to Intel's new HMOS technology, they provide larger program and data memory spaces, more flexible I/O and peripheral capabilities, greater speed, and lower system cost than any previous-generation single-chip microcomputer.

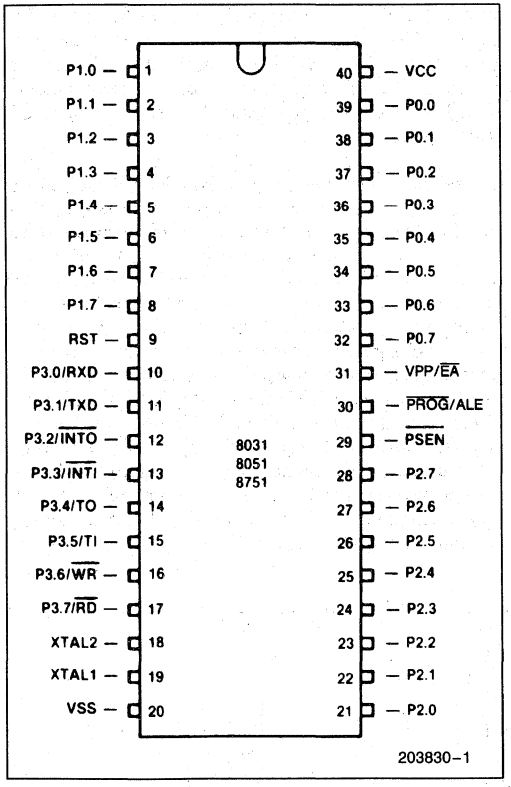


Figure 1. 8051 Family Pinout Diagram

Table 1 summarizes the quantitative differences between the members of the MCS®-48 and 8051 families. The 8751 contains 4K bytes of EPROM program memory fabricated on-chip, while the 8051 replaces the EPROM with 4K bytes of lower-cost mask-programmed ROM. The 8031 has no program memory on-chip; instead, it accesses up to 64K bytes of program memory from external memory. Otherwise, the three new family members are identical. Throughout this Note, the term "8051" will represent all members of the 8051 Family, unless specifically stated otherwise.

The CPU in each microcomputer is one of the industry's fastest and most efficient for numerical calculations on byte operands. But controllers often deal with bits, not bytes: in the real world, switch contacts can only be open or closed, indicators should be either lit or dark, motors are either turned on or off, and so forth. For such control situations the most significant aspect of the MCS®-51 architecture is its complete hardware support for one-bit, or *Boolean* variables (named in honor of Mathematician George Boole) as a separate data type.

The 8051 incorporates a number of special features which support the direct manipulation and testing of individual bits and allow the use of single-bit variables in performing logical operations. Taken together, these features are referred to as the MCS-51 *Boolean Processor*. While the bit-processing capabilities alone would be adequate to solve many control applications, their true power comes when they are used in conjunction with the microcomputer's byte-processing and numerical capabilities.

Many concepts embodied by the Boolean Processor will certainly be new even to experienced microcomputer system designers. The purpose of this Application Note is to explain these concepts and show how they are used.

For detailed information on these parts refer to the **Intel Microcontroller Handbook,** order number 210918. The instruction set, assembly language, and use of the 8051 assembler (ASM51) are further described in the **MCS®-51 Macro Assembler User's Guide for DOS Systems,** order number 122753.

Table 1. Features of Intel's Single-Chip Microcomputers

EPROM Program Memory	ROM Program Memory	External Program Memory	Program Memory (Int/Max)	Data Memory (Bytes)	Instr. Cycle Time	Input/ Output Pins	Interrupt Sources	Reg. Banks
8748	8048	8035	1K 4K	64	2.5 μs	27	2	2
—	8049	8039	2K 4K	128	1.36 μs	27	2	2
8751	8051	8031	4K 64K	128	1.0 μs	32	5	4

2.0 BOOLEAN PROCESSOR OPERATION

The Boolean Processing capabilities of the 8051 are based on concepts which have been around for some time. Digital computer systems of widely varying designs all have four functional elements in common (Figure 2):

- a central processor (CPU) with the control, timing, and logic circuits needed to execute stored instructions:
- a memory to store the sequence of instructions making up a program or algorithm:
- data memory to store variables used by the program:
  and
- some means of communicating with the outside world.

The CPU usually includes one or more accumulators or special registers for computing or storing values during program execution. The instruction set of such a processor generally includes, at a minimum, operation classes to perform arithmetic or logical functions on program variables, move variables from one place to another, cause program execution to jump or conditionally branch based on register or variable states, and instructions to call and return from subroutines. The program and data memory functions sometimes share a single memory space, but this is not always the case. When the address spaces are separated, program and data memory need not even have the same basic word width.

A digital computer's flexibility comes in part from combining simple fast operations to produce more complex (albeit slower) ones, which in turn link together eventually solving the problem at hand. A four-bit CPU executing multiple precision subroutines can, for example, perform 64-bit addition and subtraction. The subroutines could in turn be building blocks for floating-point multiplication and division routines. Eventually, the four-bit CPU can simulate a far more complex "virtual" machine.

In fact, *any* digital computer with the above four functional elements can (given time) complete *any* algorithm (though the proverbial room full of chimpanzees at word processors might first re-create Shakespeare's classics and this Application Note)! This fact offers little consolation to product designers who want programs to run as quickly as possible. By definition, a real-time control algorithm *must* proceed quickly enough to meet the preordained speed constraints of other equipment.

One of the factors determining how long it will take a microcomputer to complete a given chore is the number of instructions it must execute. What makes a given computer architecture particularly well- or poorly-suited for a class of problems is how well its instruction set matches the tasks to be performed. The better the "primitive" operations correspond to the steps taken by the control algorithm, the lower the number of instructions needed, and the quicker the program will run. All else being equal, a CPU supporting 64-bit arithmetic directly could clearly perform floating-point math faster than a machine bogged-down by multiple-precision subroutines. In the same way, direct support for bit manipulation naturally leads to more efficient programs handling the binary input and output conditions inherent in digital control problems.

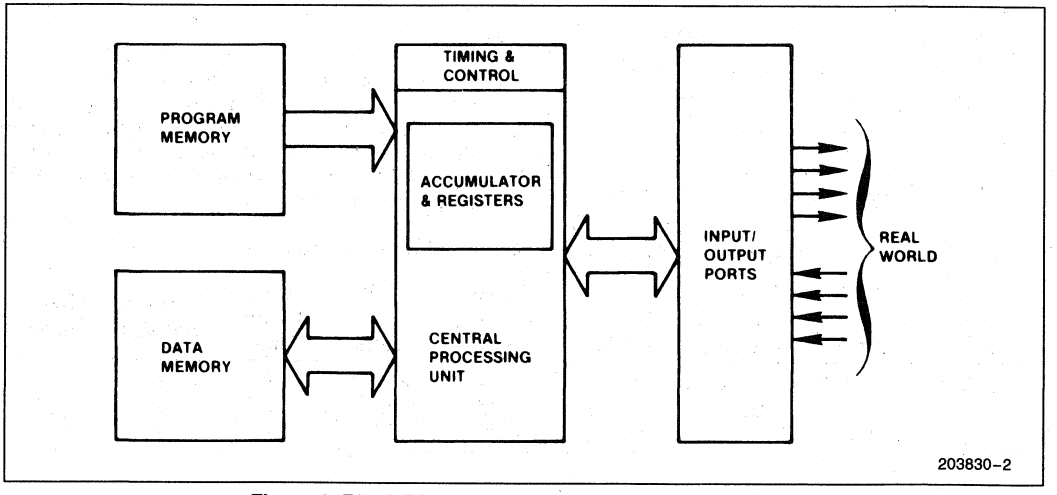


Figure 2. Block Diagram for Abstract Digital Computer

Processing Elements

The introduction stated that the 8051's bit-handling capabilities alone would be sufficient to solve some control applications. Let's see how the four basic elements of a digital computer—a CPU with associated registers, program memory, addressable data RAM, and I/O capability—relate to Boolean variables.

CPU. The 8051 CPU incorporates special logic devoted to executing several bit-wide operations. All told, there are 17 such instructions, all listed in Table 2. Not shown are 94 other (mostly byte-oriented) 8051 instructions.

Program Memory. Bit-processing instructions are fetched from the same program memory as other arithmetic and logical operations. In addition to the instructions of Table 2, several sophisticated program control features like multiple addressing modes, subroutine nesting, and a two-level interrupt structure are useful in structuring Boolean Processor-based programs.

Table 2. MCS-51™ Boolean Processing Instruction Subset

Mnemonic		Description	Byte	Cyc
SETB	C	Set Carry flag	1	1
SETB	bit	Set direct Bit	2	1
CLR	C	Clear Carry flag	1	1
CLR	bit	Clear direct bit	2	1
CPL	C	Complement Carry flag	1	1
CPL	bit	Complement direct bit	2	1
MOV	C.bit	Move direct bit to Carry flag	2	1
MOV	bit.C	Move Carry flag to direct bit	2	2
ANL	C.bit	AND direct bit to Carry flag	2	2
ANL	C.bit	AND complement of direct bit to Carry flag	2	2
ORL	C.bit	OR direct bit to Carry flag	2	2
ORL	C.bit	OR complement of direct bit to Carry flag	2	2
JC	rel	Jump if Carry is flag is set	2	2
JNC	rel	Jump if No Carry flag	2	2
JB	bit.rel	Jump if direct Bit set	3	2
JNB	bit.rel	Jump if direct Bit Not set	3	2
JBC	bit.rel	Jump if direct Bit is set & Clear bit	3	2

Address mode abbreviations

C—Carry flag.
bit—128 software flags, any I/O pin, control or status bit.
rel—All conditional jumps include an 8-bit offset byte. Range is +127 −128 bytes relative to first byte of the following instruction.

Boolean instructions are one, two, or three bytes long, depending on what function they perform. Those involving only the carry flag have either a single-byte opcode or an opcode followed by a conditional-branch destination byte (Figure 3a). The more general instructions add a "direct address" byte after the opcode to specify the bit affected, yielding two or three byte encodings (Figure 3b). Though this format allows potentially 256 directly addressable bit locations, not all of them are implemented in the 8051 family.

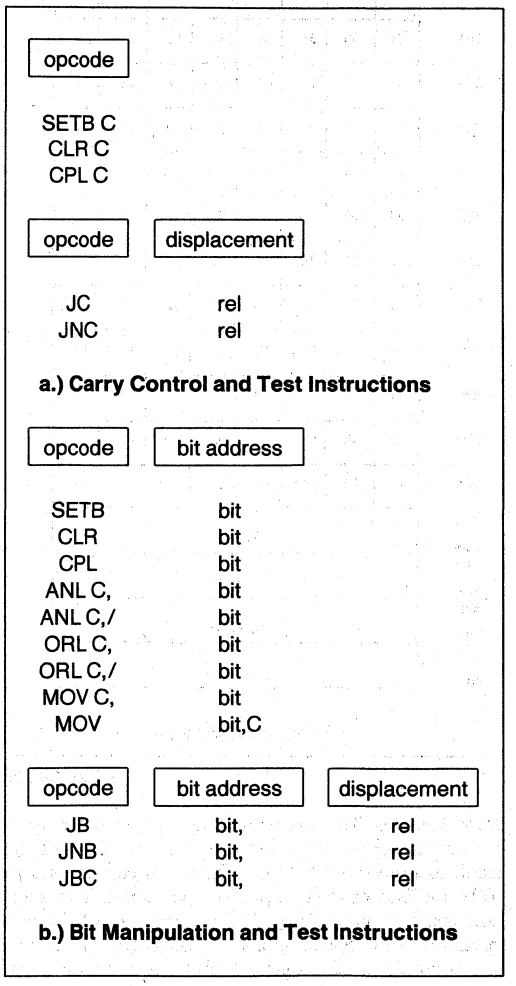


Figure 3. Bit Addressing Instruction Formats

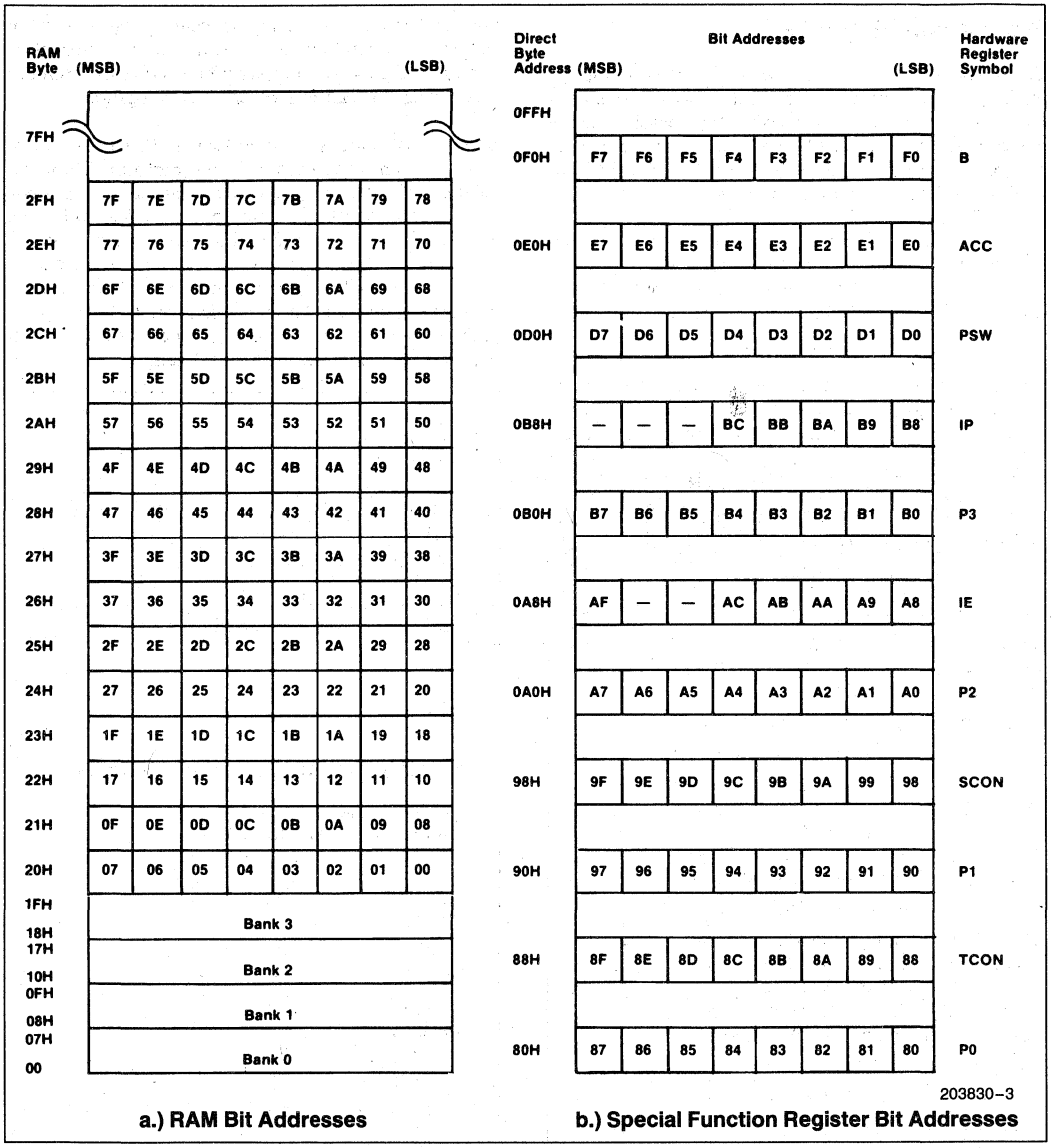


Figure 4. Bit Address Maps

Data Memory. The instructions in Figure 3b can operate directly upon 144 general purpose bits forming the Boolean processor "RAM." These bits can be used as software flags or to store program variables. Two operand instructions use the CPU's carry flag ("C") as a special one-bit register: in a sense, the carry is a "Boolean accumulator" for logical operations and data transfers.

Input/Output. All 32 I/O pins can be addressed as individual inputs, outputs, or both, in any combination. Any pin can be a control strobe output, status (Test) input, or serial I/O link implemented via software. An additional 33 individually addressable bits reconfigure, control, and monitor the status of the CPU and all on-chip peripheral functions (timer counters, serial port modes, interrupt logic, and so forth).

(MSB)							(LSB)
CY	AC	F0	RS1	RS0	OV	—	P

Symbol	Position	Name and Significance
CY	PSW.7	Carry flag. Set/cleared by hardware or software during certain arithmetic and logical instructions.
AC	PSW.6	Auxiliary Carry flag. Set/cleared by hardware during addition or subtraction instructions to indicate carry or borrow out of bit 3.
F0	PSW.5	Flag 0. Set/cleared/tested by software as a user-defined status flag.
RS1	PSW.4	Register bank Select control bits.
RS0	PSW.3	1 & 0. Set/cleared by software to determine working register bank (see Note).
OV	PSW.2	Overflow flag. Set/cleared by hardware during arithmetic instructions to indicate overflow conditions.
—	PSW.1	(reserved)
P	PSW.0	Parity flag. Set/cleared by hardware each instruction cycle to indicate an odd/even number of "one" bits in the accumulator, i.e., even parity.

Note- the contents of (RS1, RS0) enable the working register banks as follows:

(0,0) - Bank 0	(00H–07H)
(0,1) - Bank 1	(08H–0FH)
(1,0) - Bank 2	(10H–17H)
(1,1) - Bank 3	(18H–1FH)

Figure 5. PSW—Program Status Word Organization

(MSB)							(LSB)
RD	WR	T1	T0	INT1	INT0	TXD	RXD

Symbol	Position	Name and Significance
RD	P3.7	Read data control output. Active low pulse generated by hardware when external data memory is read.
WR	P3.6	Write data control output. Active low pulse generated by hardware when external data memory is written.
T1	P3.5	Timer/counter 1 external input or test pin.
T0	P3.4	Timer/counter 0 external input or test pin.
INT1	P3.3	Interrupt 1 input pin. Low-level or falling-edge triggered.
INT0	P3.2	Interrupt 0 input pin. Low-level or falling-edge triggered.
TXD	P3.1	Transmit Data pin for serial port in UART mode. Clock output in shift register mode.
RXD	P3.0	Receive Data pin for serial port in UART mode. Data I/O pin in shift register mode.

Figure 6. P3—Alternate I/O Functions of Port 3

Direct Bit Addressing

The most significant bit of the direct address byte selects one of two groups of bits. Values between 0 and 127 (00H and 7FH) define bits in a block of 32 bytes of on-chip RAM, between RAM addresses 20H and 2FH (Figure 4a). They are numbered consecutively from the lowest-order byte's lowest-order bit through the highest-order byte's highest-order bit.

Bit addresses between 128 and 255 (80H and 0FFH) correspond to bits in a number of special registers, mostly used for I/O or peripheral control. These positions are numbered with a different scheme than RAM: the five high-order address bits match those of the register's own address, while the three low-order bits identify the bit position within that register (Figure 4b).

Notice the column labeled "Symbol" in Figure 5. Bits with special meanings in the PSW and other registers have corresponding symbolic names. General-purpose (as opposed to carry-specific) instructions may access the carry like any other bit by using the mnemonic CY in place of C, P0, P1, P2, and P3 are the 8051's four I/O ports: secondary functions assigned to each of the eight pins of P3 are shown in Figure 6.

Figure 7 shows the last four bit addressable registers. TCON (Timer Control) and SCON (Serial port Control) control and monitor the corresponding peripherals, while IE (Interrupt Enable) and IP (Interrupt Priority) enable and prioritize the five hardware interrupt sources. Like the reserved hardware register addresses, the five bits not implemented in IE and IP should not be accessed: they can *not* be used as software flags.

Addressable Register Set. There are 20 special function registers in the 8051, but the advantages of bit addressing only relate to the 11 described below. Five potentially bit-addressable register addresses (0C0H, 0C8H, 0D8H, 0E8H, & 0F8H) are being reserved for possible future expansion in microcomputers based on the MCS-51 architecture. Reading or writing non-existent registers in the 8051 series is pointless, and may cause unpredictable results. Byte-wide logical operations can be used to manipulate bits in all *non*-bit addressable registers and RAM.

(MSB)							(LSB)
TF1	TR1	TF0	TR0	IE1	IT1	IE0	IT0

Symbol	Position	Name and Significance
TF1	TCON.7	Timer 1 overflow Flag. Set by hardware on timer/counter overflow. Cleared when interrupt processed.
TR1	TCON.6	Timer 1 Run control bit. Set/cleared by software to turn timer/counter on/off.
TF0	TCON.5	Timer 0 overflow Flag. Set by hardware on timer/counter overflow. Cleared when interrupt processed.
TR0	TCON.4	Timer 0 Run control bit. Set/cleared by software to turn timer/counter on/off.
IE1	TCON.3	Interrupt 1 Edge flag. Set by hardware when external interrupt edge detected. Cleared when interrupt processed.
IT1	TCON.2	Interrupt 1 Type control bit. Set/cleared by software to specify falling edge/low level triggered external interrupts.
IE0	TCON.1	Interrupt 0 Edge flag. Set by hardware when external interrupt edge detected. Cleared when interrupt processed.
IT0	TCON.0	Interrupt 0 Type control bit. Set/cleared by software to specify falling edge/low level triggered external interrupts.

a.) TCON—Timer/Counter Control/Status Register

(MSB)							(LSB)
SM0	SM1	SM2	REN	TB8	RB8	TI	RI

Symbol	Position	Name and Significance
SM0	SCON.7	Serial port Mode control bit 0. Set/cleared by software (see note).
SM1	SCON.6	Serial port Mode control bit 1. Set/cleared by software (see note).
SM2	SCON.5	Serial port Mode control bit 2. Set by software to disable reception of frames for which bit 8 is zero.
REN	SCON.4	Receiver Enable control bit. Set/cleared by software to enable/disable serial data reception.
TB8	SCON.3	Transmit Bit 8. Set/cleared by hardware to determine state of ninth data bit transmitted in 9-bit UART mode.
RB8	SCON.2	Receive Bit 8. Set/cleared by hardware to indicate state of ninth data bit received.
TI	SCON.1	Transmit Interrupt flag. Set by hardware when byte transmitted. Cleared by software after servicing.
RI	SCON.0	Receive Interrupt flag. Set by hardware when byte received. Cleared by software after servicing.

Note- the state of (SM0, SM1) selects:
(0,0)—Shift register I/O expansion.
(0,1)—8-bit UART, variable data rate.
(1,0)—9-bit UART, fixed data rate.
(1,1)—9-bit UART, variable data rate.

b.) SCON—Serial Port Control/Status Register

Figure 7. Peripheral Configuration Registers

(MSB) (LSB)

EA	—	—	ES	ET1	EX1	ET1	EX0

Symbol	Position	Name and Significance
EA	IE.7	Enable All control bit. Cleared by software to disable all interrupts, independent of the state of IE.4–IE.0.
—	IE.6	(reserved)
—	IE.5	
ES	IE.4	Enable Serial port control bit. Set/cleared by software to enable/disable interrupts from TI or RI flags.
ET1	IE.3	Enable Timer 1 control bit. Set/cleared by software to enable/disable interrupts from timer/counter 1.
EX1	IE.2	Enable External interrupt 1 control bit. Set/cleared by software to enable/disable interrupts from INT1.
ET0	IE.1	Enable Timer 0 control bit. Set/cleared by software to enable/disable interrupts from timer/counter 0.
EX0	IE.0	Enable External interrupt 0 control bit. Set/cleared by software to enable/disable interrupts from INT0.

c.) IE—Interrupt Enable Register

(MSB) (LSB)

—	—	—	PS	PT1	PX1	PT0	PX0

Symbol	Position	Name and Significance
—	IP.7	(reserved)
—	IP.6	(reserved)
—	IP.5	(reserved)
PS	IP.4	Serial port Priority control bit. Set/cleared by software to specify high/low priority interrupts for Serial port.
PT1	IP.3	Timer 1 Priority control bit. Set/cleared by software to specify high/low priority interrupts for timer/counter 1.
PX1	IP.2	External interrupt 1 Priority control bit. Set/cleared by software to specify high/low priority interrupts for INT1.
PT0	IP.1	Timer 0 Priority control bit. Set/cleared by software to specify high/low priority interrupts for timer/counter 0.
PX0	IP.0	External interrupt 0 Priority control bit. Set/cleared by software to specify high/low priority interrupts for INT0.

d.) IP—Interrupt Priority Control Register

Figure 7. Peripheral Configuration Registers (Continued)

The accumulator and B registers (A and B) are normally involved in byte-wide arithmetic, but their individual bits can also be used as 16 general software flags. Added with the 128 flags in RAM, this gives 144 general purpose variables for bit-intensive programs. The program status word (PSW) in Figure 5 is a collection of flags and machine status bits including the carry flag itself. Byte operations acting on the PSW can therefore affect the carry.

Instruction Set

Having looked at the bit variables available to the Boolean Processor, we will now look at the four classes of instructions that manipulate these bits. It may be helpful to refer back to Table 2 while reading this section.

State Control. Addressable bits or flags may be set, cleared, or logically complemented in one instruction cycle with the two-byte instructions SETB, CLR, and CPL. (The "B" affixed to SETB distinguishes it from the assembler "SET" directive used for symbol definition.) SETB and CLR are analogous to loading a bit with a constant: 1 or 0. Single byte versions perform the same three operations on the carry.

The MCS-51 assembly language specifies a bit address in any of three ways:

- by a number or expression corresponding to the direct bit address (0–255):

- by the name or address of the register containing the bit, the *dot operator* symbol (a period: "."), and the bit's position in the register (7–0):
- in the case of control and status registers, by the predefined assembler symbols listed in the first columns of Figures 5–7.

Bits may also be given user-defined names with the assembler "BIT" directive and any of the above techniques. For example, bit 5 of the PSW may be cleared by any of the four instructions.

```
USR_FLG BIT   PSW.5     ; User Symbol Definition
        ...   ...
        CLR   0D5H      ; Absolute Addressing
        CLR   PSW.5     ; Use of Dot Operator
        CLR   F0        ; Pre-Defined Assembler
                        ; Symbol
        CLR   USR_FLG   ; User-Defined Symbol
```

Data Transfers. The two-byte MOV instructions can transport any addressable bit to the carry in one cycle, or copy the carry to the bit in two cycles. A bit can be moved between two arbitrary locations via the carry by combining the two instructions. (If necessary, push and pop the PSW to preserve the previous contents of the carry.) These instructions can replace the multi-instruction sequence of Figure 8, a program structure appearing in controller applications whenever flags or outputs are conditionally switched on or off.

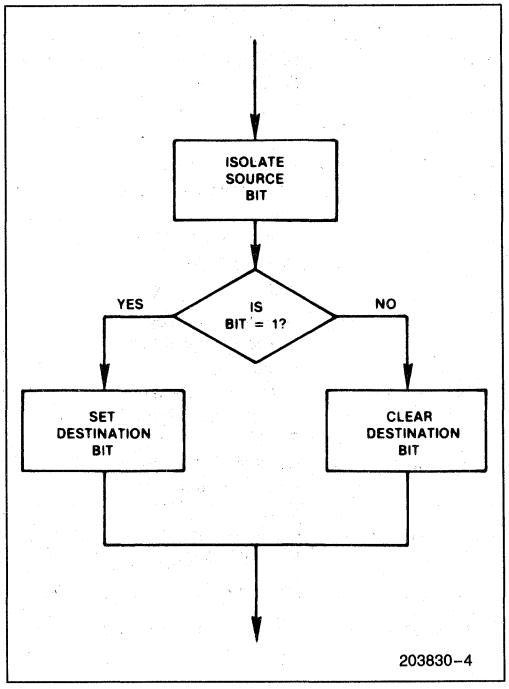


Figure 8. Bit Transfer Instruction Operation

Logical Operations. Four instructions perform the logical-AND and logical-OR operations between the carry and another bit, and leave the results in the carry. The instruction mnemonics are ANL and ORL; the absence or presence of a slash mark ("/") before the source operand indicates whether to use the positive-logic value or the logical complement of the addressed bit. (The source operand itself is never affected.)

Bit-test Instructions. The conditional jump instructions "JC rel" (Jump on Carry) and "JNC rel" (Jump on Not Carry) test the state of the carry flag, branching if it is a one or zero, respectively. (The letters "rel" denote relative code addressing.) The three-byte instructions "JB bit.rel" and "JNB bit.rel" (Jump on Bit and Jump on Not Bit) test the state of *any* addressable bit in a similar manner. A fifth instruction combines the Jump on Bit and Clear operations. "JBC bit.rel" conditionally branches to the indicated address, then clears the bit in the same two cycle instruction. This operation is the same as the MCS-48 "JTF" instructions.

All 8051 conditional jump instructions use program counter-relative addressing, and all execute in two cycles. The last instruction byte encodes a signed displacement ranging from −128 to +127. During execution, the CPU adds this value to the incremented program counter to produce the jump destination. Put another way, a conditional jump to the immediately following instruction would encode 00H in the offset byte.

A section of program or subroutine written using only relative jumps to nearby addresses will have the same machine code independent of the code's location. An assembled routine may be repositioned anywhere in memory, even crossing memory page boundaries, without having to modify the program or recompute destination addresses. To facilitate this flexibility, there is an unconditional "Short Jump" (SJMP) which uses relative addressing as well. Since a programmer would have quite a chore trying to compute relative offset values from one instruction to another, ASM51 automatically computes the displacement needed given only the destination address or label. An error message will alert the programmer if the destination is "out of range."

The so-called "Bit Test" instructions implemented on many other microprocessors simply perform the logical-AND operation between a byte variable and a constant mask, and set or clear a zero flag depending on the result. This is essentially equivalent to the 8051 "MOV C.bit" instruction. A second instruction is then needed to conditionally branch based on the state of the zero flag. This does *not* constitute abstract bit-addressing in the MCS-51 sense. A flag exists only as a field

within a register: to reference a bit the programmer must know and specify both the encompassing register and the bit's position therein. This constraint severely limits the flexibility of symbolic bit addressing and reduces the machine's code-efficiency and speed.

Interaction with Other Instructions. The carry flag is also affected by the instructions listed in Table 3. It can be rotated through the accumulator, and altered as a side effect of arithmetic instructions. Refer to the User's Manual for details on how these instructions operate.

Simple Instruction Combinations

By combining general purpose bit operations with certain addressable bits, one can "custom build" several hundred useful instructions. All eight bits of the PSW can be tested directly with conditional jump instructions to monitor (among other things) parity and overflow status. Programmers can take advantage of 128 software flags to keep track of operating modes, resource usage, and so forth.

The Boolean instructions are also the most efficient way to control or reconfigure peripheral and I/O registers. All 32 I/O lines become "test pins," for example, tested by conditional jump instructions. Any output pin can be toggled (complemented) in a single instruction cycle. Setting or clearing the Timer Run flags (TR0 and TR1) turn the timer/counters on or off; polling the same flags elsewhere lets the program determine if a timer is running. The respective overflow flags (TF0 and TF1) can be tested to determine when the desired period or count has elapsed, then cleared in preparation for the next repetition. (For the record, these bits are all part of the TCON register, Figure 7a. Thanks to symbolic bit addressing, the programmer only needs to remember the mnemonic associated with each function. In other words, don't bother memorizing control word layouts.)

In the MCS-48 family, instructions corresponding to some of the above functions require specific opcodes. Ten different opcodes serve to clear complement the software flags F0 and F1, enable/disable each interrupt, and start/stop the timer. In the 8051 instruction set, just three opcodes (SETB, CLR, CPL) with a direct bit address appended perform the same functions. Two test instructions (JB and JNB) can be combined with bit addresses to test the software flags, the 8048 I/O pins T0, T1, and INT, and the eight accumulator bits, replacing 15 more different instructions.

Table 4a shows how 8051 programs implement software flag and machine control functions associated with special opcodes in the 8048. In every case the MCS-51 solution requires the same number of machine cycles, and executes 2.5 times faster.

Table 3. Other Instructions Affecting the Carry Flag

Mnemonic		Description	Byte	Cyc
ADD	A,Rn	Add register to Accumulator	1	1
ADD	A,direct	Add direct byte to Accumulator	2	1
ADD	A,@Ri	Add indirect RAM to Accumulator	1	1
ADD	A,#data	Add immediate data to Accumulator	2	1
ADDC	A,Rn	Add register to Accumulator with Carry flag	1	1
ADDC	A,direct	Add direct byte to Accumulator with Carry flag	2	1
ADDC	A,@Ri	Add indirect RAM to Accumulator with Carry flag	1	1
ADDC	A,#data	Add immediate data to Acc with Carry flag	2	1
SUBB	A,Rn	Subtract register from Accumulator with borrow	1	1
SUBB	A,direct	Subtract direct byte from Acc with borrow	2	1
SUBB	A,@Ri	Subtract indirect RAM from Acc with borrow	1	1
SUBB	A,#data	Subtract immediate data from Acc with borrow	2	1
MUL	AB	Multiply A & B	1	4
DIV	AB	Divide A by B	1	4
DA	A	Decimal Adjust Accumulator	1	1
RLC	A	Rotate Accumulator Left through the Carry flag	1	1
RRC	A	Rotate Accumulator Right through Carry flag	1	1
CJNE	A,direct.rel	Compare direct byte to Acc & Jump if Not Equal	3	2
CJNE	A,#data.rel	Compare immediate to Acc & Jump if Not Equal	3	2
CJNE	Rn,#data.rel	Compare immed to register & Jump if Not Equal	3	2
CJNE	@Ri,#data.rel	Compare immed to indirect & Jump if Not Equal	3	2

Table 4a. Contrasting 8048 and 8051 Bit Control and Testing Instructions

8048 Instruction		Bytes	Cycles	μSec	8x51 Instruction		Bytes	Cycles & μSec
Flag Control								
CLR	C	1	1	2.5	CLR	C	1	1
CPL	F0	1	1	2.5	CPL	F0	2	1
Flag Testing								
JNC	offset	2	2	5.0	JNC	rel	2	2
JF0	offset	2	2	5.0	JB	F0.rel	3	2
JB7	offset	2	2	5.0	JB	ACC.7.rel	3	2
Peripheral Polling								
JT0	offset	2	2	5.0	JB	T0.rel	3	2
JN1	offset	2	2	5.0	JNB	INT0.rel	3	2
JTF	offset	2	2	5.0	JBC	TF0.rel	3	2
Machine and Peripheral Control								
STRT	T	1	1	2.5	SETB	TR0	2	1
EN	1	1	1	2.5	SETB	EX0	2	1
DIS	TCNT1	1	1	2.5	CLR	ET0	2	1

2

Table 4b. Replacing 8048 Instruction Sequences with Single 8x51 Instructions

8048 Instruction		Bytes	Cycles	μSec	8051 Instruction		Bytes	Cycles & μSec
Flag Control								
Set carry								
CLR	C							
CPL	C	= 2	2	5.0	SETB	C	1	1
Set Software Flag								
CLR	F0							
CPL	F0	= 2	2	5.0	SETB	F0	2	1
Turn Off Output Pin								
ANL	P1.#0FBH	= 2	2	5.0	CLR	P1.2	2	1
Complement Output Pin								
IN	A.P1							
XRL	A.#04H							
OUTL	P1.A	= 4	6	15.0	CPL	P1.2	2	1
Clear Flag in RAM								
MOV	R0.#FLGADR							
MOV	A.@R0							
ANL	A.#FLGMASK							
MOV	@R0.A	= 6	6	15.0	CLR	USER_FLG	2	1

Table 4b. Replacing 8048 Instruction Sequences with Single 8x51 Instructions (Continued)

8048 Instruction		Bytes	Cycles	μSec	8x51 Instruction		Bytes	Cycles & μSec
Flag Testing:								
Jump if Software Flag is 0								
JF0	$+4							
JMP	offset	= 4	4	10.0	JNB	F0.rel	3	2
Jump if Accumulator bit is 0								
CPL	A							
JB7	offset							
CPL	A	= 4	4	10.0	JNB	ACC.7.rel	3	2
Peripheral Polling								
Test if Input Pin is Grounded								
IN	A.P1							
CPL	A							
JB3	offset	= 4	5	12.5	JNB	P1.3.rel	3	2
Test if Interrupt Pin is High								
JN1	$+4							
JMP	offset	= 4	4	10.0	JB	INT0.rel	3	2

3.0 BOOLEAN PROCESSOR APPLICATIONS

So what? Then what does all this buy you?

Qualitatively, nothing. All the same capabilities *could* be (and often have been) implemented on other machines using awkward sequences of other basic operations. As mentioned earlier, any CPU can solve any problem given enough time.

Quantitatively, the differences between a solution allowed by the 8051 and those required by previous architectures are numerous. What the 8051 Family buys you is a faster, cleaner, lower-cost solution to microcontroller applications.

The opcode space freed by condensing many specific 8048 instructions into a few general operations has been used to add new functionality to the MCS-51 architecture—both for byte and bit operations. 144 software flags replace the 8048's two. These flags (and the carry) may be directly set, not just cleared and complemented, and all can be tested for either state, not just one. Operating mode bits previously inaccessible may be read, tested, or saved. Situations where the 8051 instruction set provides new capabilities are contrasted with 8048 instruction sequences in Table 4b. Here the 8051 speed advantage ranges from 5x to 15x!

Combining Boolean and byte-wide instructions can produce great synergy. An MCS-51 based application will prove to be:

- simpler to write since the architecture correlates more closely with the problems being solved:
- easier to debug because more individual instructions have no unexpected or undesirable side-effects:
- more byte efficient due to direct bit addressing and program counter relative branching:
- faster running because fewer bytes of instruction need to be fetched and fewer conditional jumps are processed:
- lower cost because of the high level of system-integration within one component.

These rather unabashed claims of excellence shall not go unsubstantiated. The rest of this chapter examines less trivial tasks simplified by the Boolean processor. The first three compare the 8051 with other microprocessors; the last two go into 8051-based system designs in much greater depth.

Design Example # 1—Bit Permutation

First off, we'll use the bit-transfer instructions to permute a lengthy pattern of bits.

A steadily increasing number of data communication products use encoding methods to protect the security of sensitive information. By law, interstate financial transactions involving the Federal banking system must be transmitted using the Federal Information Processing *Data Encryption Standard* (DES).

Basically, the DES combines eight bytes of "plaintext" data (in binary, ASCII, or any other format) with a 56-bit "key", producing a 64-bit encrypted value for transmission. At the receiving end the same algorithm is applied to the incoming data using the same key, reproducing the original eight byte message. The algorithm used for these permutations is fixed; different user-defined keys ensure data privacy.

It is not the purpose of this note to describe the DES in any detail. Suffice it to say that encryption/decryption is a long, iterative process consisting of rotations, exclusive -OR operations, function table look-ups, and an extensive (and quite bizarre) sequence of bit permutation, packing, and unpacking steps. (For further details refer to the June 21, 1979 issue of **Electronics** magazine.) The bit manipulation steps are included, it is rumored, to impede a general purpose digital supercomputer trying to "break" the code. Any algorithm implementing the DES with previous generation microprocessors would spend virtually all of its time diddling bits.

The bit manipulation performed is typified by the Key Schedule Calculation represented in Figure 9. This step is repeated 16 times for each key used in the course of a transmission. In essence, a seven-byte, 56-bit "Shifted Key Buffer" is transformed into an eight-byte, "Permutation Buffer" without altering the shifted Key. The arrows in Figure 9 indicate a few of the translation steps. Only six bits of each byte of the Permutation Buffer are used; the two high-order bits of each byte are cleared. This means only 48 of the 56 Shifted Key Buffer bits are used in any one iteration.

Different microprocessor architectures would best implement this type of permutation in different ways. Most approaches would share the steps of Figure 10a:

- Initialize the Permutation Buffer to default state (ones or zeroes):
- Isolate the state of a bit of a byte from the Key Buffer. Depending on the CPU, this might be accomplished by rotating a word of the Key Buffer through a carry flag or testing a bit in memory or an accumulator against a mask byte:
- Perform a conditional jump based on the carry or zero flag if the Permutation Buffer default state is correct:
- Otherwise reverse the corresponding bit in the permutation buffer with logical operations and mask bytes.

Each step above may require several instructions. The last three steps must be repeated for all 48 bits. Most microprocessors would spend 300 to 3,000 microseconds on each of the 16 iterations.

Notice, though, that this flow chart looks a lot like Figure 8. The Boolean Processor can permute bits by simply moving them from the source to the carry to the destination—a total of two instructions taking four bytes and three microseconds per bit. Assume the Shifted Key Buffer and Permutation Buffer both reside in bit-addressable RAM, with the bits of the former assigned symbolic names SKB_1, SKB_2, . . . SKB_56, and that the bytes of the latter are named PB_1, . . . PB_8. Then working from Figure 9, the software for the permutation algorithm would be that of Example 1a. The total routine length would be 192 bytes, requiring 144 microseconds.

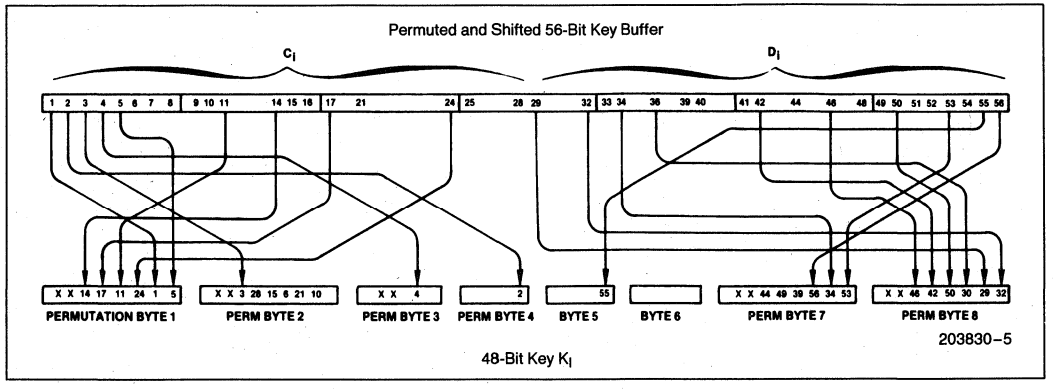


Figure 9. DES Key Schedule Transformation

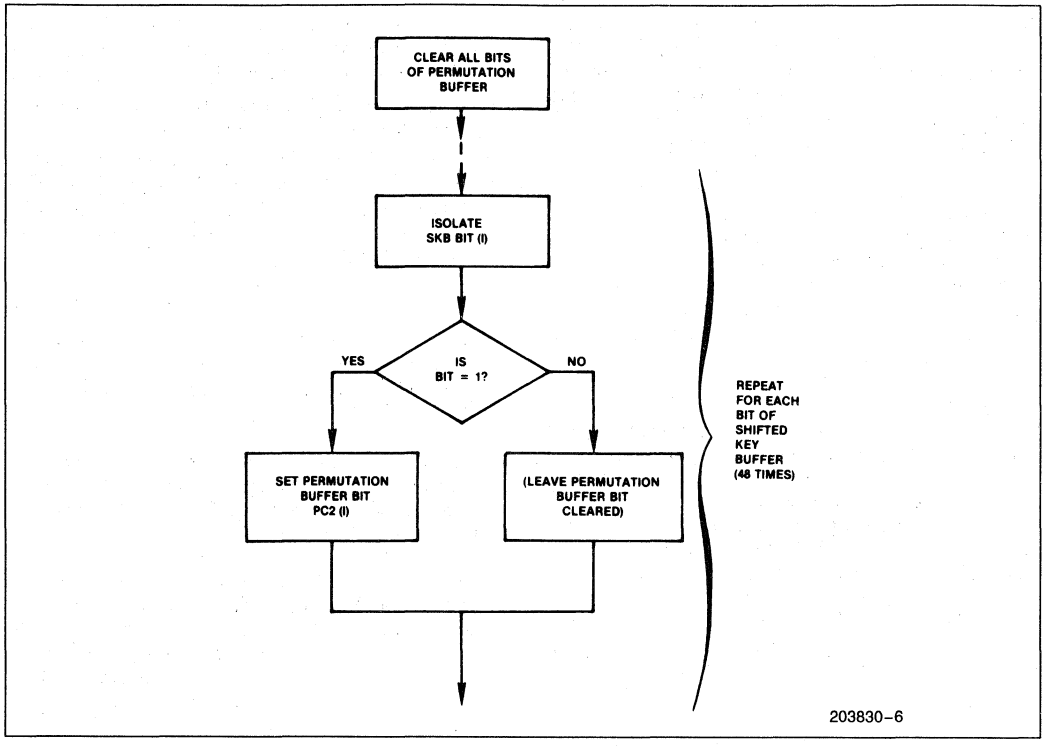


Figure 10a. Flowchart for Key Permutation Attempted with a Byte Processor

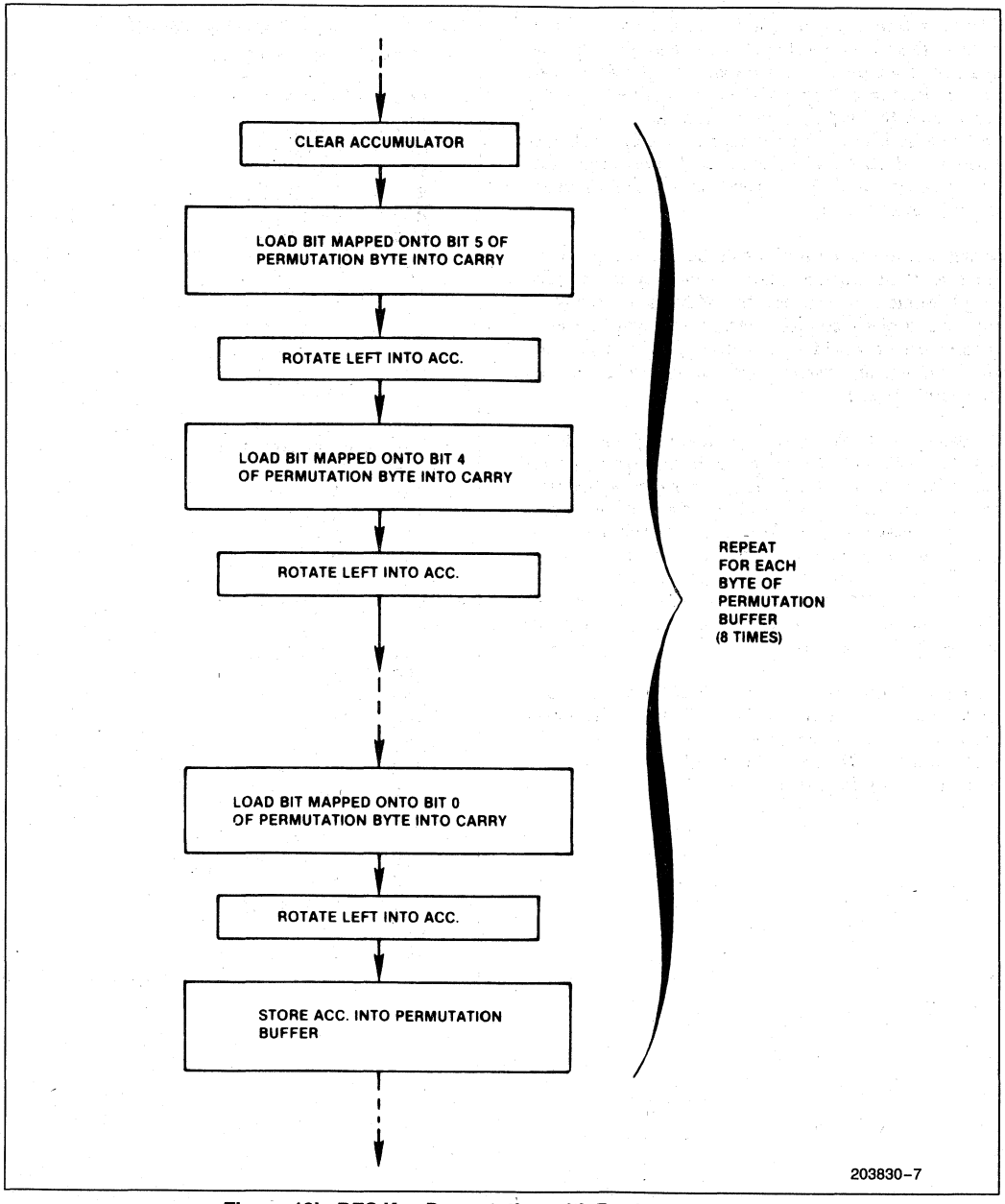


Figure 10b. DES Key Permutation with Boolean Processor

The algorithm of Figure 10b is just slightly more efficient in this time-critical application and illustrates the synergy of an integrated byte and bit processor. The bits needed for each byte of the Permutation Buffer are assimilated by loading each bit into the carry (1 μs.) and shifting it into the accumulator (1 μs.). Each byte is stored in RAM when completed. Forty-eight bits thus need a total of 112 instructions, some of which are listed in Example 1b.

Worst-case execution time would be 112 microseconds, since each instruction takes a single cycle. Routine length would also decrease, to 168 bytes. (Actually, in the context of the complete encryption algorithm, each permuted byte would be processed as soon as it is assimilated—saving memory and cutting execution time by another 8 μs.)

To date, most banking terminals and other systems using the DES have needed special boards or peripheral controller chips just for the encryption/decryption process, and still more hardware to form a serial bit stream for transmission (Figure 11a). An 8051 solution could pack most of the entire system onto the one chip (Figure 11b). The whole DES algorithm would require less than one-fourth of the on-chip program memory, with the remaining bytes free for operating the banking terminal (or whatever) itself.

Moreover, since transmission and reception of data is performed through the on-board UART, the unencrypted data (plaintext) never even exists outside the microcomputer! Naturally, this would afford a high degree of security from data interception.

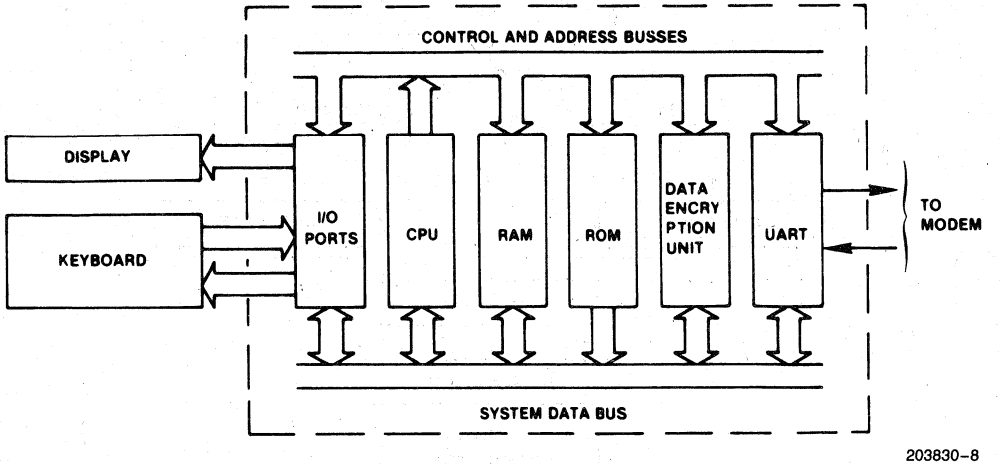
Example 1. DES Key Permutation Software.

a.) "Brute Force" technique

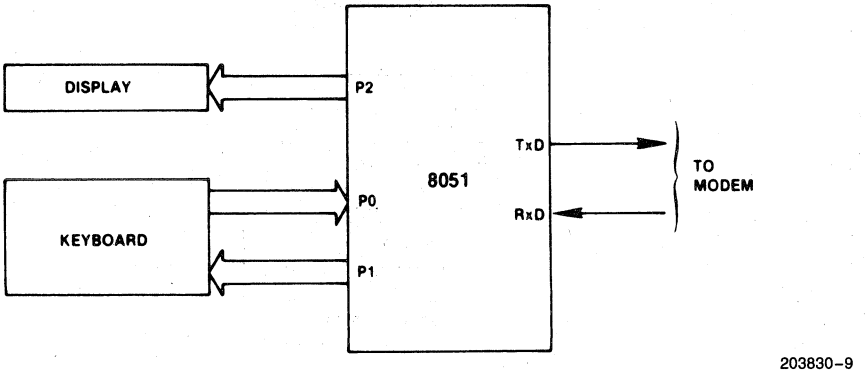
```
MOV     C,SKB_1
MOV     PB_1.1,C
MOV     C,SKB_2
MOV     PB_4.0,C
MOV     C,SKB_3
MOV     PB_2.5,C
MOV     C,SKB_4
MOV     PB_1.0,C
...     .....
...     .....
MOV     C,SKB_55
MOV     PB_5.0,C
MOV     C,SKB_56
MOV     PB_7.2,C
```

b.) Using Accumulator to Collect Bits

```
CLR     A
MOV     C,SKB_14
RLC     A
MOV     C,SKB_17
RLC     A
MOV     C,SKB_11
RLC     A
MOV     C,SKB_24
RLC     A
MOV     C,SKB_1
RLC     A
MOV     C,SKB_5
RLC     A
MOV     PB_1,A
...     .....
...     .....
MOV     C,SKB_29
RLC     A
MOV     C,SKB_32
RLC     A
MOV     PB_8,A
```



a.) Using Multi-Chip Processor Technology



b.) Using One Single-Chip Microcomputer

Figure 11. Secure Banking Terminal Block Diagram

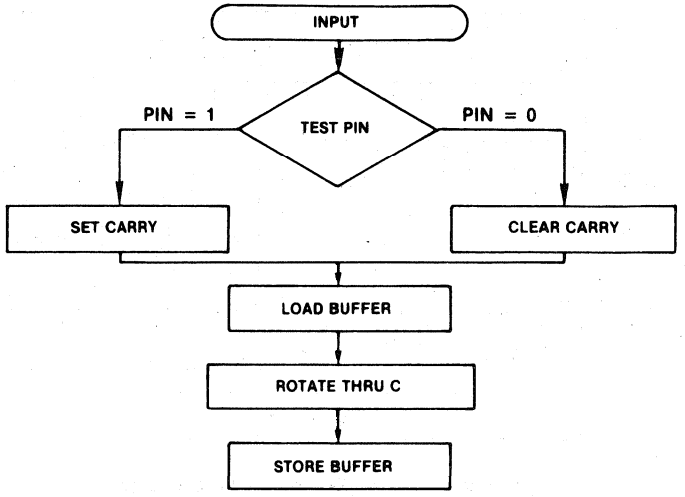
Design Example #2—Software Serial I/O

An exercise often imposed on beginning microcomputer students is to write a program simulating a UART. Though doing this with the 8051 Family may appear to be a moot point (given that the hardware for a full UART is on-chip), it is still instructive to see how it would be done, and maintains a product line tradition.

As it turns out, the 8051 microcomputers can receive or transmit serial data via software very efficiently using the Boolean instruction set. Since any I/O pin may be a serial input or output, several serial links could be maintained at once.

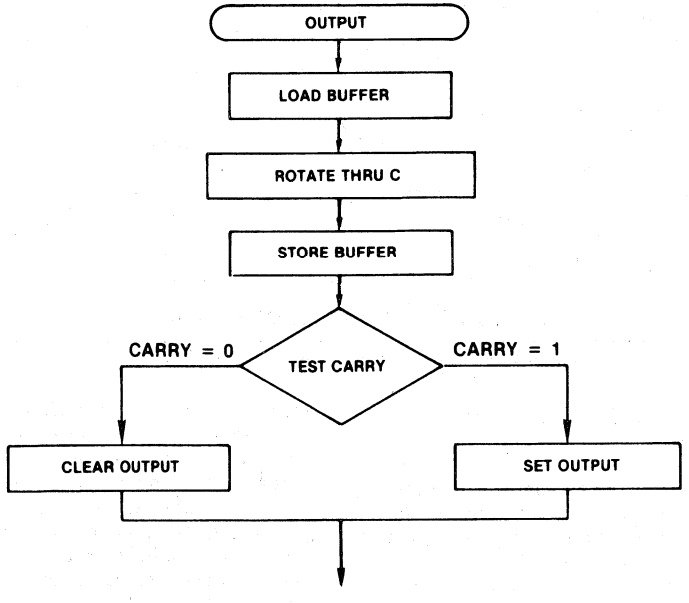
Figures 12a and 12b show algorithms for receiving or transmitting a byte of data. (Another section of program would invoke this algorithm eight times, synchronizing it with a start bit, clock signal, software delay, or timer interrupt.) Data is received by testing an input pin, setting the carry to the same state, shifting the carry into a data buffer, and saving the partial frame in internal RAM. Data is transmitted by shifting an output buffer through the carry, and generating each bit on an output pin.

A side-by-side comparison of the software for this common "bit-banging" application with three different microprocessor architectures is shown in Table 5a and 5b. The 8051 solution is more efficient than the others on every count!



203830-10

a.) Reception



203830-11

b.) Transmission

Figure 12. Serial I/O Algorithms

Table 5. Serial I/O Programs for Various Microprocessors

a.) Input Routine.

8085		8048		8051
IN	SERPORT			MOV C,SERPIN
ANI	MASK	CLR	C	
JZ	I.O	JNT0	I.O	
CMC		CPL	C	
I.O: LXI	HL,SERBUF	MOV	R0,#SERBUF	
MOV	A,M	MOV	A,@R0	MOV A,SERBUF
RR		RRC	A	RRC A
MOV	M,A	MOV	@R0,A	MOV SERBUF,A

RESULTS:

8 INSTRUCTIONS	7 INSTRUCTIONS	4 INSTRUCTIONS
14 BYTES	9 BYTES	7 BYTES
56 STATES	9 CYCLES	4 CYCLES
19 uSEC.	22.5 uSEC.	4 uSEC.

b.) Output Routine.

8085		8048		8051
LXI	HL,SERBUF	MOV	R0,#SERBUF	
MOV	A,M	MOV	A,@R0	MOV A,SERBUF
RR		RRC	A	RRC A
MOV	M,A	MOV	@R0,A	MOV SERBUF,A
IN	SERPORT			
JC	HI	JC	HI	
I.O: ANI	NOT MASK	ANL	SERPRT,#NOT MASK	MOV SERPIN,C
JMP	CNT	JMP	CNT	
HI: ORI	MASK	HI: ORL	SERPRT,#MASK	
CNT: OUT	SERPORT	CNT:		

RESULTS:

10 INSTRUCTIONS	8 INSTRUCTIONS	4 INSTRUCTIONS
20 BYTES	13 BYTES	7 BYTES
72 STATES	11 CYCLES	5 CYCLES
24 uSEC.	27.5 uSEC.	5 uSEC.

203830-30

Design Example #3—Combinatorial Logic Equations

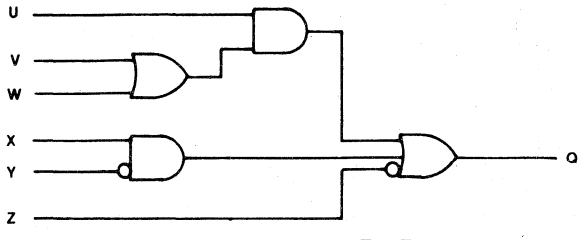
Next we'll look at some simple uses for bit-test instructions and logical operations. (This example is also presented in Application Note AP-69.)

Virtually all hardware designers have solved complex functions using combinatorial logic. While the hardware involved may vary from relay logic, vacuum tubes, or TTL or to more esoteric technologies like fluidics, in each case the goal is the same: to solve a problem represented by a logical function of several Boolean variables.

Figure 13 shows TTL and relay logic diagrams for a function of the six variables U through Z. Each is a solution of the equation.

$$Q = (U \bullet (V + W)) + (X \bullet \overline{Y}) + \overline{Z}$$

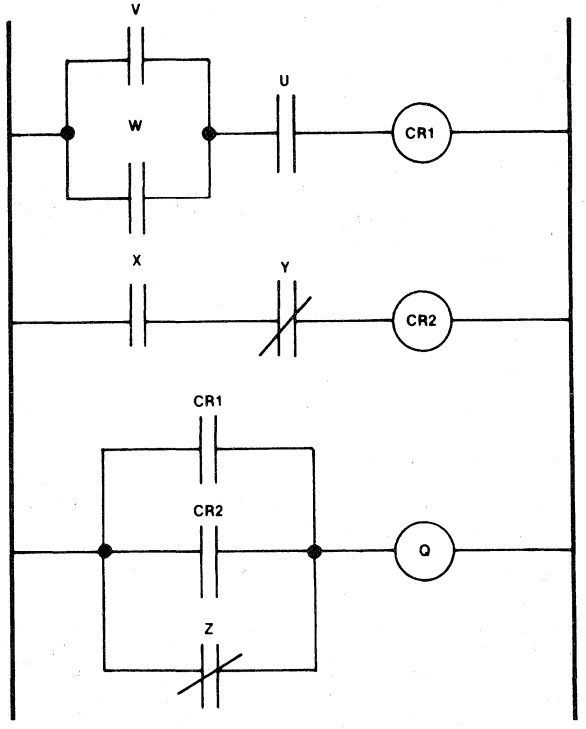
Equations of this sort might be reduced using Karnaugh Maps or algebraic techniques, but that is not the purpose of this example. As the logic complexity increases, so does the difficulty of the reduction process. Even a minor change to the function equations as the design evolves would require tedious re-reduction from scratch.



203830-12

$Q = (U \bullet (V + W)) + (X \bullet \overline{Y}) + \overline{Z}$

a.) Using TTL



203830-13

b.) Using Relay Logic

Figure 13. Hardware Implementations of Boolean Functions

For the sake of comparison we will implement this function three ways, restricting the software to three proper subsets of the MCS-51 instruction set. We will also assume that U and V are input pins from different input ports, W and X are status bits for two peripheral controllers, and Y and Z are software flags set up earlier in the program. The end result must be written to an output pin on some third port. The first two implementations follow the flow-chart shown in Figure 14. Program flow would embark on a route down a test-and-branch tree and leaves either the "True" or "Not True" exit ASAP—as soon as the proper result has been determined. These exits then rewrite the output port with the result bit respectively one or zero.

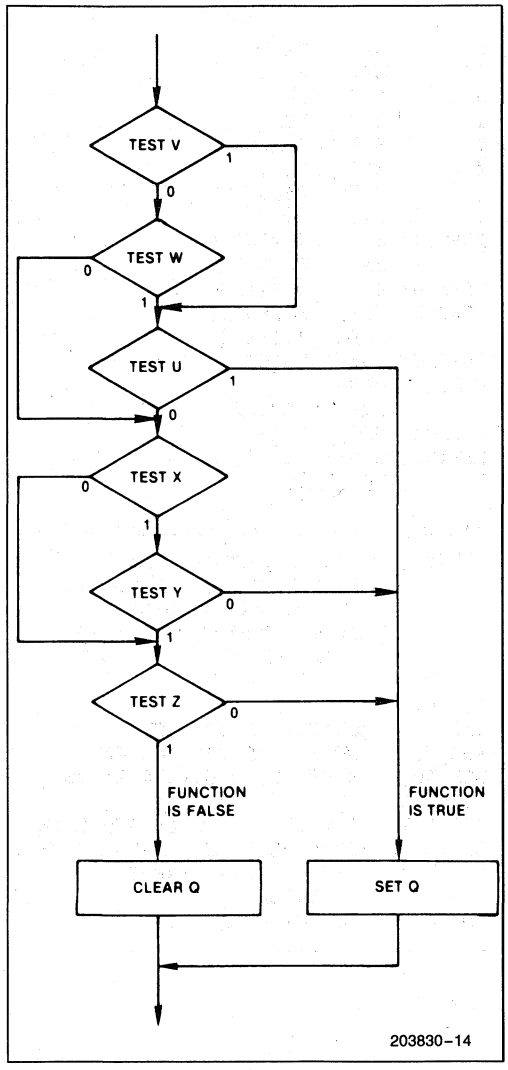


Figure 14. Flow Chart for Tree-Branching Algorithm

Other digital computers must solve equations of this type with standard word-wide logical instructions and conditional jumps. So for the first implementation, we won't use any generalized bit-addressing instructions. As we shall soon see, being constrained to such an instruction subset produces somewhat sloppy software solutions. MCS-51 mnemonics are used in Example 2a: other machines might further cloud the situation by requiring operation-specific mnemonics like INPUT, OUTPUT, LOAD, STORE, etc., instead of the MOV mnemonic used for all variable transfers in the 8051 instruction set.

The code which results is cumbersome and error prone. It would be difficult to prove whether the software worked for all input combinations in programs of this sort. Furthermore, execution time will vary widely with input data.

Thanks to the direct bit-test operations, a single instruction can replace each move mask conditional jump sequence in Example 2a, but the algorithm would be equally convoluted (see Example 2b). To lessen the confusion "a bit" each input variable is assigned a symbolic name.

A more elegant and efficient implementation (Example 2c) strings together the Boolean ANL and ORL functions to generate the output function with straight-line code. When finished, the carry flag contains the result, which is simply copied out to the destination pin. No flow chart is needed—code can be written directly from the logic diagrams in Figure 14. The result is simplicity itself: fast, flexible, reliable, easy to design, and easy to debug.

An 8051 program can simulate an N-input AND or OR gate with at most N + 1 lines of source program—one for each input and one line to store the results. To simulate NAND and NOR gates, complement the carry after computing the function. When some inputs to the gate have "inversion bubbles", perform the ANL or ORL operation on inverted operands. When the first input is inverted, either load the operand into the carry and then complement it, or use DeMorgan's Theorem to convert the gate to a different form.

Example 2. Software Solutions to Logic Function of Figure 13.

a.) Using only byte-wide logical instructions

```
:BFUNCI  SOLVE RANDOM LOGIC
;        FUNCTION OF 6 VARIABLES
;        BY LOADING AND MASKING
;        THE APPROPRIATE BITS IN
;        THE ACCUMULATOR. THEN
;        EXECUTING CONDITIONAL
;        JUMPS BASED ON ZERO
;        CONDITION. (APPROACH USED
;        BY BYTE-ORIENTED
;        ARCHITECTURES.) BYTE AND
;        MASK VALUES CORRESPOND TO
;        RESPECTIVE BYTE ADDRESS
;        AND BIT POSITIONS.
;
OUTBUF   DATA 22H
;OUTPUT PIN STATE MAP
;
```

```
TESTV:  MOV  A,P2
        ANL  A,#00000100B
        JNZ  TESTU
        MOV  A,TCON
        ANL  A,#00100000B
        JZ   TESTX
TESTU:  MOV  A,P1
        ANL  A,#00000010B
        JNZ  SETQ
TESTX:  MOV  A,TCON
        ANL  A,#00001000B
        JZ   TESTZ
        MOV  A,20H
        ANL  A,#00000001B
        JZ   SETQ
TESTZ:  MOV  A,21H
        ANL  A,#00000010B
        JZ   SETQ
CLRQ:   MOV  A,OUTBUF
        ANL  A,#11110111B
        JMP  OUTQ
SETQ:   MOV  A,OUTBUF
        ORL  A,#00001000B
OUTQ:   MOV  OUTBUF,A
        MOV  P3,A
```

b.) Using only bit-test instructions

```
:BFUNC2  SOLVE A RANDOM LOGIC
;        FUNCTION OF 6 VARIABLES
;        BY DIRECTLY POLLING EACH
;        BIT. (APPROACH USING
;        MCS-51 UNIQUE BIT-TEST
;        INSTRUCTION CAPABILITY.)
;        SYMBOLS USED IN LOGIC
;        DIAGRAM ASSIGNED TO
;        CORRESPONDING 8x51 BIT
;        ADDRESSES.
;
U        BIT   P1.1
V        BIT   P2.2
W        BIT   TF0
X        BIT   IE1
Y        BIT   20H.0
Z        BIT   21H.1
Q        BIT   P3.3
;        ...   ....
TEST_V:  JB    V,TEST_U
         JNB   W,TEST_X
TEST_U:  JB    U,SET_Q
TEST_X:  JNB   X,TEST_Z
         JNB   Y,SET_Q
TEST_Z:  JNB   Z,SET_Q
CLR_Q:   CLR   Q
         JMP   NXTTST
SET_Q:   SETB  Q
NXTTST:(CONTINUATION OF
       :PROGRAM)
```

c.) Using logical operations on Boolean variables

```
:FUNC3  SOLVE A RANDOM LOGIC
;       FUNCTION OF 6 VARIABLES
;       USING STRAIGHT_LINE
;       LOGICAL INSTRUCTIONS ON
;       MCS-51 BOOLEAN VARIABLES.
;
MOV C,V
ORL C,W   ;OUTPUT OF OR GATE
ANL C,U   ;OUTPUT OF TOP AND GATE
MOV F0,C  ;SAVE INTERMEDIATE STATE
MOV C,X
ANL C,Y   ;OUTPUT OF BOTTOM AND GATE
ORL C,F0  ;INCLUDE VALUE SAVED ABOVE
ORL C,Z   ;INCLUDE LAST INPUT
          ;VARIABLE
MOV Q,C   ;OUTPUT COMPUTED RESULT
```

An upper-limit can be placed on the complexity of software to simulate a large number of gates by summing the total number of inputs and outputs. The *actual* total should be somewhat shorter, since calculations can be "chained," as shown. The output of one gate is often the first input to another, bypassing the intermediate variable to eliminate two lines of source.

Design Example #4—Automotive Dashboard Functions

Now let's apply these techniques to designing the software for a complete controller system. This application is patterned after a familiar real-world application which isn't nearly as trivial as it might first appear: automobile turn signals.

Imagine the three position turn lever on the steering column as a single-pole, triple-throw toggle switch. In its central position all contacts are open. In the up or down positions contacts close causing corresponding lights in the rear of the car to blink. So far very simple.

Two more turn signals blink in the front of the car, and two others in the dashboard. All six bulbs flash when an emergency switch is closed. A thermo-mechanical relay (accessible under the dashboard in case it wears out) causes the blinking.

Applying the brake pedal turns the tail light filaments on constantly . . . unless a turn is in progress, in which case the blinking tail light is not affected. (Of course, the front turn signals and dashboard indicators are not affected by the brake pedal.) Table 6 summarizes these operating modes.

Table 6. Truth Table for Turn-Signal Operation

Input Signals				Output Signals			
Brake Switch	**Emerg. Switch**	**Left Turn Switch**	**Right Turn Switch**	**Left Front & Dash**	**Right Front & Dash**	**Left Rear**	**Right Rear**
0	0	0	0	Off	Off	Off	Off
0	0	0	1	Off	Blink	Off	Blink
0	0	1	0	Blink	Off	Blink	Off
0	1	0	0	Blink	Blink	Blink	Blink
0	1	0	1	Blink	Blink	Blink	Blink
0	1	1	0	Blink	Blink	Blink	Blink
1	0	0	0	Off	Off	On	On
1	0	0	1	Off	Blink	On	Blink
1	0	1	0	Blink	Off	Blink	On
1	1	0	0	Blink	Blink	On	On
1	1	0	1	Blink	Blink	On	Blink
1	1	1	0	Blink	Blink	Blink	On

But we're not done yet. Each of the exterior turn signal (but not the dashboard) bulbs has a second, somewhat dimmer filament for the parking lights. Figure 15 shows TTL circuitry which could control all six bulbs. The signals labeled "High Freq." and "Low Freq." represent two square-wave inputs. Basically, when one of the turn switches is closed or the emergency switch is activated the low frequency signal (about 1 Hz) is gated through to the appropriate dashboard indicator(s) and turn signal(s). The rear signals are also activated when the brake pedal is depressed provided a turn is not being made in the same direction. When the parking light switch is closed the higher frequency oscillator is gated to each front and rear turn signal, sustaining a low-intensity background level. (This is to eliminate the need for additional parking light filaments.)

In most cars, the switching logic to generate these functions requires a number of multiple-throw contacts. As many as 18 conductors thread the steering column of some automobiles solely for turn-signal and emergency blinker functions. (The author discovered this recently to his astonishment and dismay when replacing the whole assembly because of one burned contact.)

A multiple-conductor wiring harness runs to each corner of the car, behind the dash, up the steering column, and down to the blinker relay below. Connectors at each termination for each filament lead to extra cost and labor during construction, lower reliability and safety, and more costly repairs. And considering the system's present complexity, increasing its reliability or detecting failures would be quite difficult.

There are two reasons for going into such painful detail describing this example. First, to show that the messiest part of many system designs is determining what the controller should do. Writing the software to solve these functions will be comparatively easy. Secondly, to show the many potential failure points in the system. Later we'll see how the peripheral functions and intelligence built into a microcomputer (with a little creativity) can greatly reduce external interconnections and mechanical part count.

The Single-Chip Solution

The circuit shown in Figure 16 indicates five input pins to the five input variables—left-turn select, right-turn select, brake pedal down, emergency switch on, and parking lights on. Six output pins turn on the front, rear, and dashboard indicators for each side. The microcomputer implements all logical functions through software, which periodically updates the output signals as time elapses and input conditions change.

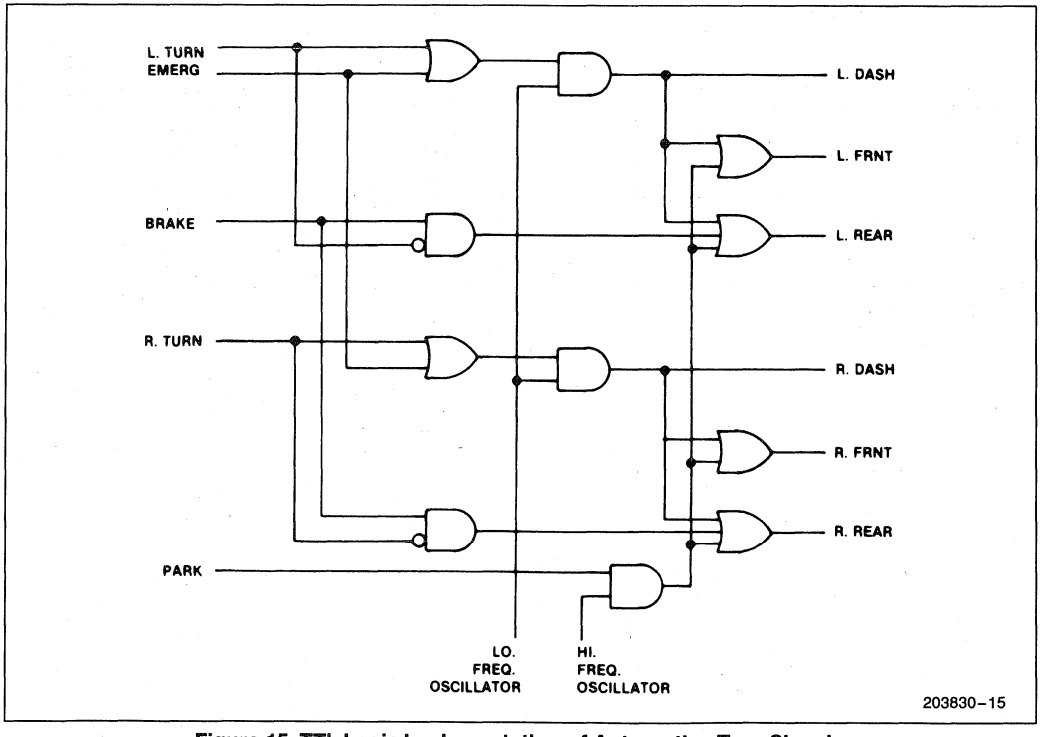


Figure 15. TTL Logic Implementation of Automotive Turn Signals

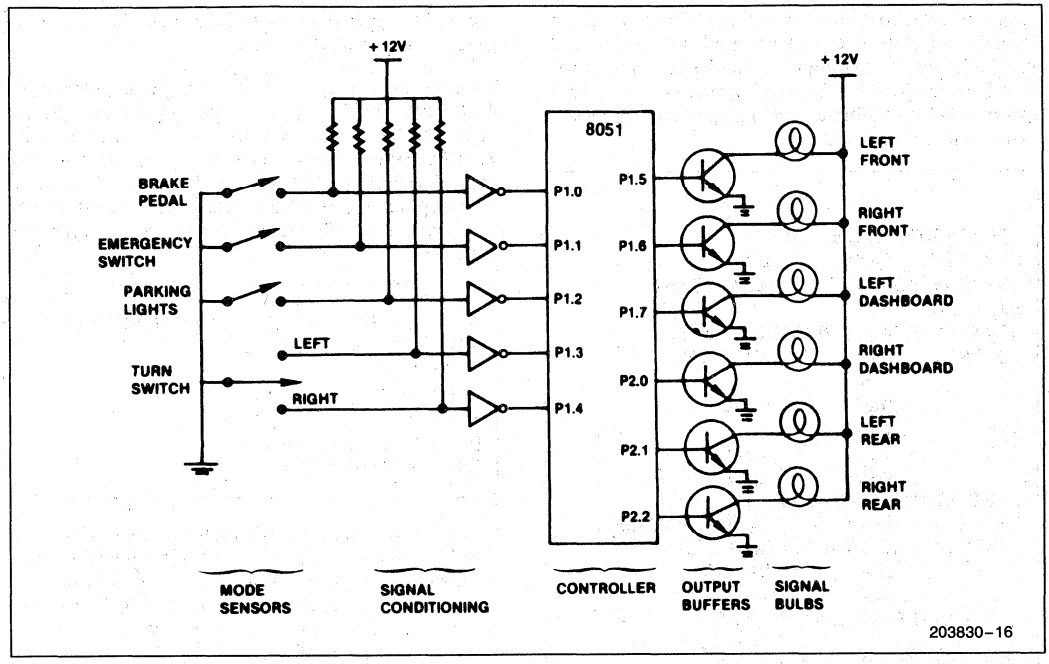


Figure 16. Microcomputer Turn-Signal Connections

Design Example #3 demonstrated that symbolic addressing with user-defined bit names makes code and documentation easier to write and maintain. Accordingly, we'll assign these I/O pins names for use throughout the program. (The format of this example will differ somewhat from the others. Segments of the overall program will be presented in sequence as each is described.)

```
;
;       INPUT PIN DECLARATIONS:
;(ALL INPUTS ARE POSITIVE-TRUE LOGIC)
;
BRAKE   BIT P1.0 ;BRAKE PEDAL
                 ;DEPRESSED
EMERG   BIT P1.1 ;EMERGENCY BLINKER
                 ;ACTIVATED
PARK    BIT P1.2 ;PARKING LIGHTS ON
I_TURN  BIT P1.3 ;TURN LEVER DOWN
R_TURN  BIT P1.4 ;TURN LEVER UP
;
;       OUTPUT PIN DECLARATIONS:
;
I_FRNT  BIT P1.5 ;FRONT LEFT-TURN
                 ;INDICATOR
R_FRNT  BIT P1.6 ;FRONT RIGHT-TURN
                 ;INDICATOR
I_DASH  BIT P1.7 ;DASHBOARD LEFT-TURN
                 ;INDICATOR
```

```
R_DASH  BIT P2.0 ;DASHBOARD RIGHT-
                 ;TURN INDICATOR
I_REAR  BIT P2.1 ;REAR LEFT-TURN
                 ;INDICATOR
R_REAR  BIT P2.2 ;REAR RIGHT-TURN
                 ;INDICATOR
;
```

Another key advantage of symbolic addressing will appear further on in the design cycle. The locations of cable connectors, signal conditioning circuitry, voltage regulators, heat sinks, and the like all affect P.C. board layout. It's quite likely that the somewhat arbitrary pin assignment defined early in the software design cycle will prove to be less than optimum; rearranging the I/O pin assignment could well allow a more compact module, or eliminate costly jumpers on a single-sided board. (These considerations apply especially to automotive and other cost-sensitive applications needing single-chip controllers.) Since other architectures mask bytes or use "clever" algorithms to isolate bits by rotating them into the carry, re-routing an input signal (from bit 1 of port 1, for example, to bit 4 of port 3) could require extensive modifications throughout the software.

The Boolean Processor's direct bit addressing makes such changes absolutely trivial. The number of the port containing the pin is irrelevent, and masks and complex

program structures are not needed. Only the initial Boolean variable declarations need to be changed; ASM51 automatically adjusts all addresses and symbolic references to the reassigned variables. The user is assured that no additional debugging or software verification will be required.

```
;           ...         .....
;INTERRUPT RATE SUBDIVIDER
SUB_DIV    DATA        20H
;HIGH-FREQUENCY OSCILLATOR BIT
HI_FREQ    BIT         SUB_DIV,0
;LOW-FREQUENCY OSCILLATOR BIT
LO_FREQ    BIT         SUB_DIV,7
;           ...
           ORG         0000H
JMP        INIT
;           ...         .....
           ORG         100H
;PUT TIMER 0 IN MODE 1
INIT;      MOV         TMOD,#00000001B
;INITIALIZE TIMER REGISTERS
           MOV         TL0,#0
           MOV         TH0,#-16
;SUBDIVIDE INTERRUPT RATE BY 244
           MOV         SUB_DIV,#244
;ENABLE TIMER INTERRUPTS
           SETB        ET0
;GLOBALLY ENABLE ALL INTERRUPTS
           SETB        EA
;START TIMER
           SETB        TR0
;
;(CONTINUE WITH BACKGROUND PROGRAM)
;
;PUT TIMER 0 IN MODE 1
;INITIALIZE TIMER REGISTERS

;SUBDIVIDE INTERRUPT RATE BY 244
;ENABLE TIMER INTERRUPTS
;GLOBALLY ENABLE ALL INTERRUPTS
;START TIMER
```

Timer 0 (one of the two on-chip timer counters) replaces the thermo-mechanical blinker relay in the dashboard controller. During system initialization it is configured as a timer in mode 1 by setting the least significant bit of the timer mode register (TMOD). In this configuration the low-order byte (TL0) is incremented every machine cycle, overflowing and incrementing the high-order byte (TH0) every 256 μs. Timer interrupt 0 is enabled so that a hardware interrupt will occur each time TH0 overflows.

An eight-bit variable in the bit-addressable RAM array will be needed to further subdivide the interrupts via software. The lowest-order bit of this counter toggles very fast to modulate the parking lights: bit 7 will be "tuned" to approximately 1 Hz for the turn- and emergency-indicator blinking rate.

Loading TH0 with -16 will cause an interrupt after 4.096 ms. The interrupt service routine reloads the high-order byte of timer 0 for the next interval, saves the CPU registers likely to be affected on the stack, and then decrements SUB_DIV. Loading SUB_DIV. with 244 initially and each time it decrements to zero will produce a 0.999 second period for the highest-order bit.

```
ORG   000BH   ;TIMER 0 SERVICE VECTOR
MOV   TH0,#-16
PUSH  PSW
PUSH  ACC
PUSH  B
DJNZ  SUB_DIV,TOSERV
MOV   SUB_DIV,#244
```

The code to sample inputs, perform calculations, and update outputs—the real "meat" of the signal controller algorithm—may be performed either as part of the interrupt service routine or as part of a background program loop. The only concern is that it must be executed at least serveral dozen times per second to prevent parking light flickering. We will assume the former case, and insert the code into the timer 0 service routine.

First, notice from the logic diagram (Figure 15) that the subterm (PARK • H_FREQ), asserted when the parking lights are to be on dimly, figures into four of the six output functions. Accordingly, we will first compute that term and save it in a temporary location named "DIM". The PSW contains two general purpose flags: F0, which corresponds to the 8048 flag of the same name, and PSW.1. Since the PSW has been saved and will be restored to its previous state after servicing the interrupt, we can use either bit for temporary storage.

```
  DIM BIT   PSW.1 ;DECLARE TEMP
                  ;STORAGE FLAG
; ... .....
  MOV C,PARK      ;GATE PARKING
                  ;LIGHT SWITCH
  ANL HI_FREQ     ;WITH HIGH
                  ;FREQUENCY
                  ;SIGNAL
  MOV DIM,C       ;AND SAVE IN
                  ;TEMP. VARIABLE
```

This simple three-line section of code illustrates a remarkable point. The software indicates in very abstract terms exactly what function is being performed, inde-

pendent of the hardware configuration. The fact that these three bits include an input pin, a bit within a program variable, and a software flag in the PSW is totally invisible to the programmer.

Now generate and output the dashboard left turn signal.

```
;
  MOV C,L_TURN      ;SET CARRY IF
                    ;TURN
  ORL C,EMERG       ;OR EMERGENCY
                    ;SELECTED
  ANL C,LO_FREQ     ;GATE IN 1 HZ
                    ;SIGNAL
  MOV I_DASH,C      ;AND OUTPUT TO
                    ;DASHBOARD
```

To generate the left front turn signal we only need to add the parking light function in F0. But notice that the function in the carry will also be needed for the rear signal. We can save effort later by saving its current state in F0.

```
;
  MOV F0,C          ;SAVE FUNCTION
                    ;SO FAR
  ORL C,DIM         ;ADD IN PARKING
                    ;LIGHT FUNCTION
  MOV L_FRNT,C      ;AND OUTPUT TO
                    ;TURN SIGNAL
```

Finally, the rear left turn signal should also be on when the brake pedal is depressed, provided a left turn is not in progress.

```
MOV C,BRAKE       ;GATE BRAKE
                  ;PEDAL SWITCH
ANL C,L_TURN      ;WITH TURN
                  ;LEVER
ORL C,F0          ;INCLUDE TEMP.
                  ;VARIABLE FROM DASH
ORL C,DIM         ;AND PARKING
                  ;LIGHT FUNCTION
MOV L_REAR,C      ;AND OUTPUT TO
                  ;TURN SIGNAL
```

Now we have to go through a similar sequence for the right-hand equivalents to all the left-turn lights. This also gives us a chance to see how the code segments above look when combined.

```
MOV C.R_TURN      ;SET CARRY H-
                  ;TURN
ORL C.EMERG       ;OR EMERGENCY
                  ;SELECTED
ANL C,LO_FREQ     ;IF SO. GATE IN 1
                  ;HZ SIGNAL
MOV R_DASH.C      ;AND OUTPUT TO
                  ;DASHBOARD
MOV F0.C          ;SAVE FUNCTION
                  ;SO FAR
ORL C.DIM         ;ADD IN PARKING
                  ;LIGHT FUNCTION
MOV R_FRNT.C      ;AND OUTPUT TO
                  ;TURN SIGNAL
MOV C.BRAKE       ;GATE BRAKE
                  ;PEDAL SWITCH
ANL C. R_TURN     ;WITH TURN
                  ;LEVER
ORL C.F0          ;INCLUDE TEMP.
                  ;VARIABLE FROM
                  ;DASH
ORL C.DIM         ;AND PARKING
                  ;LIGHT FUNCTION
MOV R_REAR.C      ;AND OUTPUT TO
                  ;TURN SIGNAL
```

(The perceptive reader may notice that simply rearranging the steps could eliminate one instruction from each sequence.)

Now that all six bulbs are in the proper states, we can return from the interrupt routine, and the program is finished. This code essentially needs to reverse the status saving steps at the beginning of the interrupt.

Table 7. Non-Trivial Duty Cycles

Sub_Div Bits								Duty Cycles						
7	6	5	4	3	2	1	0	12.5%	25.0%	37.5%	50.0%	62.5%	75.0%	87.5%
X	X	X	X	X	0	0	0	Off	Off	Off	Off	Off	Off	Off
X	X	X	X	X	0	0	1	Off	Off	Off	Off	Off	Off	On
X	X	X	X	X	0	1	0	Off	Off	Off	Off	Off	On	On
X	X	X	X	X	0	1	1	Off	Off	Off	Off	On	On	On
X	X	X	X	X	1	0	0	Off	Off	Off	On	On	On	On
X	X	X	X	X	1	0	1	Off	Off	On	On	On	On	On
X	X	X	X	X	1	1	0	Off	On	On	On	On	On	On
X	X	X	X	X	1	1	1	On	On	On	On	On	On	On

```
POP  B          ;RESTORE CPU
                ;REGISTERS.
POP ACC
POP PSW
RETI
```

Program Refinements. The luminescence of an incandescent light bulb filament is generally non-linear: the 50% duty cycle of HI_FREQ may not produce the desired intensity. If the application requires, duty cycles of 25%, 75%, etc. are easily achieved by ANDing and ORing in additional low-order bits of SUB_DIV. For example, 30 H/ signals of seven different duty cycles could be produced by considering bits 2–0 as shown in Table 7. The only software change required would be to the code which sets-up variable DIM;

```
MOV C,SUB_DIV.1;START WITH 50
                ;PERCENT
ANL C,SUB_DIV.0;MASK DOWN TO 25
                ;PERCENT
ORL C,SUB_DIV.2;AND BUILD BACK TO
                ;62 PERCENT
MOV DIM,C       ;DUTY CYCLE FOR
                ;PARKING LIGHTS.
```

Interconnections increase cost and decrease reliability. The simple buffered pin-per-function circuit in Figure 16 is insufficient when many outputs require higher-than-TTL drive levels. A lower-cost solution uses the 8051 serial port in the shift-register mode to augment I/O. In mode 0, writing a byte to the serial port data buffer (SBUF) causes the data to be output sequentially through the "RXD" pin while a burst of eight clock pulses is generated on the "TXD" pin. A shift register connected to these pins (Figure 17) will load the data byte as it is shifted out. A number of special peripheral driver circuits combining shift-register inputs with high drive level outputs have been introduced recently.

Cascading multiple shift registers end-to-end will expand the number of outputs even further. The data rate in the I/O expansion mode is one megabaud, or 8 μs. per byte. This is the mode which the serial port defaults to following a reset, so no initialization is required.

The software for this technique uses the B register as a "map" corresponding to the different output functions. The program manipulates these bits instead of the output pins. After all functions have been calculated the B register is shifted by the serial port to the shift-register driver. (While some outputs may glitch as data is shifted through them, at 1 Megabaud most people wouldn't notice. Some shift registers provide an "enable" bit to hold the output states while new data is being shifted in.)

This is where the earlier decision to address bits symbolically throughout the program is going to pay off. This major I/O restructuring is nearly as simple to implement as rearranging the input pins. Again, only the bit declarations need to be changed.

```
I_FRNT BIT B.0  ;FRONT LEFT-TURN
                ;INDICATOR
R_FRNT BIT B.1  ;FRONT RIGHT-TURN
                ;INDICATOR
I_DASH BIT B.2  ;DASHBOARD LEFT-TURN
                ;INDICATOR
R_DASH BIT B.3  ;DASHBOARD RIGHT-TURN
                ;INDICATOR
I_REAR BIT B.4  ;REAR LEFT-TURN
                ;INDICATOR
R_REAR BIT B.5  ;REAR RIGHT-TURN
                ;INDICATOR
```

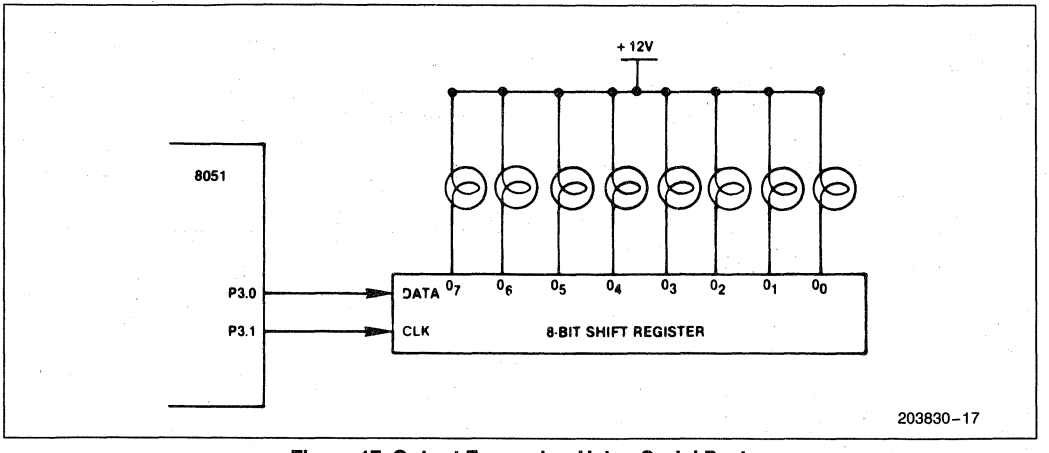


Figure 17. Output Expansion Using Serial Port

The original program to compute the functions need not change. After computing the output variables, the control map is transmitted to the buffered shift register through the serial port.

```
MOV SBUF,B ;LOAD BUFFER AND TRANSMIT
```

The Boolean Processor solution holds a number of advantages over older methods. Fewer switches are required. Each is simpler, requiring fewer poles and lower current contacts. The flasher relay is eliminated entirely. Only six filaments are driven, rather than 10. The wiring harness is therefore simpler and less expensive—one conductor for each of the six lamps and each of the five sensor switches. The fewer conductors use far fewer connectors. The whole system is more reliable.

And since the system is much simpler it would be feasible to implement redundancy and or fault detection on the four main turn indicators. Each could still be a standard double filament bulb, but with the filaments driven in parallel to tolerate single-element failures.

Even with redundancy, the lights will eventually fail. To handle this inescapable fact current or voltage sensing circuits on each main drive wire can verify that each bulb and its high-current driver is functioning properly. Figure 18 shows one such circuit.

Assume all of the lights are turned on except one: i.e., all but one of the collectors are grounded. For the bulb which is turned off, if there is continuity from +12V through the bulb base and filament, the control wire, all connectors, and the P.C. board traces, and if the transistor is indeed not shorted to ground, then the collector will be pulled to +12V. This turns on the base of Q8 through the corresponding resistor, and grounds the input pin, verifying that the bulb circuit is operational. The continuity of each circuit can be checked by software in this way.

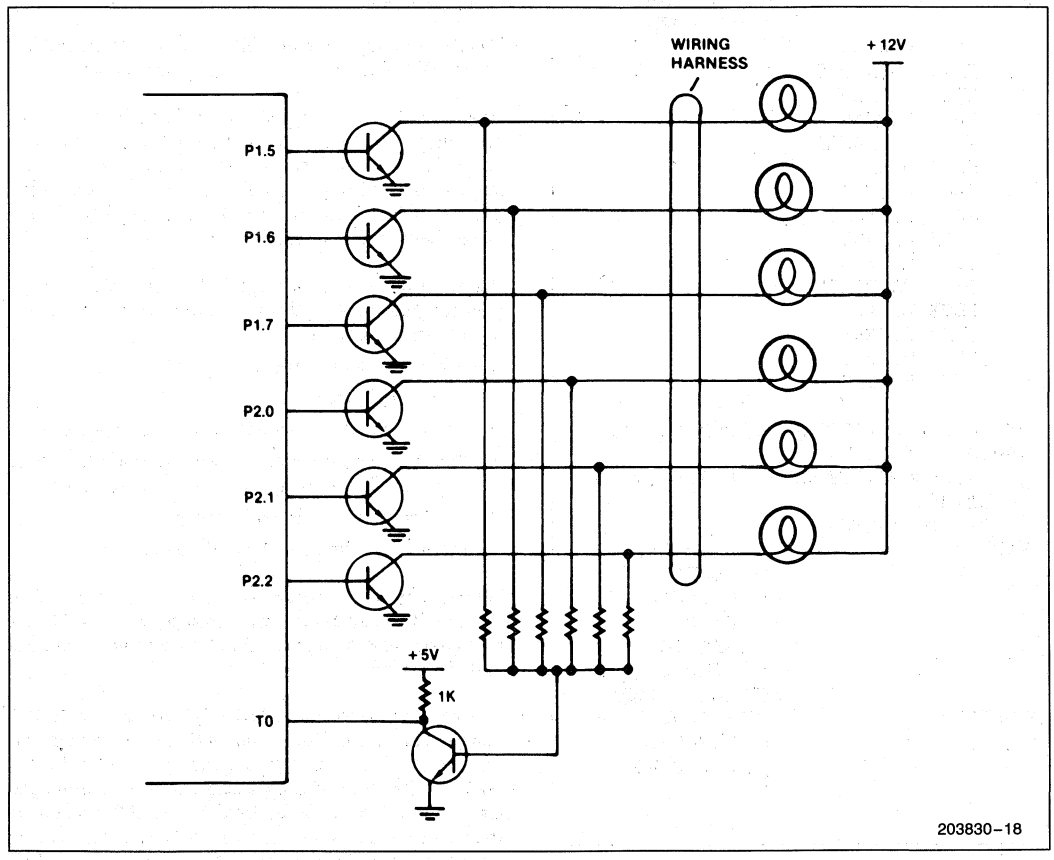


Figure 18

Now turn *all* the bulbs on, grounding all the collectors. Q7 should be turned off, and the Test pin should be high. However, a control wire shorted to + 12V or an open-circuited drive transistor would leave one of the collectors at the higher voltage even now. This too would turn on Q7, indicating a different type of failure. Software could perform these checks once per second by executing the routine every time the software counter SUB_DIV is reloaded by the interrupt routine.

```
DJNZ SUB_DIV,TOSERV
MOV SUB_DIV,#244      ;RELOAD COUNTER
ORL P1,#11100000B     ;SET CONTROL
                      ;OUTPUTS HIGH
ORL P2,#00000111B
CLR I_FRNT            ;FLOAT DRIVE
                      ;COLLECTOR
JB  TO,FAULT          ;TO SHOULD BE
                      ;PULLED LOW
SETB L_FRNT           ;PULL COLLECTOR
                      ;BACK DOWN
    CLR  L_DASH
    JB   TO,FAULT
    SETB L_DASH
    CLR  L_REAR
    JB   TO,FAULT
    SETB L_REAR
    CLR  R_FRNT
    JB   TO,FAULT
    SETB R_FRNT
    CLR  R_DASH
    JB   TO,FAULT
    SETB R_DASH
    CLR  R_REAR
    JB   TO,FAULT
    SETB R_REAR
;
;WITH ALL COLLECTORS GROUNDED. TO
 SHOULD BE HIGH
;IF SO. CONTINUE WITH INTERRUPT
 ROUTINE.
  JB   TO,TOSERV
FAULT:                ;ELECTRICAL
                      ;FAILURE
                      ;PROCESSING
                      ;ROUTINE
                      ;(LEFT TO
                      ;READER'S
                      ;IMAGINATION)
TOSERV:               ;CONTINUE WITH
                      ;INTERRUPT
                      ;PROCESSING
;
;
```

The complete assembled program listing is printed in Appendix A. The resulting code consists of 67 program statements, not counting declarations and comments, which assemble into 150 bytes of object code. Each pass through the service routine requires (coincidently) 67 μs plus 32 μs once per second for the electrical test. If executed every 4 ms as suggested this software would typically reduce the throughput of the background program by less than 2%.

Once a microcomputer has been designed into a system, new features suddenly become virtually free. Software could make the emergency blinkers flash alternately or at a rate faster than the turn signals. Turn signals could override the emergency blinkers. Adding more bulbs would allow multiple tail light sequencing and syncopation—true flash factor, so to speak.

Design Example #5—Complex Control Functions

Finally, we'll mix byte and bit operations to extend the use of 8051 into extremely complex applications.

Programmers can arbitrarily assign I/O pins to input and output functions only if the total does not exceed 32, which is insufficient for applications with a very large number of input variables. One way to expand the number of inputs is with a technique similar to multiplexed-keyboard scanning.

Figure 19 shows a block diagram for a moderately complex programmable industrial controller with the following characteristics:

- 64 input variable sensors:
- 12 output signals:
- Combinational and sequential logic computations:
- Remote operation with communications to a host processor via a high-speed full-duplex serial link:
- Two prioritized external interrupts:
- Internal real-time and time-of-day clocks.

While many microprocessors could be programmed to provide these capabilities with assorted peripheral support chips, an 8051 microcomputer needs no other integrated circuits!

The 64 input sensors are logically arranged as an 8x8 matrix. The pins of Port 1 sequentially enable each column of the sensor matrix: as each is enabled Port 0 reads in the state of each sensor in that column. An eight-byte block in bit-addressable RAM remembers the data as it is read in so that after each complete scan cycle there is an internal map of the current state of all sensors. Logic functions can then directly address the elements of the bit map.

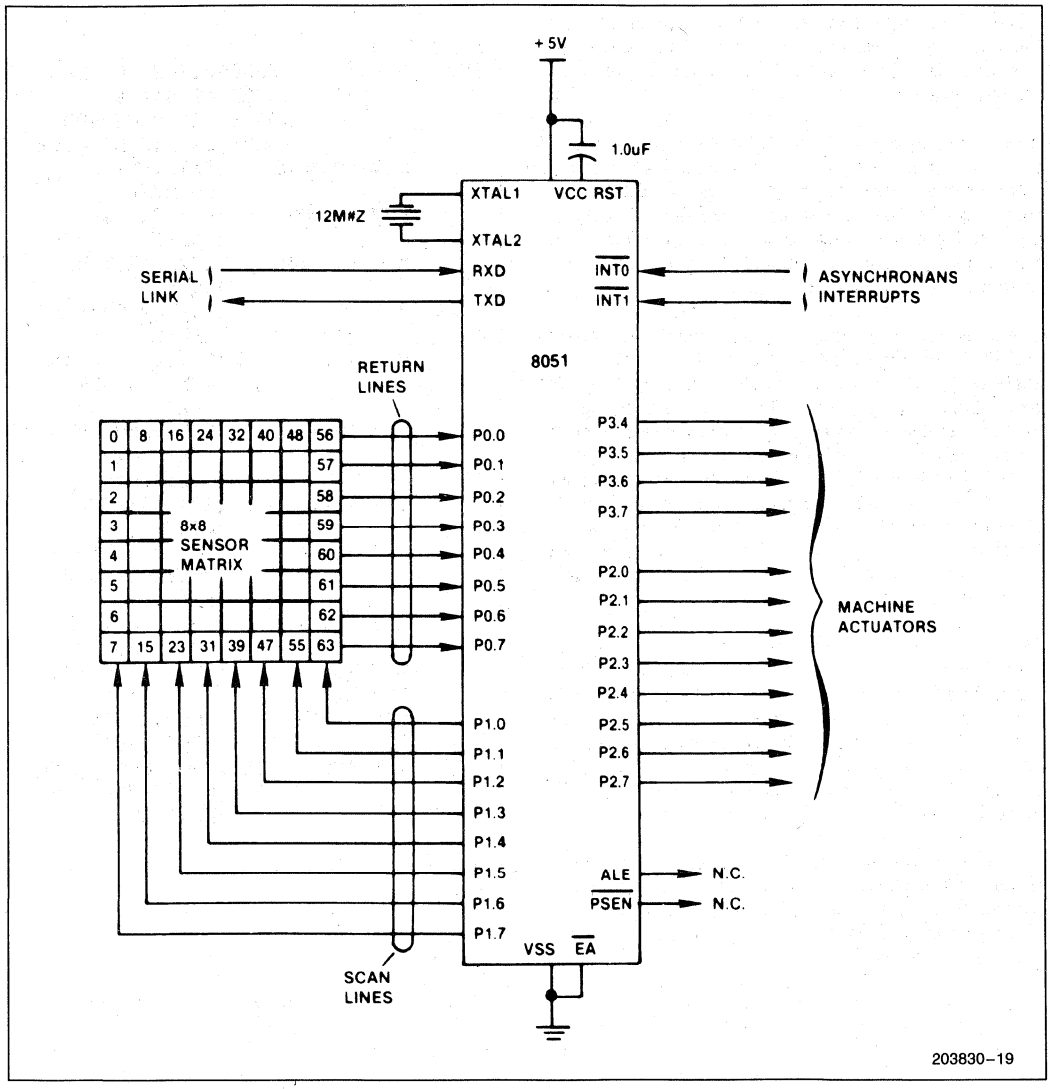


Figure 19. Block Diagram of 64-Input Machine Controller

The computer's serial port is configured as a nine-bit UART, transferring data at 17,000 bytes-per-second. The ninth bit may distinguish between address and data bytes.

The 8051 serial port can be configured to detect bytes with the address bit set, automatically ignoring all others. Pins INT0 and INT1 are interrupts configured respectively as high-priority, falling-edge triggered and low-priority, low-level triggered. The remaining 12 I/O pins output TTL-level control signals to 12 actuators.

There are several ways to implement the sensor matrix circuitry, all logically similar. Figure 20a shows one possibility. Each of the 64 sensors consists of a pair of simple switch contacts in series with a diode to permit multiple contact closures throughout the matrix.

The scan lines from Port 1 provide eight un-encoded active-high scan signals for enabling columns of the matrix. The return lines on rows where a contact is closed are pulled high and read as logic ones. Open return lines are pulled to ground by one of the 40 kΩ resistors and are read as zeroes. (The resistor values must be chosen to ensure all return lines are pulled above the 2.0V logic threshold, even in the worst-case,

where all contacts in an enabled column are closed.) Since P0 is provided open-collector outputs and high-impedance MOS inputs its input loading may be considered negligible.

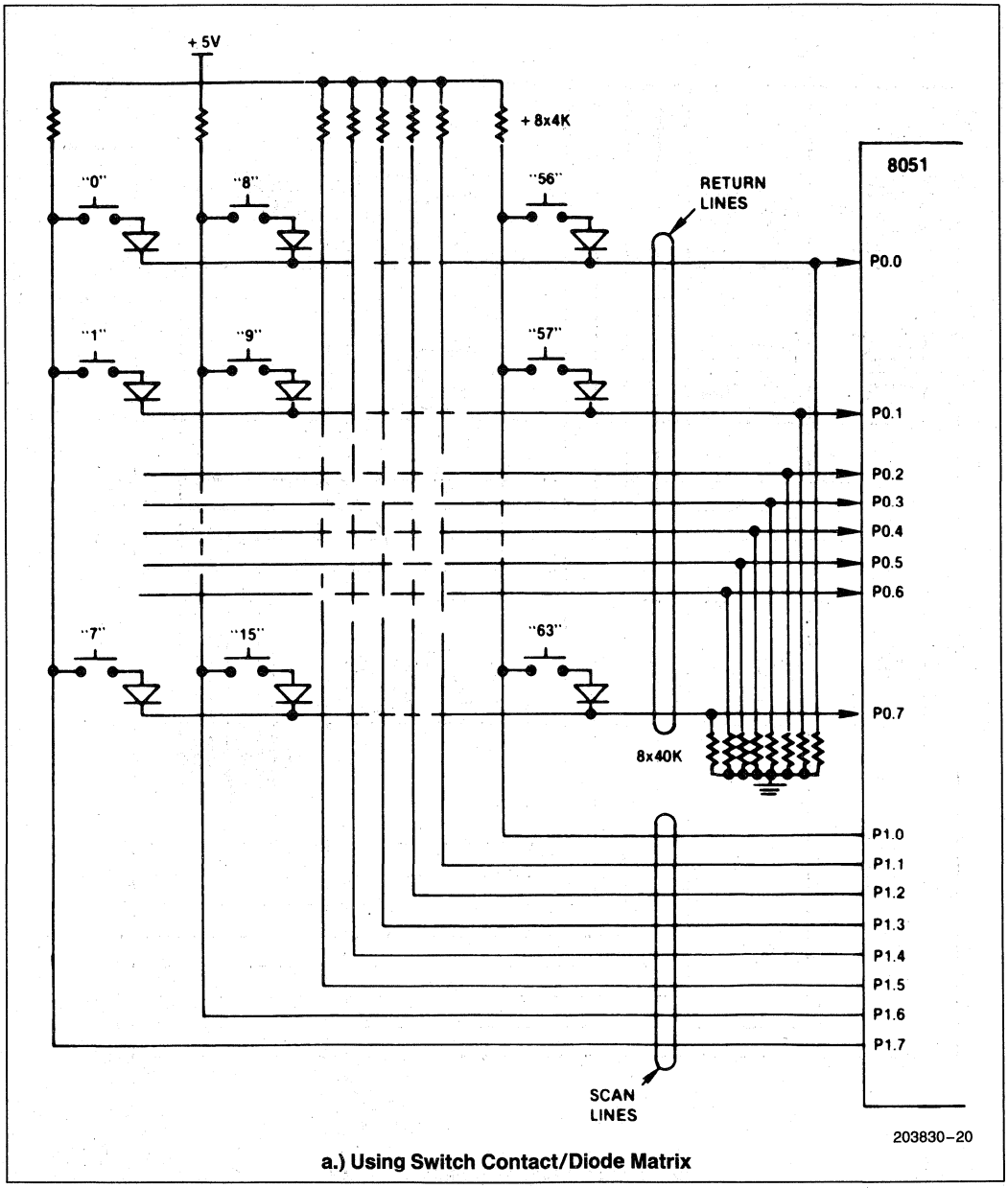
The circuits in Figures 20b–20d are variations on this theme. When input signals must be electrically isolated from the computer circuitry as in noisy industrial environments, phototransistors can replace the switch diode pairs and provide optical isolation as in Figure 20b. Additional opto-isolators could also be used on the control output and special signal lines.

The other circuits assume that input signals are already at TTL levels. Figure 20c uses octal three-state buffers enabled by active-low scan signals to gate eight signals onto Port 0. Port 0 is available for memory expansion or peripheral chip interfacing between sensor matrix scans. Eight-to-one multiplexers in Figure 20d select one of eight inputs for each return line as determined by encoded address bits output on three pins of Port 1. (Five more output pins are thus freed for more control functions.) Each output can drive at least one standard TTL or up to 10 low-power TTL loads without additional buffering.

Going back to the original matrix circuit, Figure 21 shows the method used to scan the sensor matrix. Two complete bit maps are maintained in the bit-addressable region of the RAM: one for the current state and one for the previous state read for each sensor. If the need arises, the program could then sense input transitions and or debounce contact closures by comparing each bit with its earlier value.

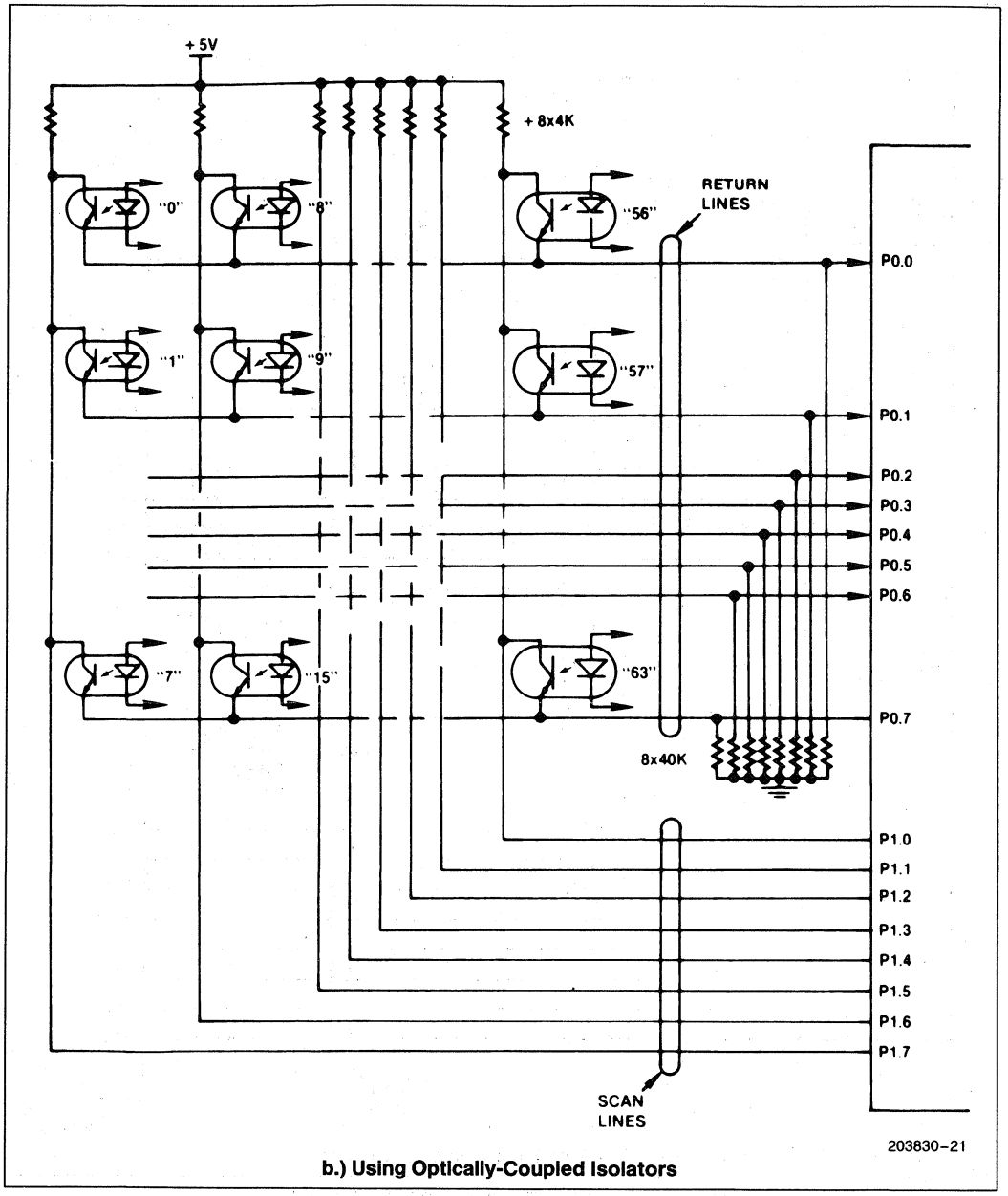
The code in Example 3 implements the scanning algorithm for the circuits in Figure 20a. Each column is enabled by setting a single bit in a field of zeroes. The bit maps are positive logic; ones represent contacts that are closed or isolators turned on.

```
Example 3.
INPUT_SCAN:     ;SUBROUTINE TO READ
                ;CURRENT STATE
                ;OF 64 SENSORS AND
                ;SAVE IN RAM 20H-27H
      MOV R0,#20H    ;INITIALIZE
                     ;POINTERS
      MOV R1,#28H    ;FOR BIT MAP
                     ;BASES
      MOV A,#80H     ;SET FIRST BIT
                     ;IN ACC
SCAN; MOV P1,A       ;OUTPUT TO SCAN
                     ;LINES
      RR  A          ;SHIFT TO ENABLE
                     ;NEXT COLUMN
                     ;NEXT
      MOV R2,A       ;REMEMBER CUR-
                     ;RENT SCAN
                     ;POSITION
      MOV A,P0       ;READ RETURN
                     ;LINES
      XCH A,@R0      ;SWITCH WITH
                     ;PREVIOUS MAP
                     ;BITS
      MOV @R1,A      ;SAVE PREVIOUS
                     ;STATE AS WELL
      INC R0         ;BUMP POINTERS
      INC R1
      MOV A,R2       ;RELOAD SCAN
                     ;LINE MASK
      JNB ACC,7;SCAN;LOOP UNTIL ALL
                     ;EIGHT COLUMNS
                     ;READ
      RET
```



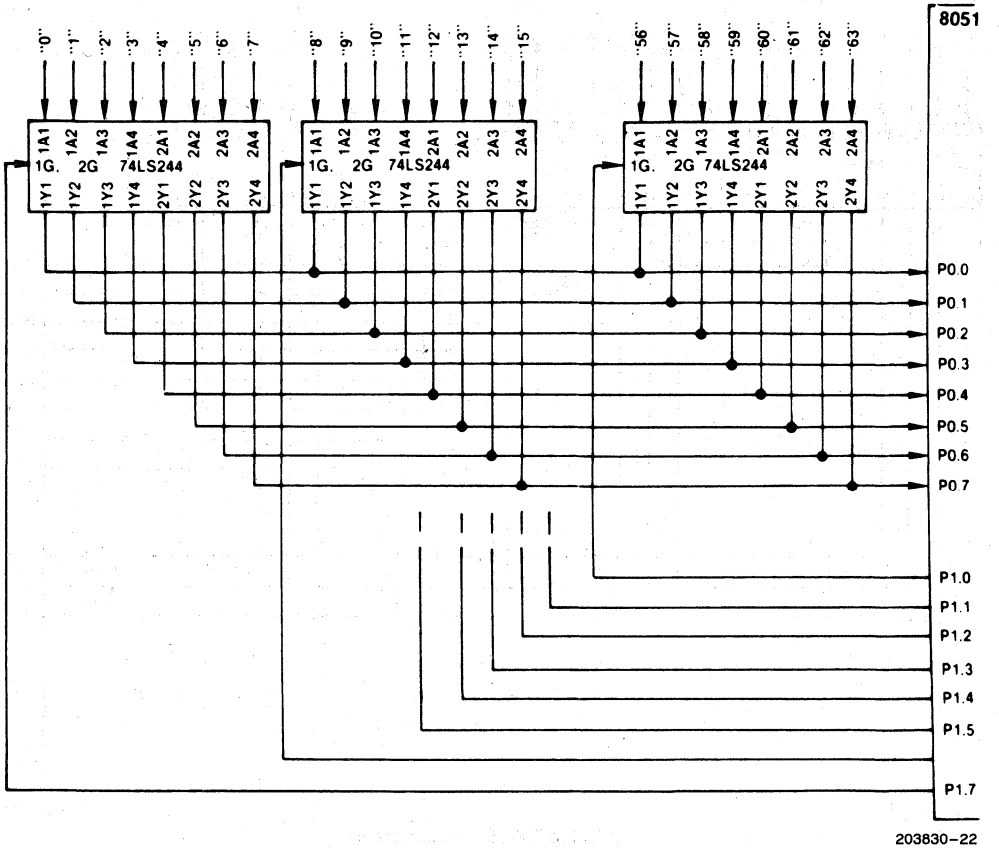
a.) Using Switch Contact/Diode Matrix

Figure 20. Sensor Matrix Implementation Methods



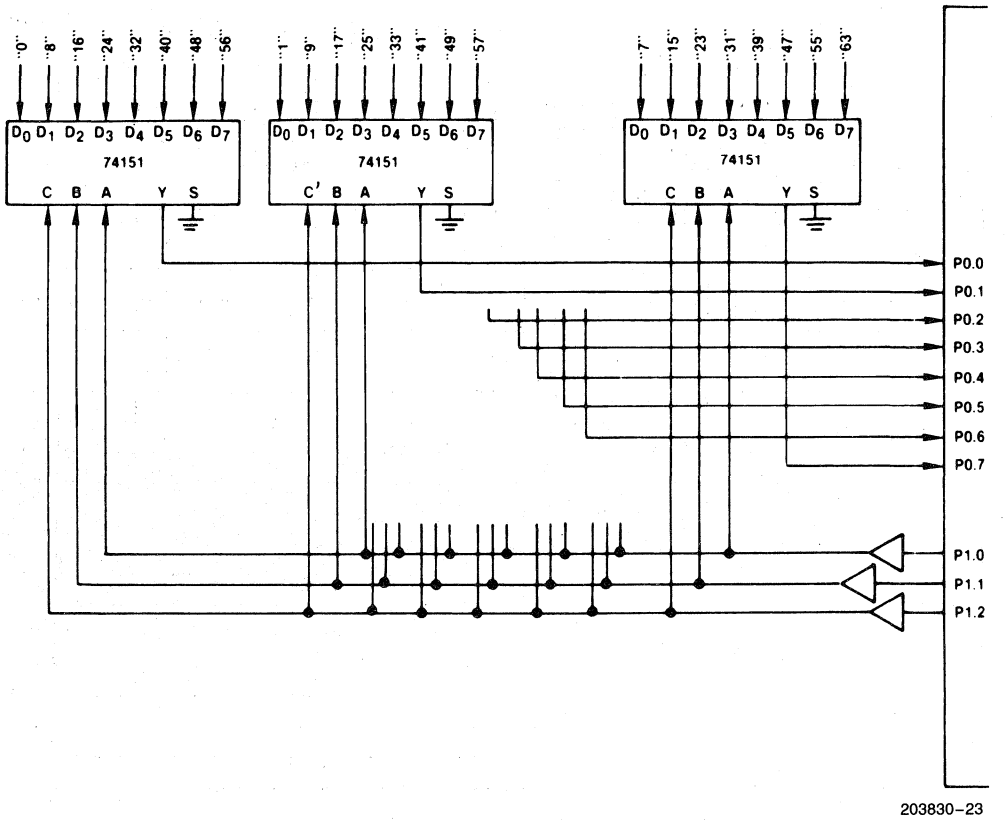
b.) Using Optically-Coupled Isolators

Figure 20. Sensor Matrix Implementation Methods (Continued)



c.) Using TTL Three-State Buffers

Figure 20. Sensor Matrix Implementation Methods (Continued)



d.) Using TTL Data Selectors

Figure 20. Sensor Matrix Implementation Methods (Continued)

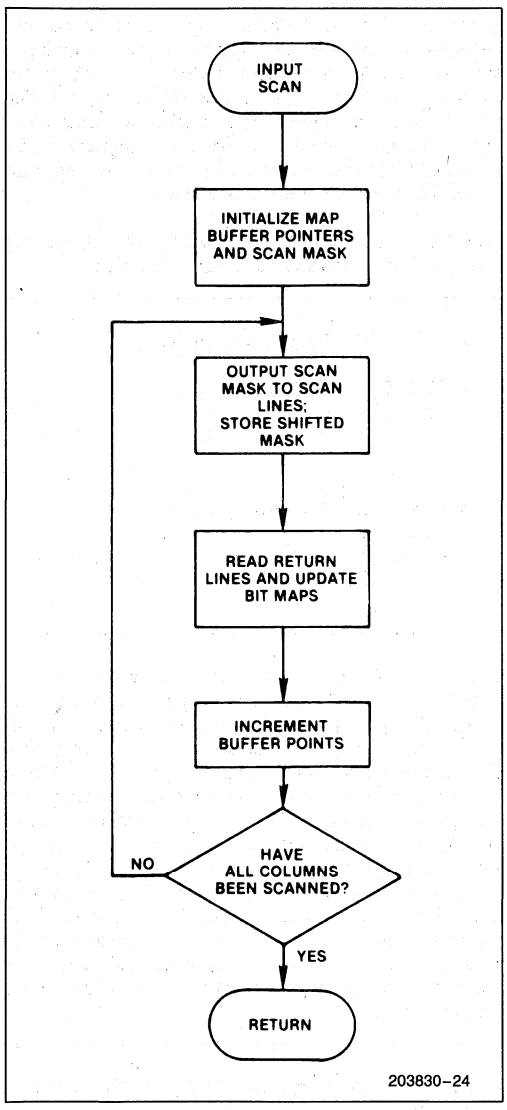


Figure 21. Flowchart for Reading in Sensor Matrix

What happens after the sensors have been scanned depends on the individual application. Rather than inventing some artificial design problem, software corresponding to commonplace logic elements will be discussed.

Combinatorial Output Variables. An output variable which is a simple (or not so simple) combinational function of several input variables is computed in the spirit of Design Example 3. All 64 inputs are represented in the bit maps: in fact, the sensor numbers in Figure 20 correspond to the absolute bit addresses in RAM! The code in Example 4 activates an actuator connected to P2.2 when sensors 12, 23, and 34 are closed and sensors 45 and 56 are open.

Example 4.

Simple Combinatorial Output Variables.

```
;SET P2.2=(12)(23)(34)( 45)( 56)
      MOV C,12
      ANL C,23
      ANL C,34
      ANL C, 45
      ANL C, 56
      MOV P2.2,C
```

Intermediate Variables. The examination of a typical relay-logic ladder diagram will show that many of the rungs control *not* outputs but rather relays whose contacts figure into the computation of other functions. In effect, these relays indicate the state of intermediate variables of a computation.

The MCS-51 solution can use any directly addressable bit for the storage of such intermediate variables. Even when all 128 bits of the RAM array are dedicated (to input bit maps in this example), the accumulator, PSW, and B register provide 18 additional flags for intermediate variables.

For example, suppose switches 0 through 3 control a safety interlock system. Closing any of them should deactivate certain outputs. Figure 22 is a ladder diagram for this situation. The interlock function could be recomputed for every output affected, or it may be computed once and save (as implied by the diagram). As the program proceeds this bit can qualify each output.

Example 5. Incorporating Override signal into actuator outputs.

```
;       CALL INPUT_SCAN
        MOV C,0
        ORL C,1
        ORL C,2
        ORL C,3
        MOV F0,C
;     .....  .....
;     COMPUTE FUNCTION 0
;
        ANL C, F0
        MOV PL0,C
;     .....  .....
;     COMPUTE FUNCTION 1
;
        ANL C, F0
        MOV P1,1,C
;     .....  .....
;     COMPUTE FUNCTION 2
;
        ANL C, F0
        MOV P1,2,C
;     .....  .....
```

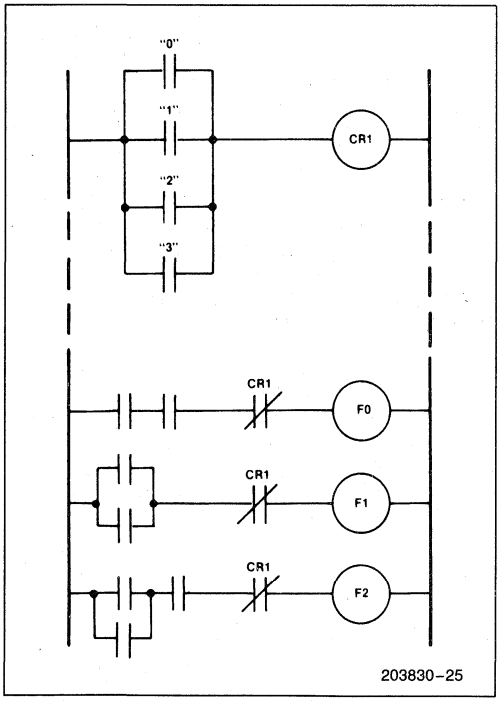


Figure 22. Ladder Diagram for Output Override Circuitry

Latching Relays. A latching relay can be forced into either the ON or OFF state by two corresponding input signals, where it will remain until forced onto the opposite state—analogous to a TTL Set/Reset flip-flop. The relay is used as an intermediate variable for other calculations. In the previous example, the emergency condition could be remembered and remain active until an "emergency cleared" button is pressed.

Any flag or addressable bit may represent a latching relay with a few lines of code (see Example 6).

Example 6. Simulating a latching relay.

```
;I_SET SET FLAG 0 IF C=1
I_SET:  ORL C,F0
        MOV F0,C
;

;I_RSET RESET FLAG 0 IF C=1
I_RSET: CPS C
        ANL C,F0
        MOV F0,C
;
```

Time Delay Relays. A time delay relay does not respond to an input signal until it has been present (or absent) for some predefined time. For example, a ballast or load resistor may be switched in series with a D.C. motor when it is first turned on, and shunted from the circuit after one second. This sort of time delay may be simulated by an interrupt routine driven by one of the two 8051 timer counters. The procedure followed by the routine depends heavily on the details of the exact function needed: time-outs or time delays with resettable or non-resettable inputs are possible. If the interrupt routine is executed every 10 milliseconds the code in Example 7 will clear an intermediate variable set by the background program after it has been active for two seconds.

Example 7. Code to clear USRFLG after a fixed time delay.

```
        JNB  USR_FLG,NXTTST
        DJNZ DLAY_COUNT,NXTTST
        CLR  USR_FLG
        MOV  DLAY_COUNT,#200
NXTTST; ;..  .....
```

Serial Interface to Remote Processor. When it detects emergency conditions represented by certain input combinations (such as the earlier Emergency Override), the controller could shut down the machine immediately and/or alert the host processor via the serial port. Code bytes indicating the nature of the problem could be transmitted to a central computer. In fact, at 17,000 bytes-per-second, the entire contents of both bit maps could be sent to the host processor for further analysis in less than a millisecond! If the host decides that conditions warrant, it could alert other remote processors in the system that a problem exists and specify which shut-down sequence each should initiate. For more information on using the serial port, consult the MCS-51 User's Manual.

Response Timing

One difference between relay and programmed industrial controllers (when each is considered as a "black box") is their respective reaction times to input changes. As reflected by a ladder diagram, relay systems contain a large number of "rungs" operating in parallel. A change in input conditions will begin propagating through the system immediately, possibly affecting the output state within milliseconds.

Software, on the other hand, operates sequentially. A change in input states will not be detected until the next time an input scan is performed, and will not affect the outputs until that section of the program is reached. For that reason the raw speed of computing the logical functions is of extreme importance.

Here the Boolean processor pays off. *Every instruction mentioned in this Note* completes in one or two microseconds—the *minimum* instruction execution time for many other microcontrollers! A ladder diagram containing a hundred rungs, with an average of four contacts per rung can be replaced by approximately five hundred lines of software. A complete pass through the entire matrix scanning routine and all computations would require about a millisecond: less than the time it takes for most relays to change state.

A programmed controller which simulates each Boolean function with a subroutine would be less efficient by at least an order of magnitude. Extra software is needed for the simulation routines, and each step takes longer to execute for three reasons: several byte-wide logical instructions are executed per user program step (rather than one Boolean operation): most of those instructions take longer to execute with microprocessors performing multiple off-chip accesses: and calling and returning from the various subroutines requires overhead for stack operations.

In fact, the speed of the Boolean Processor solution is likely to be much faster than the system requires. The CPU might use the time left over to compute feedback parameters, collect and analyze execution statistics, perform system diagnostics, and so forth.

2

Additional Functions and Uses

With the building-block basics mentioned above many more operations may be synthesized by short instruction sequences.

Exclusive-OR. There are no common mechanical devices or relays analogous to the Exclusive-OR operation, so this instruction was omitted from the Boolean Processor. However, the Exclusive-OR or Exclusive-NOR operation may be performed in two instructions by conditionally complementing the carry or a Boolean variable based on the state of any other testable bit.

```
;EXCLUSIVE-;OR FUNCTION IMPOSED ON CARRY
;USING F0 IS INPUT VARIABLE.
;XOR_F0: JNB F0,XORCNT ;("JB" FOR X-NOR)
        CPL C
;XORCNT: ... .....
```

XCH. The contents of the carry and some other bit may be exchanged (switched) by using the accumulator as temporary storage. Bits can be moved into and out of the accumulator simultaneously using the Rotate-

through-carry instructions, though this would alter the accumulator data.

```
;EXCHANGE CARRY WITH USRFLG
XCHBIT: RLC   A
        MOV   C,USR_FLG
        RRC   A
        MOV   USR_FLG,C
        RLC   A
```

Extended Bit Addressing. The 8051 can directly address 144 general-purpose bits for all instructions in Figure 3b. Similar operations may be extended to any bit anywhere on the chip with some loss of efficiency.

The logical operations AND, OR, and Exclusive-OR are performed on byte variables using six different addressing modes, one of which lets the source be an immediate mask, and the destination any directly addressable byte. Any bit may thus be set, cleared, or complemented with a three-byte, two-cycle instruction if the mask has all bits but one set or cleared.

Byte variables, registers, and indirectly addressed RAM may be moved to a bit addressable register (usually the accumulator) in one instruction. Once transferred, the bits may be tested with a conditional jump, allowing any bit to be polled in 3 microseconds—still much faster than most architectures—or used for logical calculations. (This technique can also simulate additional bit addressing modes with byte operations.)

Parity of bytes or bits. The parity of the current accumulator contents is always available in the PSW, from whence it may be moved to the carry and further processed. Error-correcting Hamming codes and similar applications require computing parity on groups of isolated bits. This can be done by conditionally complementing the carry flag based on those bits or by gathering the bits into the accumulator (as shown in the DES example) and then testing the parallel parity flag.

Multiple byte shift and CRC codes

Though the 8051 serial port can accommodate eight- or nine-bit data transmissions, some protocols involve much longer bit streams. The algorithms presented in Design Example 2 can be extended quite readily to 16 or more bits by using multi-byte input and output buffers.

Many mass data storage peripherals and serial communications protocols include Cyclic Redundancy (CRC) codes to verify data integrity. The function is generally computed serially by hardware using shift registers and Exclusive-OR gates, but it can be done with software. As each bit is received into the carry, appropriate bits in the multi-byte data buffer are conditionally complemented based on the incoming data bit. When finished, the CRC register contents may be checked for zero by ORing the two bytes in the accumulator.

4.0 SUMMARY

A truly unique facet of the Intel MCS-51 microcomputer family design is the collection of features optimized for the one-bit operations so often desired in real-world, real-time control applications. Included are 17 special instructions, a Boolean accumulator, implicit and direct addressing modes, program and mass data storage, and many I/O options. These are the world's first single-chip microcomputers able to efficiently manipulate, operate on, and transfer either bytes or individual bits as data.

This Application Note has detailed the information needed by a microcomputer system designer to make full use of these capabilities. Five design examples were used to contrast the solutions allowed by the 8051 and those required by previous architectures. Depending on the individual application, the 8051 solution will be easier to design, more reliable to implement, debug, and verify, use less program memory, and run up to an order of magnitude faster than the same function implemented on previous digital computer architectures.

Combining byte- and bit-handling capabilities in a single microcomputer has a strong synergistic effect: the power of the result exceeds the power of byte- and bit-processors laboring individually. Virtually all user applications will benefit in some way from this duality. Data intensive applications will use bit addressing for test pin monitoring or program control flags: control applications will use byte manipulation for parallel I/O expansion or arithmetic calculations.

It is hoped that these design examples give the reader an appreciation of these unique features and suggest ways to exploit them in his or her own application.

APPENDIX A
Automobile Turn-Indicator Controller Program Listing

```
ISIS-II MCS-51 MACRO ASSEMBLER V1.0
OBJECT MODULE PLACED IN :F0:AP70.HEX
ASSEMBLER INVOKED BY:  :f1:asm51 ap70 src date(328)
LOC  OBJ             LINE     SOURCE

                        1     $XREF TITLE(AP-70 APPENDIX)
                        2     ;*******************************************************
                        3     ;
                        4     ;       THE FOLLOWING PROGRAM USES THE BOOLEAN INSTRUCTION SET
                        5     ;       OF THE INTEL 8051 MICROCOMPUTER TO PERFORM A NUMBER OF
                        6     ;       AUTOMOTIVE DASHBOARD CONTROL FUNCTIONS RELATING TO
                        7     ;       TURN SIGNAL CONTROL, EMERGENCY BLINKERS, BRAKE LIGHT
                        8     ;       CONTROL, AND PARKING LIGHT OPERATION.
                        9     ;       THE ALGORITHMS AND HARDWARE ARE DESCRIBED IN DESIGN
                       10     ;       EXAMPLE #4 OF INTEL APPLICATION NOTE AP-70,
                       11     ;                "USING THE INTEL MCS-51(TM)
                       12     ;              BOOLEAN PROCESSING CAPABILITIES"
                       13     ;
                       14     ;*******************************************************
                       15     ;
                       16     ;       INPUT PIN DECLARATIONS:
                       17     ;        (ALL INPUTS ARE POSITIVE-TRUE LOGIC.
                       18     ;       INPUTS ARE HIGH WHEN RESPECTIVE SWITCH CONTACT IS CLOSED.)
                       19     ;
0090                   20     BRAKE   BIT     P1.0    ; BRAKE PEDAL DEPRESSED
0091                   21     EMERG   BIT     P1.1    ; EMERGENCY BLINKER ACTIVATED
0092                   22     PARK    BIT     P1.2    ; PARKING LIGHTS ON
0093                   23     L_TURN  BIT     P1.3    ; TURN LEVER DOWN
0094                   24     R_TURN  BIT     P1.4    ; TURN LEVER UP
                       25     ;
                       26     ;       OUTPUT PIN DECLARATIONS:
                       27     ;       (ALL OUTPUTS ARE POSITIVE TRUE LOGIC.
                       28     ;       BULB IS TURNED ON WHEN OUTPUT PIN IS HIGH.)
                       29     ;
0095                   30     L_FRNT  BIT     P1.5    ; FRONT LEFT-TURN INDICATOR
0096                   31     R_FRNT  BIT     P1.6    ; FRONT RIGHT-TURN INDICATOR
0097                   32     L_DASH  BIT     P1.7    ; DASHBOARD LEFT-TURN INDICATOR
00A0                   33     R_DASH  BIT     P2.0    ; DASHBOARD RIGHT-TURN INDICATOR
00A1                   34     L_REAR  BIT     P2.1    ; REAR LEFT-TURN INDICATOR
00A2                   35     R_REAR  BIT     P2.2    ; REAR RIGHT-TURN INDICATOR
                       36     ;
00A3                   37     S_FAIL  BIT     P2.3    ; ELECTRICAL SYSTEM FAULT INDICATOR
                       38     ;
                       39     ;       INTERNAL VARIABLE DEFINITIONS:
                       40     ;
0020                   41     SUB_DIV DATA    20H             ; INTERRUPT RATE SUBDIVIDER
0000                   42     HI_FREQ BIT     SUB_DIV.0       ; HIGH-FREQUENCY OSCILLATOR BIT
0007                   43     LO_FREQ BIT     SUB_DIV.7       ; LOW-FREQUENCY OSCILLATOR BIT
                       44     ;
00D1                   45     DIM     BIT     PSW.1           ; PARKING LIGHTS ON FLAG
                       46     ;
                       47     ;=======================================================
                       48 +1  $EJECT
```

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```
LOC  OBJ             LINE     SOURCE

                       49             ORG     0000H           ; RESET VECTOR
0000 020040            50             LJMP    INIT
                       51     ;
000B                   52             ORG     000BH           ; TIMER 0 SERVICE VECTOR
000B 758CF0            53             MOV     TH0,#-16        ; HIGH TIMER BYTE ADJUSTED TO CONTROL INT  RATE
000E C0D0              54             PUSH    PSW             ; EXECUTE CODE TO SAVE ANY REGISTERS USED BELOW
0010 0154              55             AJMP    UPDATE          ;      (CONTINUE WITH REST OF ROUTINE)
                       56     ;
0040                   57             ORG     0040H
0040 758A00            58     INIT:   MOV     TL0,#0          ; ZERO LOADED INTO LOW-ORDER BYTE AND
0043 758CF0            59             MOV     TH0,#-16        ; -16 IN HIGH-ORDER BYTE GIVES 4 MSEC PERIOD
0046 758961            60             MOV     TMOD,#01100001B ; 8-BIT AUTO RELOAD COUNTER MODE FOR TIMER 1,
                       61                                     ;  16-BIT TIMER MODE FOR TIMER 0 SELECTED
0049 7520F4            62             MOV     SUB_DIV,#244    ; SUBDIVIDE INTERRUPT RATE BY 244 FOR 1 HZ
004C D2A9              63             SETB    ET0             ; USE TIMER 0 OVERFLOWS TO INTERRUPT PROGRAM
004E D2AF              64             SETB    EA              ; CONFIGURE IE TO GLOBALLY ENABLE INTERRUPTS
0050 D28C              65             SETB    TR0             ; KEEP INSTRUCTION CYCLE COUNT UNTIL OVERFLOW
0052 80FE              66             SJMP    $               ; START BACKGROUND PROGRAM EXECUTION
                       67     ;
                       68     ;
0054 D52038            69     UPDATE: DJNZ    SUB_DIV,TOSERV  ; EXECUTE SYSTEM TEST ONLY ONCE PER SECOND
0057 7520F4            70             MOV     SUB_DIV,#244    ; GET VALUE FOR NEXT ONE SECOND DELAY AND
                       71     ;                               ; GO THROUGH ELECTRICAL SYSTEM TEST CODE:
005A 4390E0            72             ORL     P1,#11100000B   ; SET CONTROL OUTPUTS HIGH
005D 43A007            73             ORL     P2,#00000111B
0060 C295              74             CLR     L_FRNT          ; FLOAT DRIVE COLLECTOR
0062 20B428            75             JB      T0,FAULT        ; TO SHOULD BE PULLED LOW
0065 D295              76             SETB    L_FRNT          ; PULL COLLECTOR BACK DOWN
0067 C297              77             CLR     L_DASH          ; REPEAT SEQUENCE FOR L_DASH,
0069 20B421            78             JB      T0,FAULT
006C D297              79             SETB    L_DASH
006E C2A1              80             CLR     L_REAR          ;                 L_REAR,
0070 20B41A            81             JB      T0,FAULT
0073 D2A1              82             SETB    L_REAR
0075 C296              83             CLR     R_FRNT          ;                 R_FRNT,
0077 20B413            84             JB      T0,FAULT
007A D296              85             SETB    R_FRNT
007C C2A0              86             CLR     R_DASH          ;                 R_DASH,
007E 20B40C            87             JB      T0,FAULT
0081 D2A0              88             SETB    R_DASH
0083 C2A2              89             CLR     R_REAR          ;                 AND R_REAR.
0085 20B405            90             JB      T0,FAULT
0088 D2A2              91             SETB    R_REAR
                       92     ;
                       93     ;       WITH ALL COLLECTORS GROUNDED, TO SHOULD BE HIGH
                       94     ;       IF SO, CONTINUE WITH INTERRUPT ROUTINE.
                       95     ;
008A 20B402            96             JB      T0,TOSERV
008D B2A3              97     FAULT:  CPL     S_FAIL          ; ELECTRICAL FAILURE PROCESSING ROUTINE
                       98                                     ; (TOGGLE INDICATOR ONCE PER SECOND)
                       99 +1  $EJECT
```

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```
LOC  OBJ            LINE     SOURCE

                     100      ;       CONTINUE WITH INTERRUPT PROCESSING:
                     101      ;
                     102      ;   1)  COMPUTE LOW BULB INTENSITY WHEN PARKING LIGHTS ARE ON.
                     103      ;
008F A201            104      TOSERV: MOV     C,SUB_DIV.1         ; START WITH 50 PERCENT,
0091 8200            105              ANL     C,SUB_DIV.0         ; MASK DOWN TO 25 PERCENT,
0093 7202            106              ORL     C,SUB_DIV.2         ; BUILD BACK TO 62.5 PERCENT,
0095 8292            107              ANL     C,PARK              ; GATE WITH PARKING LIGHT SWITCH,
0097 92D1            108              MOV     DIM,C               ; AND SAVE IN TEMP. VARIABLE.
                     109      ;
                     110      ;   2)  COMPUTE AND OUTPUT LEFT-HAND DASHBOARD INDICATOR.
                     111      ;
0099 A293            112              MOV     C,L_TURN            ; SET CARRY IF TURN
009B 7291            113              ORL     C,EMERG             ; OR EMERGENCY SELECTED.
009D 8207            114              ANL     C,LO_FREQ           ; IF SO, GATE IN 1 HZ SIGNAL
009F 9297            115              MOV     L_DASH,C            ; AND OUTPUT TO DASHBOARD.
                     116      ;
                     117      ;   3)  COMPUTE AND OUTPUT LEFT-HAND FRONT TURN SIGNAL.
                     118      ;
00A1 92D5            119              MOV     F0,C                ; SAVE FUNCTION SO FAR.
00A3 72D1            120              ORL     C,DIM               ; ADD IN PARKING LIGHT FUNCTION
00A5 9295            121              MOV     L_FRNT,C            ; AND OUTPUT TO TURN SIGNAL.
                     122      ;
                     123      ;   4)  COMPUTE AND OUTPUT LEFT-HAND REAR TURN SIGNAL.
                     124      ;
00A7 A290            125              MOV     C,BRAKE             ; GATE BRAKE PEDAL SWITCH
00A9 B093            126              ANL     C,/L_TURN           ; WITH TURN LEVER.
00AB 72D5            127              ORL     C,F0                ; INCLUDE TEMP. VARIABLE FROM DASH
00AD 72D1            128              ORL     C,DIM               ; AND PARKING LIGHT FUNCTION
00AF 92A1            129              MOV     L_REAR,C            ; AND OUTPUT TO TURN SIGNAL.
                     130      ;
                     131      ;   5)  REPEAT ALL OF ABOVE FOR RIGHT-HAND COUNTERPARTS.
                     132      ;
00B1 A294            133              MOV     C,R_TURN            ; SET CARRY IF TURN
00B3 7291            134              ORL     C,EMERG             ; OR EMERGENCY SELECTED.
00B5 8207            135              ANL     C,LO_FREQ           ; IF SO, GATE IN 1 HZ SIGNAL
00B7 92A0            136              MOV     R_DASH,C            ; AND OUTPUT TO DASHBOARD.
00B9 92D5            137              MOV     F0,C                ; SAVE FUNCTION SO FAR.
00BB 72D1            138              ORL     C,DIM               ; ADD IN PARKING LIGHT FUNCTION
00BD 9296            139              MOV     R_FRNT,C            ; AND OUTPUT TO TURN SIGNAL.
00BF A290            140              MOV     C,BRAKE             ; GATE BRAKE PEDAL SWITCH
00C1 B094            141              ANL     C,/R_TURN           ; WITH TURN LEVER.
00C3 72D5            142              ORL     C,F0                ; INCLUDE TEMP. VARIABLE FROM DASH
00C5 72D1            143              ORL     C,DIM               ; AND PARKING LIGHT FUNCTION
00C7 92A2            144              MOV     R_REAR,C            ; AND OUTPUT TO TURN SIGNAL.
                     145      ;
                     146      ;       RESTORE STATUS REGISTER AND RETURN.
                     147      ;
00C9 D0D0            148              POP     PSW                 ; RESTORE PSW
00CB 32              149              RETI                        ; AND RETURN FROM INTERRUPT ROUTINE
                     150      ;
                     151              END
```

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```
XREF SYMBOL TABLE LISTING
---- ------ ----- -------


NAME      TYPE      VALUE AND REFERENCES

BRAKE     N BSEG    0090H  20# 125 140
DIM       N BSEG    00D1H  45# 108 120 128 138 143
EA        N BSEG    00AFH  64
EMERG     N BSEG    0091H  21# 113 134
ETO       N BSEG    00A9H  63
FO        N BSEG    00D5H  119 127 137 142
FAULT     L CSEG    008DH  75 78 81 84 87 90 97#
HI_FREQ   N BSEG    0000H  42#
INIT      L CSEG    0040H  50 58#
L_DASH    N BSEG    0097H  32# 77 79 115
L_FRNT    N BSEG    0095H  30# 74 76 121
L_REAR    N BSEG    00A1H  34# 80 82 129
L_TURN    N BSEG    0093H  23# 112 126
LO_FREQ   N BSEG    0007H  43# 114 135
P1        N DSEG    0090H  20 21 22 23 24 30 31 32 72
P2        N DSEG    00A0H  33 34 35 37 73
PARK      N BSEG    0092H  22# 107
PSW       N DSEG    00D0H  45 54 148
R_DASH    N BSEG    00A0H  33# 86 88 136
R_FRNT    N BSEG    0096H  31# 83 85 139
R_REAR    N BSEG    00A2H  35# 89 91 144
R_TURN    N BSEG    0094H  24# 133 141
S_FAIL    N BSEG    00A3H  37# 97
SUB_DIV   N DSEG    0020H  41# 42 43 62 69 70 104 105 106
TO        N BSEG    00B4H  75 78 81 84 87 90 96
TOSERV    L CSEG    008FH  69 96 104#
THO       N DSEG    008CH  53 59
TLO       N DSEG    008AH  58
TMOD      N DSEG    0089H  60
TRO       N BSEG    008CH  65
UPDATE    L CSEG    0054H  55 69#


ASSEMBLY COMPLETE, NO ERRORS FOUND
```

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October 1984

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8051 Based CRT Terminal Controller

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Microcontroller Applications

ORDER NUMBER: 270032-001

1.0 INTRODUCTION

This is the third application note that Intel has produced on CRT terminal controllers. The first Ap Note (ref. 1), written in 1977, used the 8080 as the CPU and required 41 packages including 11 LSI devices. In 1979, another application note (ref. 2) using the 8085 as the controller was produced and the chip count decreased to 20 with 11 LSI devices.

Advancing technology has integrated a complete system onto a single device that contains a CPU, program memory, data memory, serial communication, interrupt controller, and I/O. These "computer-on-a-chip" devices are known as microcontrollers. Intel's MCS®-51 microcontroller was chosen for this application because of its highly integrated functions. This CRT terminal design uses 12 packages with only 4 LSI devices.

This application note has been divided into five general sections:

1) CRT Terminal Basics
2) 8051 Description
3) 8276 Description
4) Design Background
5) System Description

2.0 CRT TERMINAL BASICS

A terminal provides a means for humans to communicate with a computer. Terminals may be as simple as a LED display and a couple of push buttons, or it may be an elaborate graphics system that contains a full function keyboard with user programmable keys, color CRT and several processors controlling its functions. This application note describes a basic low cost terminal containing a black and white CRT display, full function keyboard and a serial interface.

2.1 CRT Description

A raster scan CRT displays its images by generating a series of lines (raster) across the face of the tube. The electron beam usually starts at the top left hand corner moves left to right, back to the left of the screen, moves down one row and continues on to the right. This is repeated until the lower right hand of the screen is reached. Then the beam returns to the top left hand corner and refreshes the screen. The beam forms a zigzag pattern as shown in Figure 2.1.0.

Two independent operating circuits control this movement across the screen. The horizontal oscillator controls the left to right motion of the beam while the vertical controls the top to bottom movement. The vertical oscillator also tells the beam when to return to the upper left hand corner or "home" position.

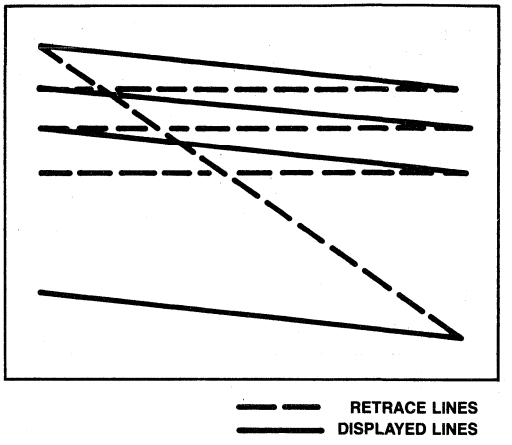


Figure 2.1.0 Raster Scan

As the electron beam moves across the screen under the control of the horizontal oscillator, a third circuit controls the current entering the electron gun. By varying the current, the image may be made as bright or as dim as the user desires. This control is also used to turn the beam off or "blank the screen".

When the beam reaches the right hand side of the screen, the beam is blanked so it does not appear on the screen as it returns to the left side. This "retrace" of the beam is at a much faster rate than it traveled across the screen to generate the image.

The time it takes to scan the whole screen and return to the home position is referred to as a "frame". In the United States, commercial television broadcast uses a horizonal sweep frequency of 15,750Hz which calculates out to 63.5 microseconds per line. The frame time is equal to 16.67 milliseconds or 60Hz vertical sweep frequency.

Although this is the commercial standard, many CRT displays operate from 18KHz to 30KHz horizonatal frequency. As the horizontal frequency increases, the number of lines per frame increases. This increase in lines or resolution is needed for graphic displays and on special text editors that display many more lines of text than the standard 24 or 25 character lines.

Since the United States operates on a 60Hz A.C. power line frequency, most CRT monitors use 60Hz as the vertical frequency. The use of 60Hz as the vertical frequency allows the magnetic and electrical variations that can modulate the electron beam to be synchronized with the display, thus they go unnoticed. If a frequency other than 60Hz is used, special shielding and power supply regu-

lating is usually required. Very few CRTs operate on a vertical frequency other than 60Hz due to the increase in the overall system cost.

The CRT controller must generate the pulses that define the horizontal and vertical timings. On most raster scan CRTs the horizontal frequency may vary as much as 500Hz without any noticeable effect on the quality of the display. This variation can change the number of horizontal lines from 256 to 270 per frame.

The CRT controller must also shift out the information to be displayed serially to the circuit that controls the electron beam's intensity as it scans across the screen. The circuits that control the timing associated with the shifting of the information are known as the dot clock and the character clock. The character clock frequency is equal to the dot clock frequency divided by the number of dots it takes to form a character in the horizontal axis. The dot clock frequency is calculated by the following equation:

$$\text{Dot Clcok (Hz)} = (N+R)*D*L*F$$

where

N is the number of displayed characters per row,
R is the number of character times for the retrace,
D is the number of dots per character in the horizontal axis,
L is the number of horizontal lines per frame,
F is the frame rate in Hz.

In this design N = 80, R = 20, D = 7, L = 270, and F = 60Hz. Plugging in the numbers results in a dot clock frequency of 11.34MHz.

The retrace number may vary on each design because it is used to set the left and right hand margins on the CRT. The number of dots per character is chosen by the designer to meet the system needs. In this design, a 5 × 7 dot matrix and 2 blank dots between each character (see Figure 2.1.1) makes D equal to 5 + 2 = 7.

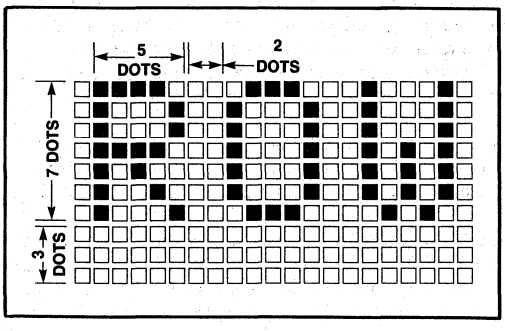


Figure 2.1.1 5 × 7 Dot Matrix

The following equation can be used to figure the number of lines per frame:

$$L = (H*Z) + V$$

where

H is the number of horizontal lines per character,
Z is the number of character lines per frame,
V is the number of horizontal line times during the vertical retrace

In this design H is equal to the 7 horizontal dots per character plus 3 blank dots between each row which adds up to 10. Also 25 lines of characters are displayed, so Z = 25. The vertical retrace time is variable to set the top and bottom margins on the CRT and in this design is equal to 20. Plugging in the numbers gives L = 270 lines per frame.

2.2 Keyboard

A keyboard is the common way a human enters commands and data to a computer. A keyboard consists of a matrix of switches that are scanned every couple of milliseconds by a keyboard controller to determine if one of the keys has been pressed. Since the keyboard is made up of mechanical switches that tend to bounce or "make and break" contact everytime they are pressed, debouncing of the switches must also be a function of the keyboard controller. There are dedicated keyboard controllers available that do everything from scanning the keyboard, debouncing the keys, decoding the ASCII code for that key closure to flagging the CPU that a valid key has been depressed. The keyboard controller may present the information to the CPU in parallel form or in a serial data stream.

This Application Note integrates the function of the keyboard controller into the 8051 which is also the terminal controller. Provisions have been made to interface the 8051 to a keyboard that uses a dedicated keyboard controller. The 8051 can accept data from the keyboard controller in either parallel or serial format.

2.3 Serial Communications

Communication between a host computer and the CRT terminal can be in either parallel or serial data format. Parallel data transmission is needed in high end graphic terminals where great amounts of information must be transferred.

One can rarely type faster than 120 words per minute, which corresponds to 12 characters per second or 1 character per 83 milliseconds. The utilization of a parallel port cannot justify the cost associated with the drivers and the amount of wire needed to perform this transmission. Full duplex serial data transmission requires 3 wires and two

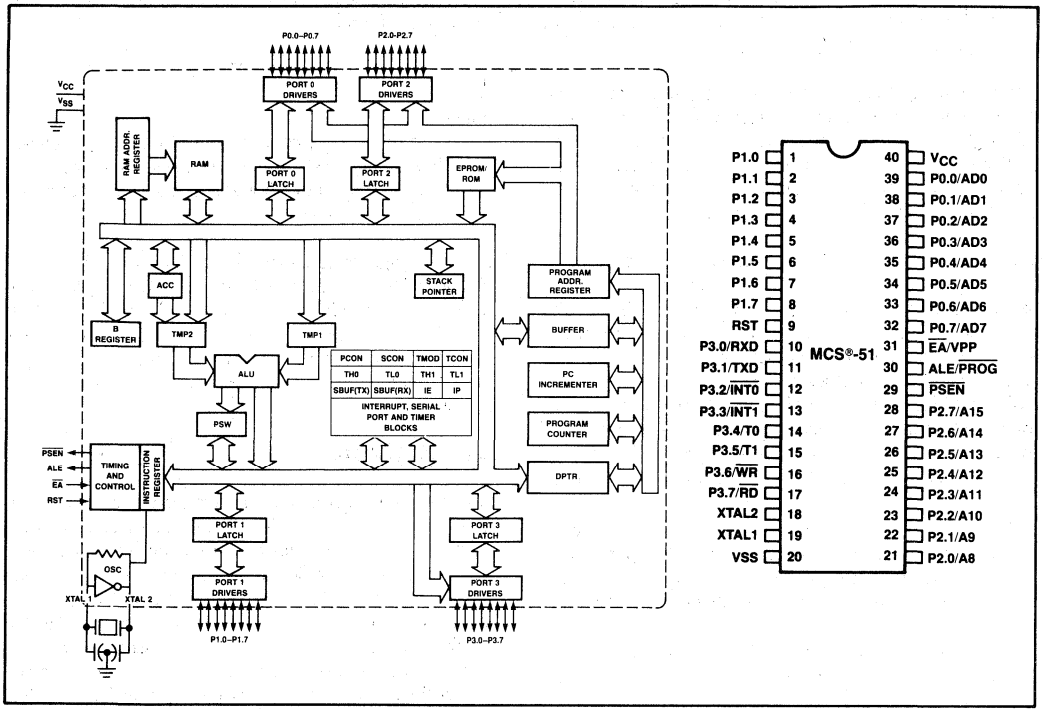


Figure 3.0.0 8051 Block Diagram

drivers to implement the communication channel between the host computer and the terminal. The data rate can be as high as 19200 BAUD in the asynchronous serial format. BAUD rate is the number of bits per second received or transmitted. In the asynchronous serial format, 10 bits of information is required to transmit one character. One character per 500 microseconds or 1,920 characters per second would then be trasmitted using 19.2 KBAUD.

This application note uses the 8051 serial port configured for full duplex asynchronous serial data transmission. The software for the 8051 has been written to support variable BAUD rates from 150 BAUD up to 9.6 KBAUD.

3.0 8051 DESCRIPTION

The 8051 is a single chip high-performance microcontroller. A block diagram is shown in figure 3.0.0. The 8051 combines CPU; Boolean processor; 4K × 8 ROM: 128 × 8 RAM; 32 I/O lines; two 16-bit timer/ event counters; a five-source, two-priority-level, nested interrupt structure; serial I/O port for either multiprocessor communications, I/O expansion, or full duplex UART; and on-chip oscillator and clock circuits.

3.1 CPU

Efficient use of program memory results from an instruction set consisting of 49 single-byte, 45 two-byte and 17 three-byte instructions. Most arithmetic, logical and branching operations can be performed using an instruction that appends either a short address or a long address. For example, branches may use either an offset that is relative to the program counter which takes two bytes or a direct 16-bit address which takes three bytes to perform. As a result, 64 instructions operate in one machine cycle, 45 in two machine cycles, and the multiply and divide instruction execute in 4 machine cycles.

The 8051 has five addressing modes for source operands: Register, Direct, Register-Indirect, Immediate, and Based-Register-plus Index-Register-Indirect Addressing.

The Boolean Processor can be thought of as a separate one-bit CPU. It has its own accumulator (the carry bit), instruction set for data moves, logic, and control transfer, and its own bit addressable RAM and I/O. The bit-manipulating instructions provide optimum code and speed efficiency for handling on chip peripherals. The

Boolean processor also provides a straight forward means of converting logic equations directly into software. Complex combinational logic functions can be resolved without extensive data movement, byte masking, and test-and-branch trees.

3.2 On-Chip Ram

The CPU manipulates operands in four memory spaces. These are the 64K-byte Program Memory, 64K-byte External Data Memory, 128-byte Internal Data Memory, and 128-byte Special Function Registers (SFRs). Four Register Banks (each with 8 registers), 128 addressable bits, and the Stack reside in the internal Data RAM. The Stack size is limited only by the available Internal Data RAM and its location is determined by the 8-bit Stack Pointer. All registers except for the Program Counter and the four 8-Register Banks reside in the SFR address space. These memory mapped registers include arithmetic registers, pointers, I/O ports, and registers for the interrupt system, timers, and serial channel.

Registers in the four 8-Register Banks can be addressed by Register, Direct, or Register-Indirect Addressing modes. The 128 bytes of internal Data Memory can be addressed by Direct or Register-Indirect modes while the SFRs are only addressed directly.

3.3 I/O Ports

The 8051 has instructions that can treat the 32 I/O lines as 32 individually addressable bits or as 4 parallel 8-bit ports addressable as Ports 0, 1, 2, and 3.

Resetting the 8051 writes a logical 1 to each pin on port 0 which places the output drivers into a high-impedance mode. Writing a logical 0 to a pin forces the pin to ground and sinks current. Re-writing the pin high will place the pin in either an open drain output or high-impedance input mode.

Ports 1, 2, and 3 are known as quasi-bidirectional I/O pins. Resetting the device writes a logical one to each pin. Writing a logical 0 to the pin will force the pin to ground and sink current. Re-writing the pin high will place the pin in an output mode with a weak depletion pullup FET or in the input mode. The weak pullup FET is easily overcome by a TTL output.

Ports 0 and 2 can also be used for off-chip peripheral expansion. Port 0 provides a multiplexed low-order address and data bus while Port 2 contains the high-order address when using external Program Memory or more than 256 byte external Data Memory.

Port 3 pins can also be used to provide external interrupt request inputs, event counter inputs, the serial port TXD and RXD pins and to generate control signals used for writing and reading external peripherals.

3.4 Interrupt System

External events and the real-time-driven on-chip peripherals require service by the CPU asynchronous to the execution of any particular section of code. A five-source, two-level, nested interrupt system ties the real time events to the normal program execution.

The 8051 has two external interrupt sources, one interrupt from each of the two timer/counters, and an interrupt from the serial port. Each interrupt vectors the program execution to its own unique memory location for servicing the interrupt. In addition, each of the five sources can be individually enabled or disabled as well as assigned to one of the two interrupt priority levels available on the 8051.

Up to two additional external interrupts can be created by configuring a timer/counter to the event counter mode. In this mode the timer/counter increments on command by either the T0 or T1 pin. An interrupt is generated when the timer/counter overflows. Thus if the timer/counter is loaded with the maximum count, the next high-to-low transition of the event counter input will cause an interrupt to be generated.

3.5 Serial Port

The 8051's serial port is useful for linking peripheral devices as well as multiple 8051s through standard asynchronous protocols with full duplex operation. The serial port also has a synchronous mode for expansion of I/O lines using shift registers. This hardware serial port saves ROM code and permits a much higher transmission rate than could be achieved through software. The processor merely needs to read or write the serial buffer in response to an interrupt. The receiver is double buffered to eliminate the possibility of overrun if the processor failed to read the buffer before the beginning of the next frame.

The full duplex asynchronous serial port provides the means of communication with standard UART devices such as CRT terminals and printers.

The reader should refer to the microcontroller handbook for a complete discussion of the 8051 and its various modes of operation.

4.0 8276 DESCRIPTION

The 8276's block diagram and pin configuration are shown in Figure 4.0.0. The following sections describe the general capabilities of the 8276.

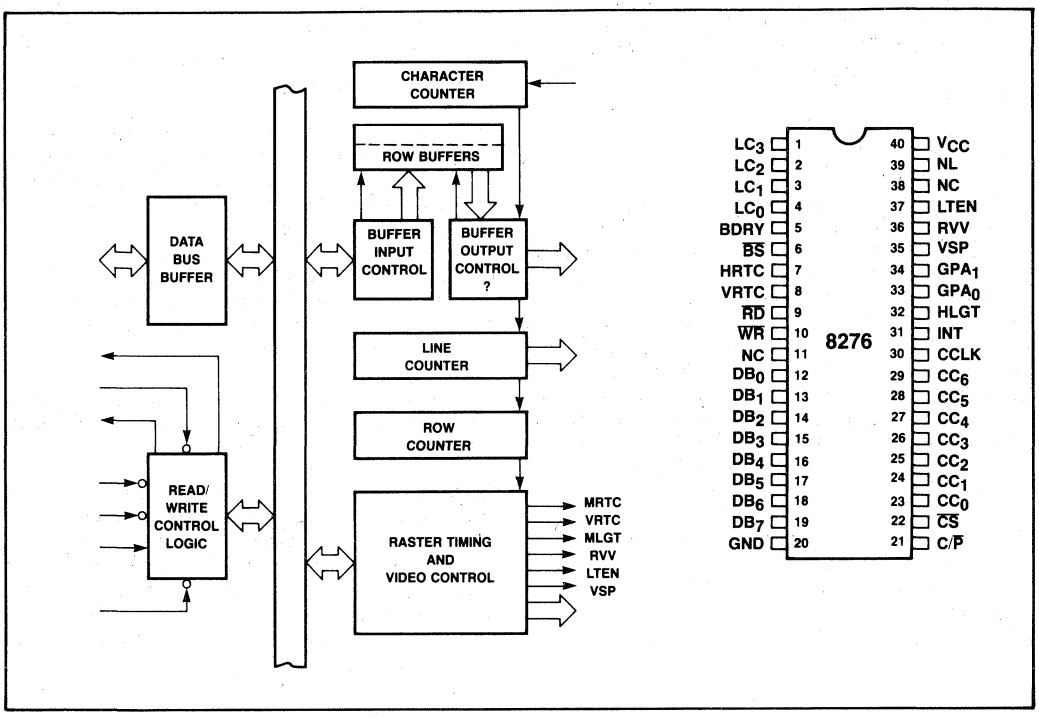


Figure 4.0.0 8276 Block Diagram

4.1 CRT Display Refreshing

The 8276, having been programmed by the system designer for a specific screen format, generates a series of Buffer Ready signals. A row of characters is then transferred by the system controller from the display memory to the 8276's row buffers. The row buffers are filled by deselecting the 8276 $\overline{CS}$ and asserting the BS and WR signals. The 8276 presents the character codes to an external character generator ROM by using outputs CC0–CC6. The parallel data from the outputs of the character generator is converted to serial information that is clocked by external dot timing logic into the video input of the CRT.

The character rows are displayed on the CRT one line at a time. Line count outputs LC0–LC3 select the current line information from the character generator ROM. The display process is illustrated in Figure 4.1.0. This process is repeated for each display character row. At the beginning of the last display row the 8276 generates an interrupt request by raising its INT output line. The interrupt request is used by the 8051 system controller to reinitialize its load buffer pointers for the next display refresh cycle.

Proper CRT refreshing requires that certain 8276 parameters be programmed at system initialization time. The 8276 has two types of internal registers; the write only Command (CREG) and Parameter (PREG) Registers, and the read only Status Register (SREG). The 8276 expects to receive a command followed by 0 to 4 parameter bytes depending on the command. A summary of the 8276's instruction set is shown in Figure 4.1.1. To access the registers, $\overline{CS}$ must be asserted along with $\overline{WR}$ or $\overline{RD}$. The status of the C/P pin determines whether the command or parameter registers are selected.

The 8276 allows the designer flexibility in the display format. The display may be from 1 to 80 characters per row, 1 to 64 rows per screen, and 1 to 16 horizontal lines per character row. In addition, four curser formats are available; blinking, non-blinking, underline, and reverse video. The curser position is programmable to anywhere on the screen via the Load Curser command.

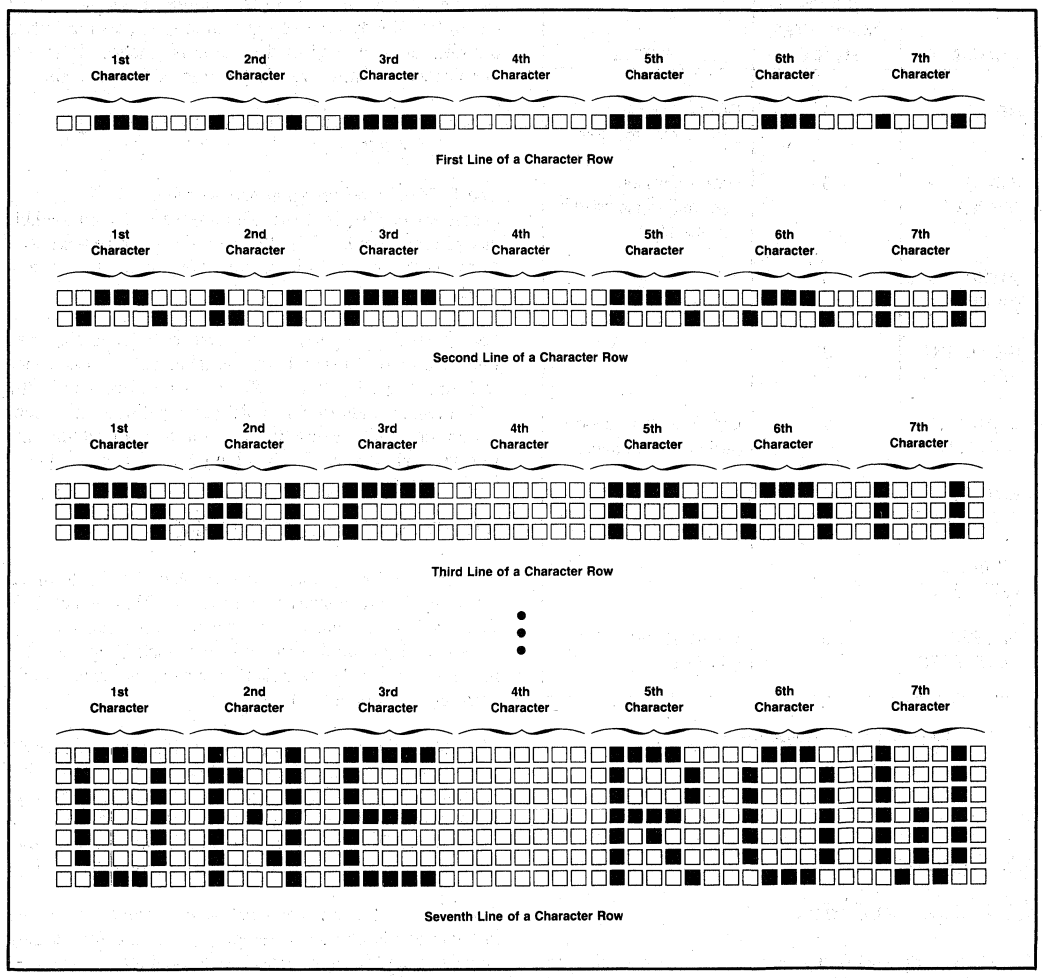


Figure 4.1.0 8276 Row Display

4.2 CRT Timing

The 8276 provides two timing outputs for controlling the CRT. The Horizontal Retrace Timing and Control (HRTC) and Vertical Retrace Timing and Control (VRTC) signals are used for synchronizing the CRT horizontal and vertical oscillators. A third output, VSP (Video Suppress), provides a signal to the dot timing logic to blank the video signal during the horizontal and vertical retraces. LTEN (Light Enable) is used to provide the ability to force the video output high regardless of the state of the VSP signal. This feature is used to place the cursor on the screen and to control attribute functions.

RVV (Reverse Video) output, if enabled, will cause the system to invert its video output. The fifth timing signal output, HLGT (highlight) allows the flexibility to increase the CRT beam intensity to a greater than normal level.

COMMAND	NO. OF PARAMETER BYTES	NOTES
RESET	4	Display format parameters required
START DISPLAY	0	DMA operation parameters included in command
STOP DISPLAY	0	—
RED LIGHT PEN	2	—
LOAD CURSOR	2	Cursor X, Y position parameters required
ENABLE INTERRUPT	0	—
DISABLE INTERRUPT	0	—
PRESET COUNTERS	0	Clears all internal counters

Figure 4.1.1 8276 Instruction Set

4.3 Special Functions

4.3.1 Special Codes

The 8276 recognizes four special codes that may be used to reduce memory, software, or system controller overhead. These characters are placed within the display memory by the system controller. The 8276 performs certain tasks when these codes are received in its row buffer memory.

1) *End of Row Code* — Activates VSP. VSP remains active until the end of the line is reached. While VSP is active the screen is blanked.

2) *End Of Row-Stop Buffer Loading Code* — Causes the Buffer Ready control logic to stop requesting buffer transfers for the rest of the row. It affects the display the same as End of Row Code.

3) *End Of Screen Code* — Activates VSP. VSP remains active until the end of the frame is reached.

4) *End Of Screen-Stop Buffer Loading Code* — Causes the Buffer Ready control logic to stop requesting buffer transfers until the end of the frame is reached. It affects the display the same way as the End of Screen code.

4.3.4 Programmable Buffer Loading Control

The 8276 can be programmed to request 1, 2, 4, or 8 characters per Buffer load. The interval between loads is also programmable. This allows the designer the flexibility to tailor the buffer transfer overhead to fit the system needs.

Each scan line requires 63.5 microseconds. A character line consists of 10 scan lines and takes 635 microseconds to form. The 8276 row buffer must be filled within the 635 microseconds or an under run condition will occur within the 8276 causing the screen to be blanked until the next vertical retrace. This blanking will be seen as a flicker in the display.

5.0 DESIGN BACKGROUND

A fully functional, microcontroller-based CRT terminal was designed and constructed using the 8051 and the 8276. The terminal has many of the functions that are found in commercially available low cost terminals. Sophisticated features such as programmable keys can be added easily with modest amounts of software.

The 8051's functions in this application note include: up to 9.6K BAUD full duplex serial transmission; decoding special messages sent from the host computer; scanning, debouncing, and decoding a full function keyboard; writing to the 8276 row buffer from the display RAM without the need for a DMA controller; and scrolling the display.

The 8276 CRT controller's functions include: presenting the data to the character generator; providing the timing signals needed for horizontal and vertical retrace; and providing blanking and video information.

5.1 Design Philosophy

Since the device count relates to costs, size, and reliability of a system, arriving at a minimum device count without degrading the performance was a driving force for this application note. LSI devices were used where possible to maintain a low chip count and to make the design cycle as short as possible.

PL/M-51 was chosen to generate the majority of the software for this application because it models the human thought process more closely than assembly language. Consequently it is easier and faster to write programs using PL/M-51 and the code is more likely to be correct because less chance exists to introduce errors.

PL/M-51 programs are easier to read and follow than assembly language programs, and thus are easier to modify and customize to the end user's application. PL/M-51 also offers lower development and maintenance costs than assembly language programming.

PL/M-51 does have a few drawbacks. It is not as efficient in code generation relative to assembly language and thus may also run slower.

This application note uses the 8051's interrupts to control the servicing of the various peripherals. The speed of the main program is less critical if interrupts are used. In the last two application notes on terminal controllers, a criterion of the system was the time required for receiving an incoming serial byte, decoding it, performing the function requested, scanning the keyboard, debouncing the keys, and transmitting the decoded ASCII code must be less than the vertical refresh time. Using the 8051 and its interrupts makes this time constraint irrelevant.

5.2 System Target Specifications

The design specifications for the CRT terminal design is as follows:

Display Format

- 80 characters/display row
- 25 display lines

Character Format

- 5 × 7 character contained within a 7 × 10 frame
- First and seventh columns blanked
- Ninth line curser position
- Programmable delay blinking underline curser

Control Characters Recognized

- Backspace
- Linefeed
- Carriage Return
- Form Feed

Escape Sequences Recognized

- ESC A, Curser up
- ESC B, Curser down
- ESC C, Curser right
- ESC D, Curser left
- ESC E, Clear screen
- ESC F, Move addressable curser
- ESC H, Home curser
- ESC J, Erase from curser to the end the screen
- ESC K, Erase the current line

Characters Displayed

- 96 ASCII Alphanumeric Characters

Characters Transmitted

- 96 ASCII Alphanumeric Characters
- ASCII Control Character Set
- ASCII Escape Sequence Set
- Auto Repeat

Display Memory

- 2K × 8 static RAM

Data Rate

- Variable rate from 150 to 9600 BAUD

CRT Monitor

- Ball Bros TV-12, 12MHZ Black and White

Keyboard

- Any standard undecoded keyboard (2 key lock-out)
- Any standard decoded keyboard with output enable pin
- Any standard decoded serial keyboard up to 150 BAUD

Scrolling Capability

Compatible With Wordstar

6.0 SYSTEM DESCRIPTION

A block diagram of the CRT terminal is shown in figure 6.0.0. The diagram shows only the essential system features. A detailed schematic of the CRT terminal is contained in the Appendix 7.1.

The "brains" of the CRT terminal is the 8051 microcontroller. The 8276 is the CRT controller in the system, and a 2716 EPROM is used as the character generator. To handle the high speed portion of the CRT, the 8276 is surrounded by a handful of TTL devices. A 2K × 8 static RAM was used as the display memory.

Following the system reset, the 8276 is initialized for curser type, number of characters per line, number of lines, and character size. The display RAM is initialized to all "spaces" (ASCII 20H). The 8051 then writes the "start display" command to the 8276. The local/line input is sampled to determine the terminal mode. If the terminal is on-line, the BAUD rate switches are read and the serial port is set up for full duplex UART mode. The processor then is put into a loop waiting to service the serial port fifo or the 8276.

The serial port is programmed to have the highest priority interrupt. If the serial port generates an interrupt, the processor reads the buffer, puts the character in a generated fifo that resides in the 8051's internal RAM, increments the fifo pointer, sets the serial interrupt flag and returns.

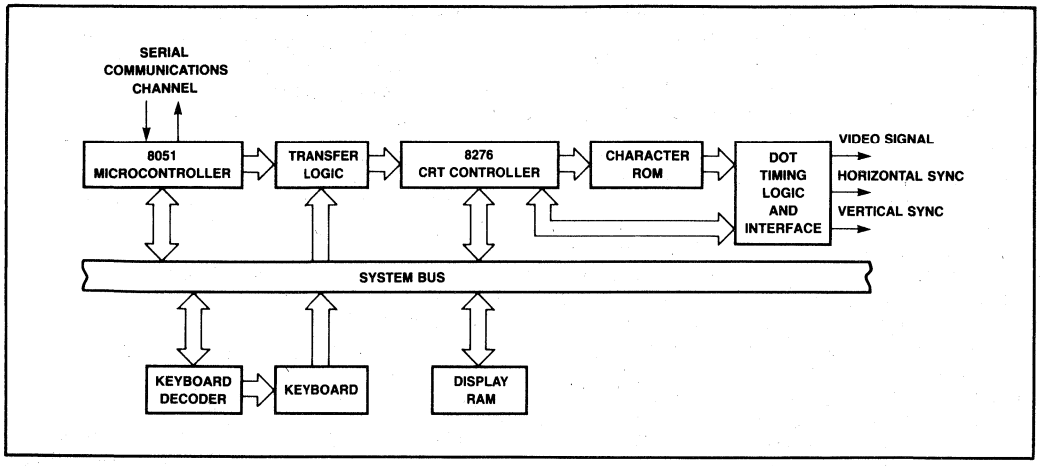


Figure 6.0.0 CRT Terminal Controller Block Diagram

The main program determines if it is a displayable character, a Control word or an ESC sequence and either puts the character in the display buffer or executes the appropriate command sent from the host computer.

If the 8276 needs servicing, the 8051 fills the row buffer for the CRT display's next line. If the 8276 generates a vertical retrace interrupt, the buffer pointers are reloaded with the display memory location that corresponds to the first character of the first display line on the CRT. The vertical retrace also signals the processor to read the keyboard for a key closure.

6.1 Hardware Description

The following section describes the unique characteristics of this design.

6.1.1 Peripheral Address Map

The display RAM, 8276 registers, and the 8276 row buffers are memory mapped into the external data RAM address area. The addresses are as follows:

Read and Write External Display RAM —	Address 1000H to 17CFH
Write to 8276 row buffers from Display RAM —	Address 1800H to 1FCFH
Write to 8276 Command Register (CREG) —	Address 0001H
Write to 8276 Parameter Register (PREG) —	Address 0000H
Read from 8276 Status Register (SREG) —	Address 0001H

Three general cases can be explored; reading and writing the display RAM, writing to the 8276 row buffers, and reading and writing the 8276's control registers.

As mentioned previously the 8051 fills the 8276 row buffer without the need of a DMA controller. This is accomplished by using a Quad 2-input multiplexor (Figure 6.1.0) as the transfer logic shown in the block diagram. The address line, P2.3, is used to select either of the two inputs. When the address line is low the $\overline{RD}$ and $\overline{WR}$ lines perform their normal functions, that is read and write the

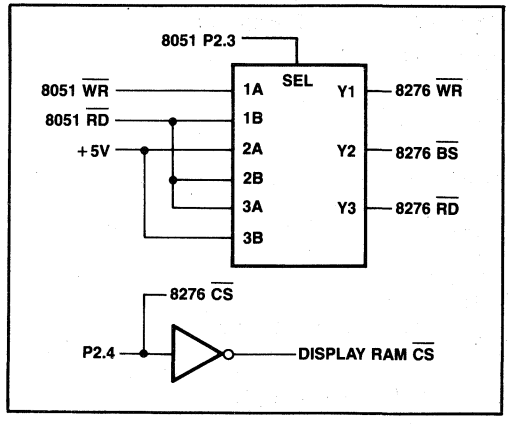


Figure 6.1.0
Simplified Version Of The Transfer Logic

8276 or the external display RAM depending on the states of their respective chip selects. If the address line is high, the 8051 $\overline{RD}$ line is transformed into $\overline{BS}$ and $\overline{WR}$ signals for the 8276. While holding the address line high, the 8051 executes an external data move (MOVX) from the display RAM to the accumulator which causes the display RAM to output the addressed byte onto the data bus. Since the multiplexor turns the same 8051 $\overline{RD}$ pulses into $\overline{BS}$ and $\overline{WR}$ pulses to the 8276, the data bus is thus read into the 8276 as a Buffer transfer. This scheme allows 80 characters to be transferred from the display RAM into the 8276 within the required character line time of 635 microseconds. The 8051 easily meets this requirement by accomplishing the task within 350 microseconds.

6.1.2 Scanning The Keyboard

Throughout this project, provision have been made to make the overall system flexible. The software has been written for various keyboards and the user simply needs to link different program modules together to suit their needs.

6.1.2.1 Undecoded Keyboard

Incorporating an undecoded keyboard controller into the other functions of the 8051 shows the flexibility and over all CPU power that is available. The keyboard in this case is a full function, non-buffered 8 × 8 matrix of switches for a total of 64 possible keys. The 8 send lines are connected to a 3-to-8 open-collector decoder as shown in Figure 6.1.1. Three high order address lines from the 8051 are the decoder inputs. The enabling of the decoder is accomplished through the use of the $\overline{PSEN}$ signal from the 8051 which makes the architecture of the separate address space for the program memory and the external data RAM work for us to eliminate the need to decode addresses externally. The move code (MOVC) instruction allows each scan line of the keyboard to be read with one instruction.

The keyboard is read by bringing one of the eight scan lines low sequentially while reading the return lines which are pulled high by an external resistor. If a switch is

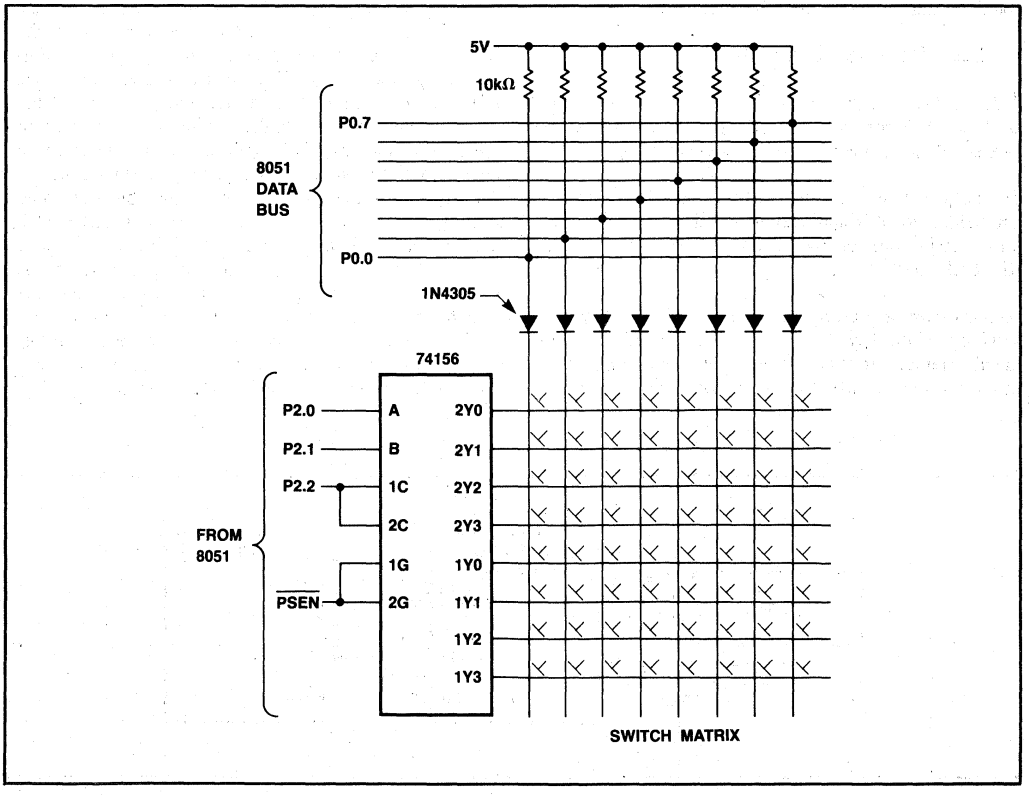


Figure 6.1.1 Keyboard

closed, the data bus line is connected through the switch to the low output of the decoder and one of the data bus lines will be read as a 0. By knowing which scan line detected a key closure and which data bus line was low, the ASCII code for that key can easily be looked up in a matrix of constants. PL/M-51 has the ability to handle arrays and structured arrays, which makes the decoding of the keyboard a trivial task.

Since the Shift, Cap Lock, and Control keys may change the ASCII code for a particular key closure, it is essential to know the status of these pins while decoding the keyboard. The Shift, Cap Lock, and Control keys are therefore not scanned but are connected to the 8051 port pins where they can be tested for closure directly.

The 8 receive lines are connected to the data bus through germanium diodes which chosen for their low forward voltage drop. The diodes keep the keyboard from interfering with the data bus during the times the keyboard is not being read. The circuit consisting of the 3-to-8 decoder and the diodes also offers some protection to the 8051 from possible Electrostatic Discharge (ESD) damage that could be transmitted through the keyboard.

6.1.2.2 Decoded Keyboard

A decoded keyboard can easily be connected to the system as shown in Figure 6.1.2. Reading the keyboard can be evoked either by interrupts or by software polling.

The software to periodically read a decoded keyboard was not written for this application note but can be accomplished with one or two PL/M-51 statements in the READER routine.

A much more interesting approach would be to have the servicing of the keyboard be interrupt driven. An additional external interrupt is created by configuring timer/counter 0 into an event counter. The event counter is initialized with the maximum count. The keyboard controller would inform the 8051 that a valid key has been depressed by pulling the input pin T0 low. This would overflow the event counter, thus causing an interrupt. The interrupt routine would simply use a MOVC ($\overline{PSEN}$ is connected to the output enable pin of the keyboard controller) to read the contents of the keyboard controller onto the data bus, reinitialize the counter to the maximum count and return from the interrupt.

6.1.2.3 Serial Decoded Keyboard

The use of detachable keyboards has become popular among the manufacturers of keyboards and personal computers. This terminal has provisions to use such a keyboard.

The keyboard controller would scan the keyboard, debounce the key and send back the ASCII code for that key closure. The message would be in an asynchronous serial format.

The flowchart for a software serial port is shown in Figure 6.1.3. An additional external interrupt is created as discussed for the decoded keyboard but the use in this case would be to detect a start bit. Once the beginning of the start bit has been detected, the timer/counter 0 is configured to become a timer. The timer is initialized to cause an interrupt one-half bit time after the beginning of the start bit. This is to validate the start bit. Once the start bit is validated, the timer is initialized with a value to cause an interrupt one bit time later to read the first data bit. This process of interrupting to read a data bit is repeated until all eight data bits have been received. After all 8 data bits are read, the software serial port is read once more to detect if a stop bit is present. If the stop bit is not present, an error flag is set, all pointers and flags are reset to their initial values, and the timer/counter is reconfigured to an event counter to detect the next start bit. If the stop bit is present, a valid flag is set and the flags and counter are reset as previously discussed.

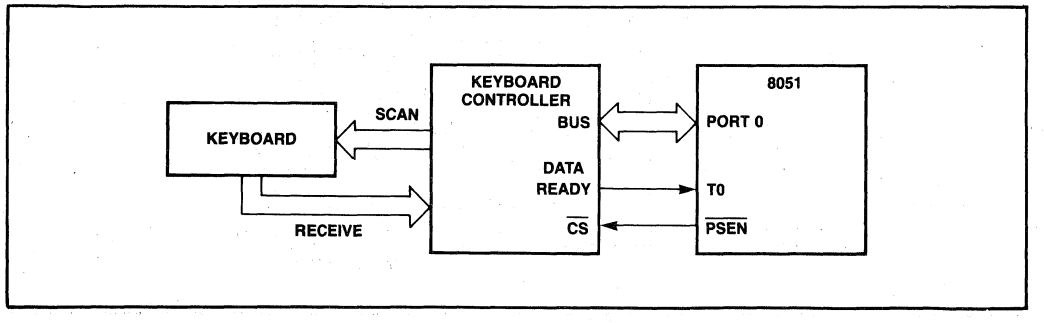


Figure 6.1.2 Using A Decoded Keyboard

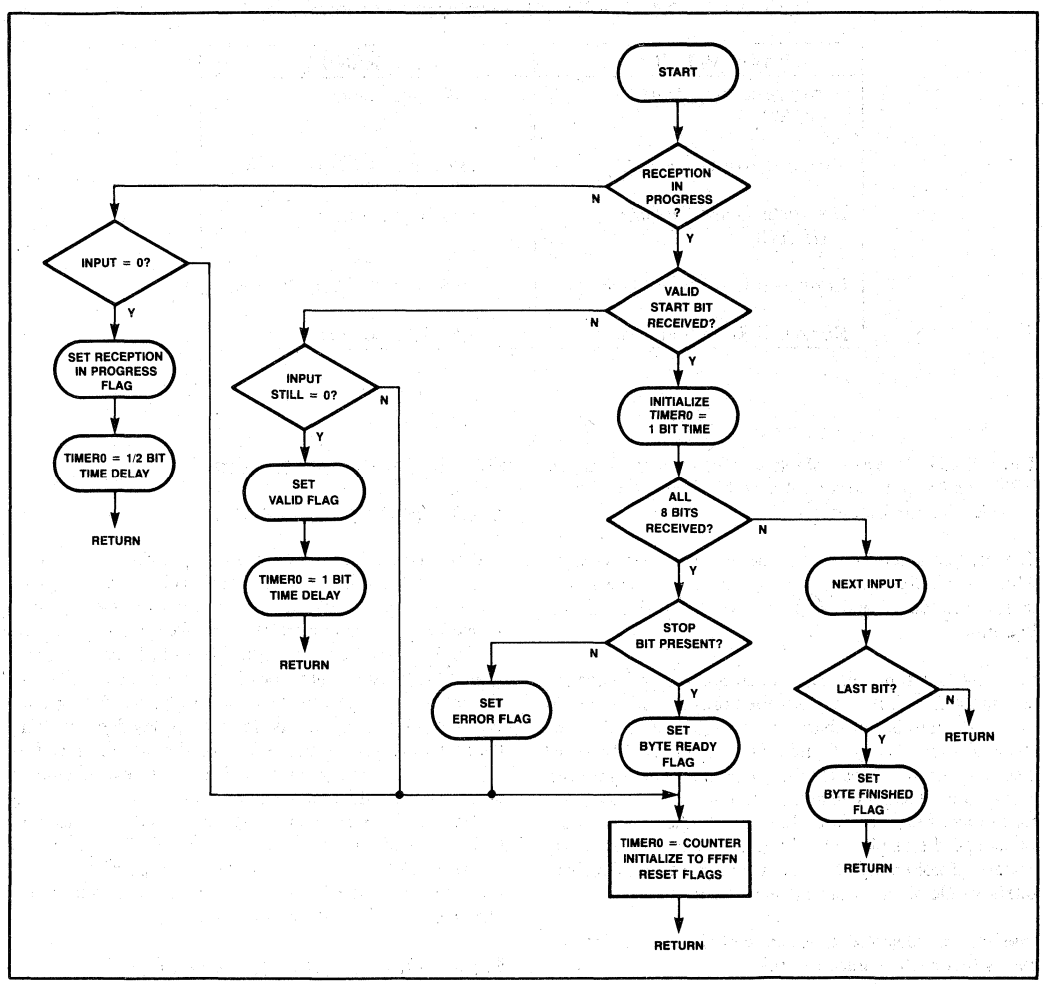


Figure 6.1.3 Flowchart for the Software Serial Port

6.1.4 System Timings

The requirements for the BALL BROTHERS. TV-12 monitor's operation is shown in table 6.1.0. From the monitor's parameters, the 8276 specifications and the system target specifications the system timing is easily calculated.

The 8276 allows the vertical retrace to be only an integer multiple of the horizontal character lines. Twenty-five display lines and a character frame of 7 × 10 are required from the target specification which will require 250 horizontal lines. If the horizontal frequency is to be within 500 Hz of 15,750 Hz, we must choose either one or two character line times for horizontal retrace. To allow for a little more margin at the top and bottom of the screen, two character line times was chosen for the vertical retrace. This choice yields 250 + 20 = 270 total character lines per frame. Assuming 60 Hz vertical retrace frequency:

60 Hz * 270 = 16,200 Hz horizontal frequency

and

1/16,200 Hz * 20 horizontal sync times = 1.2345 milliseconds

Table 6.1.0 CRT Monitor's Operational Requirements

PARAMETER	RANGE
Vertical Blanking Time (VRTC)	800 μsec nominal
Vertical Drive Pulsewidth	300 μsec $\leq$ PW $\leq$ 1.4 ms
Horizontal Blanking Time (HRTC)	11 μsec nominal
Horizontal Drive Pulsewidth	25 μsec $\leq$ PW $\leq$ 30 μsec
Horizontal Repetition Rate	15,750 $\pm$500 pps

The 1.2345 milliseconds of retrace time meets the nominal VRTC and vertical drive pulse width time of .3mSec to 1.4mSec for the Ball monitor.

The next parameter to find is the horizontal retrace time which is wholly dependent on the monitor used. Usually it lies between 15 and 30 percent of the total horizontal line time.

Since most designs display a fixed number of characters per line it is useful to express the horizontal retrace time as a given number of character times. In this design, 80 characters are displayed, and it was experimentally found that 20 character times for the horizontal retrace gave the best results. It should be noted if too much time was given for retrace, there would be less time to display the characters and the display would not fill out the screen. Conversely, if not enough time is given for retrace, the characters would seem to run off the screen.

One hundred character times per complete horizontal line means that each character needs:

(1/16,200 Hz) /100 character times = 617.3 nanoseconds

If we multiply the 20 character times needed to retrace by 617.3 nanoseconds needed for each character, we find 12.345 microseconds are allocated for retrace. This value falls short of the 25 to 30 microseconds required by the horizontal drive of the Ball monitor. To correct for this, a 74LS123 one-shot was used to extend the horizontal drive pulse width.

The dot clock frequency is easy to calculate now that we know the horizontal frequency. Since each character is formed by seven dots in the horizontal axis, the dot clock period would be the character clock (617.3 nanoseconds) divided by the 7 which is equal to 11.34 MHz. The basic dot timing and CRT timing are shown in the Appendix.

6.2 Software Description

6.2.1 Software Overview

The software for this application was written in a "foreground-background" format. The background programs are all interrupt driven and are written in assembly language due to time constraints. The foreground programs are for the most part written in PL/M-51 to ease the programming effort. A number of subroutines are written in assembly language due to time constraints during execution. Subroutines such as clearing display lines, clearing the screen, and scanning the keyboard require a great deal of 16 bit adds and compares and would execute much slower and would require more code space if written in PL/M-51. The background and foreground programs talk to each other through a set of flags. For example, the PL/M-51 foreground program tests "SERIAL$INT" to determine if a serial port interrupt had occurred and a character is waiting to be processed.

6.2.2 The Background Program

Two interrupt driven routines, VERT and BUFFER, (see Fig. 6.2.0) request service every 16.67 milliseconds and 617 microseconds respectively. VERT's request comes during the last character row of the display screen. This routine resets the buffer pointers to the first CRT display line in the display memory. VERT is also used as a time base for the foreground program. VERT sets the flag, SCAN, to tell the foreground program (PL/M-51) that it is time to scan the Keyboard. VERT also increments a counter used for the delay between transmitting characters in the AUTO$REPEAT routine.

The BUFFER routine is executed once per character row. BUFFER uses the multiplexor discussed earlier to fill the 8276's row buffer by executing 80 external data moves and incrementing the Data Pointer between each move.

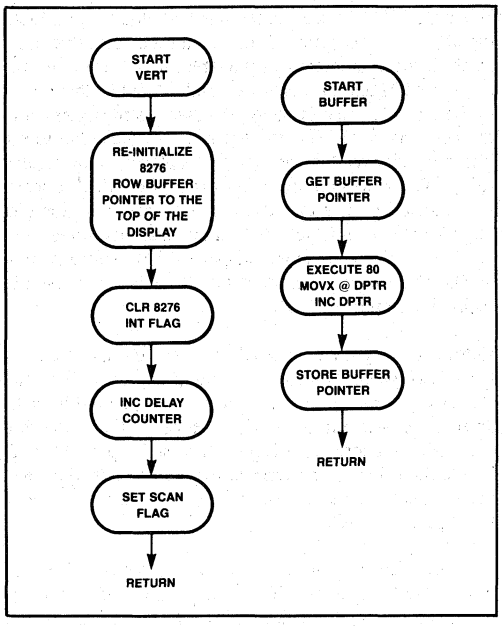


Figure 6.2.0 Flowcharts For VERT and BUFFER Routine

The MOVX reads the display RAM and writes the character into the row buffer during the same instruction.

SERBUF is an interrupt driven routine that is executed each time a character is received or transmitted through the on-chip serial port. The routine first checks if the interrupt was caused by the transmit side of the serial port, signaling that the transmitter is ready to accept another character. If the transmitter caused the interrupt, the flag "TRANSMIT$INT" is set which is checked by the foreground program before putting a character in the buffer for transmission.

If the receiver caused the interrupt, the input buffer on the serial port is read and fed into the fifo that has been manufactured in the internal RAM and increments the fifo pointer "FIFO." The flag "SERIAL$INT" is then set, telling the foreground program that there is a character in the fifo to be processed. If the read character is an ESC character, the flag "ESCSEQ" is set to tell the foreground program that an escape sequence is in the process of being received.

6.2.3 The Foreground Program

The foreground program is documented in the Appendix. The foreground program starts off by initializing the 8276 as discussed earlier. After all variables and flags are initialized, the processor is put into a loop waiting for either VERT to set SCAN so the program can scan the keyboard, or for the serial port to set SERIAL$INT so the program can process the incoming character.

The vertical retrace is used to time the delay between keyboard scans. When VERT gets set, the assembly language routine READER is called. READER scans the keyboard, writing each scan into RAM to be processed later. READER controls two flags, KEY0 and SAME. KEY0 is set when all 8 scans determine that no key is pressed. SAME is set when the same key that was pressed last time the keyboard was read is still pressed.

After READER returns execution to the main program, the flags are tested. If the KEYO flag is set the main program goes back to the loop waiting for the vertical retrace or a serial port interrupt to occur. If the SAME flag is set the main program knows that the closed key has been debounced and decoded so it sends the already known ASCII code to the AUTO$REPEAT routine which determines if that character should be transmitted or not.

If KEY0 and SAME are not set, signifying that a key is pressed but it is not the same key as before, the foreground program determines if the results from the scan are valid. First all eight scans are checked to see if only one key was closed. If only one key is closed, the ASCII code is determined, modified if necessary by the Shift, Cap Lock, or Control keys. The NEW$KEY and VALID flags are then set. The next time READER is called, if the same key is still pressed, the SAME flag will be set, causing the AUTO$REPEAT subroutine to be called as just discussed. Since the keyboard is read during the vertical retrace, 16.67 milliseconds has elapsed between the detection of the pressed key and reverifying that the key is still pressed before transmitting it, thus effectively debouncing the key.

The AUTO$REPEAT routine is written to transmit any key that the NEW$KEY flag is set for. The counter that is incremented each time the vertical refresh interrupt is serviced causes a programmable delay between the first transmission and subsequent auto repeat transmission. Once the NEW$KEY character is sent, the counter is initialized. Each time the AUTO$REPEAT routine is called, the counter is checked. Only when the counter overflows will the next character be transmitted. After the initial delay, a character will be transmitted every other time the routine is called as long as the key remains pressed.

6.2.3.1 Handling Incoming Serial Data

One of the criteria for this application note was to make the software less time dependent. By creating a fifo to store incoming characters until the 8051 has time to pro-

cess them, software timing becomes less critical. This application note uses up to 8 levels of the fifo at 9.2KBAUD, and 1 level at 4.8KBAUD and lower. As discussed earlier, the interrupt service routine for the serial port uses the fifo to store incoming data, increments the fifo pointer, "FIFO", and sets SERIAL$INT to tell the main program that the fifo needs servicing. Once the main program detects that SERIAL$INT is set the routine DECIPHER is executed.

DECIPHER has three separate blocks; a block for decoding displayable characters, a block for processing Escape sequences, and a block for processing Control codes. Each block works on the fifo independently. Before exiting a block, the contents of the fifo are shifted up by the amount of characters that were processed in that particular block. The shifting of the characters insures that the beginning of the fifo contains the next character to be processed. FIFO is then decremented by the number of characters processed.

Let's look at this process more closely. Figure 6.2.1-A shows a representation of a fifo containing 5 characters. The first three characters in the fifo contain displayable characters, A, B, and C respectively with the last two characters being an ESC sequence for moving the curser up one line (ESC A) and FIFO points to the next available location to be filled by the serial port interrupt routine, in this case, 5.

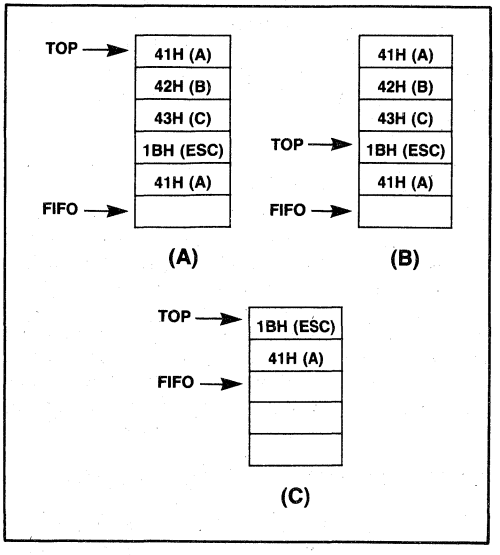


FIGURE 6.2.1 FIFO

When DECIPHER is executed, the first block begins looking at the first character of the fifo for a displayable character. If the character is displayable, it is placed into the display RAM and the software pointer "TOP" that points to the character that is being processed is incremented to the next character. The character is then looked at to see if it too is displayable and if it is, it's placed in the display RAM. The process of checking for displayable characters is continued until either the fifo is empty or a non-displayable character is detected. In our example, three characters are placed into the display RAM before a non-displayable character is detected. At this point the fifo looks like figure 6.2.1-B.

Before entering the next block, the remaining contents of the fifo between TOP, that is now pointing to 1BH and (FIFO-1) are moved up in the fifo by the amount of characters processed, in this example three. TOP is reset to 0 and FIFO is decremented by 3. The serial port interrupt is inhibited during the time the contents of the fifo and the pointers are being manipulated. The fifo now looks like figure 6.2.1-C.

The execution is now passed to the next block that processes ESC sequences. The first location of the fifo is examined to see if it is an ESC character (1BH). If not, the execution is passed to the next block of DECIPHER that processes Control codes. In this case the fifo does contain an ESC code. The flag ESC$SEQ is checked to see if the 8051 is in the process of receiving an ESC sequence thus signifying that the next byte of the sequence has not been received yet. If the ESC$SEQ is not set, the next character in the fifo is checked for a valid escape code and the proper subroutine is then called. The fifo contents are then shifted as discussed for the previous block. Due to the length of time that is needed to execute an ESC code sequence or a Control code, only one ESC code and/or Control code can be processed each time DECIPHER is executed.

If at the end of the DECIPHER routine, FIFO contains a 0, the flag SER$INT is reset. If SER$INT remains set, DECIPHER will be executed immediately after returning to the main program if SCAN had not been set during the execution of the DECIPHER routine, otherwise DECIPHER will be called after the keyboard is read.

6.2.4 Memory Pointers and Scrolling

The curser always points to the next location in display memory to be filled. Each time a character is placed in the display memory, the curser position needs to be tested to determine if the curser should be incremented to the beginning of the next line of the display or simply moved to the next position on the current display line. The curser position pointers are then updated in both the 8276 and the internal registers in the 8051.

When the 2000th character is entered into the display memory, a full display page has been reached signaling the need for the display to scroll. The memory pointer that points to the display memory that contains the first character of the first display line, LINE0, prior to scrolling contains 1800H which is the starting address of the display memory. Each scrolling operation adds 80 (50H) to LINE0 which will now point to the following row in memory as shown in figure 6.2.2-B. LINE0 is used during the vertical refresh routine to re-initialize the pointers associated with filling the 8276 row buffers.

The display memory locations that were the first line of the CRT display now becomes the last line of the CRT display. Incoming characters are now entered into the display memory starting with 1800H, which is now the first character of the last line of the display screen.

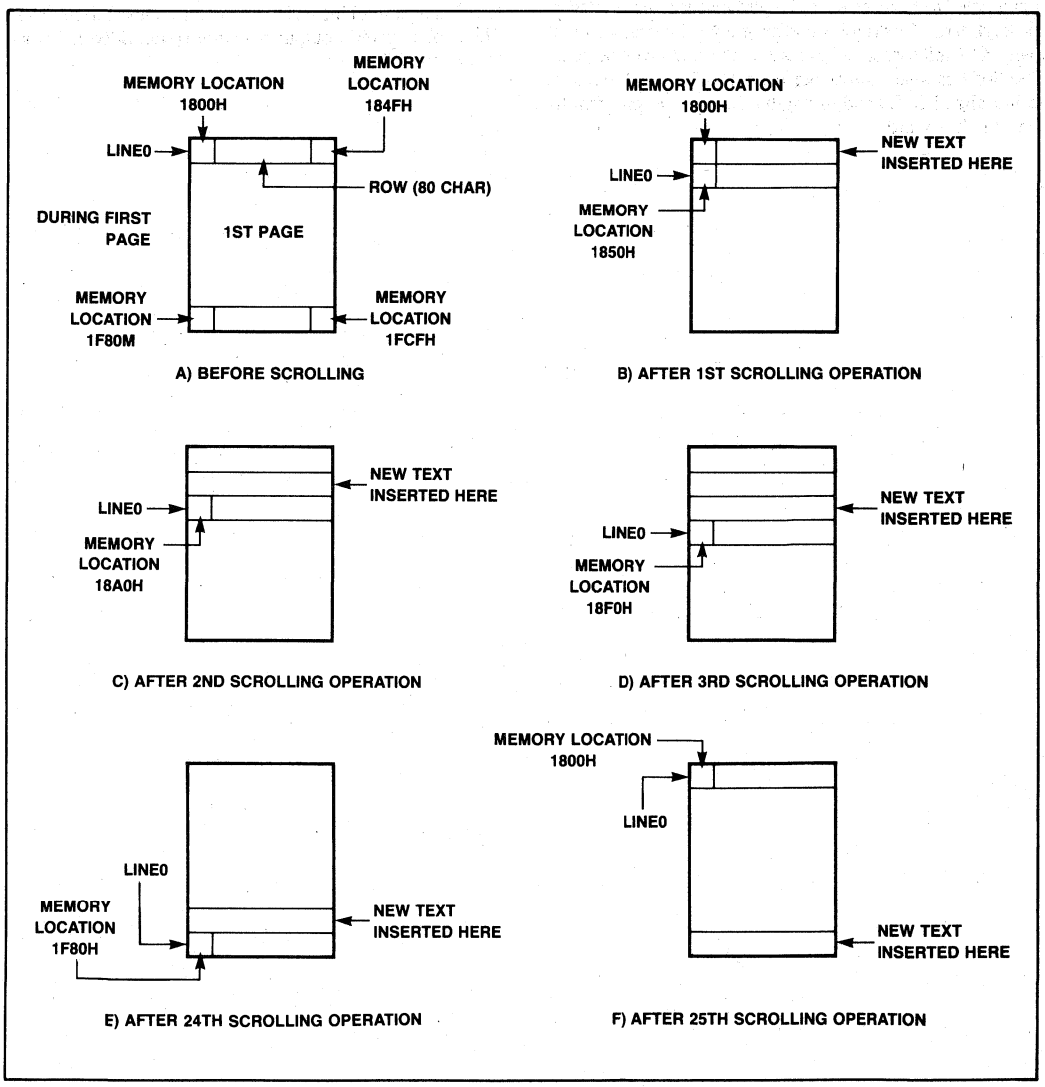


Figure 6.2.2 Pointer Manipulation During Scrolling

6.2.5 Software Timing

The use of interrupts to tie the operation of the foreground program to the real-time events of the background program has made the software timing non-critical for this system.

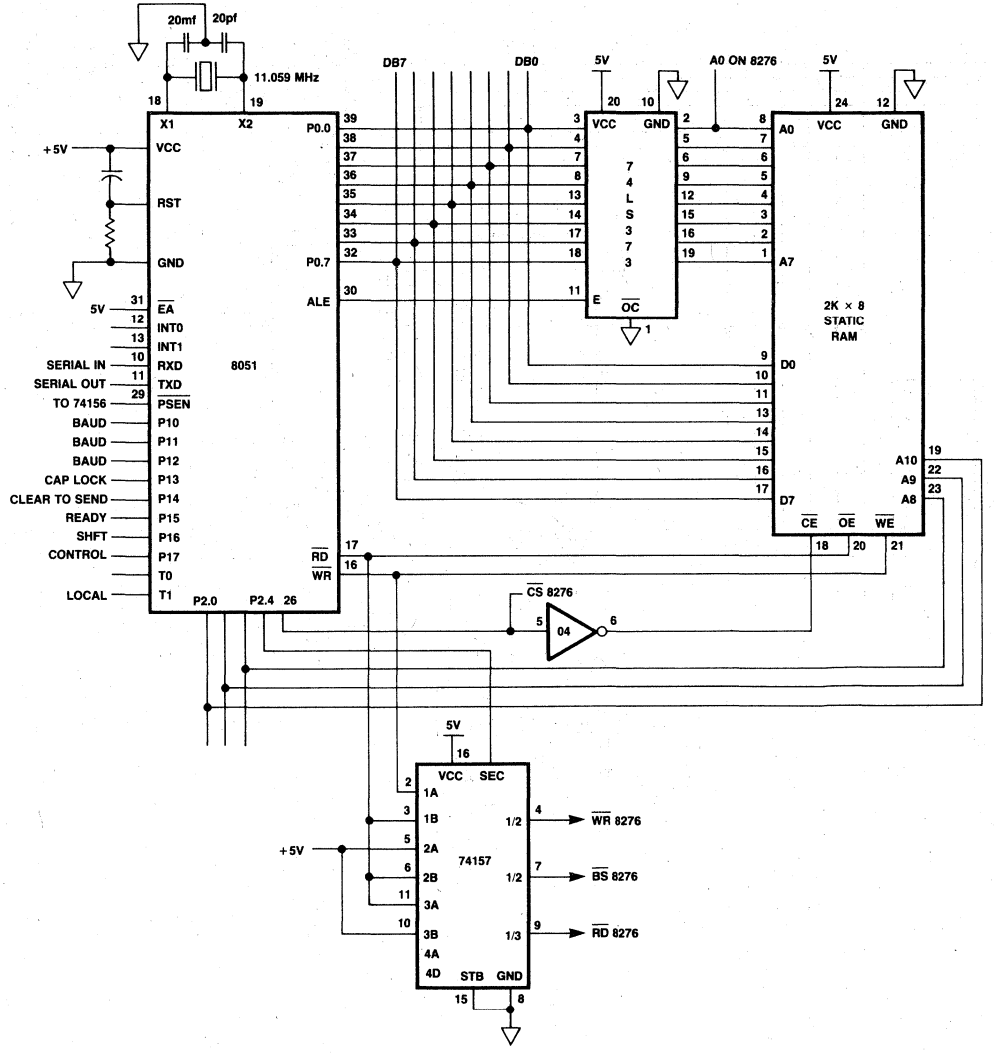
6.3 System Operation

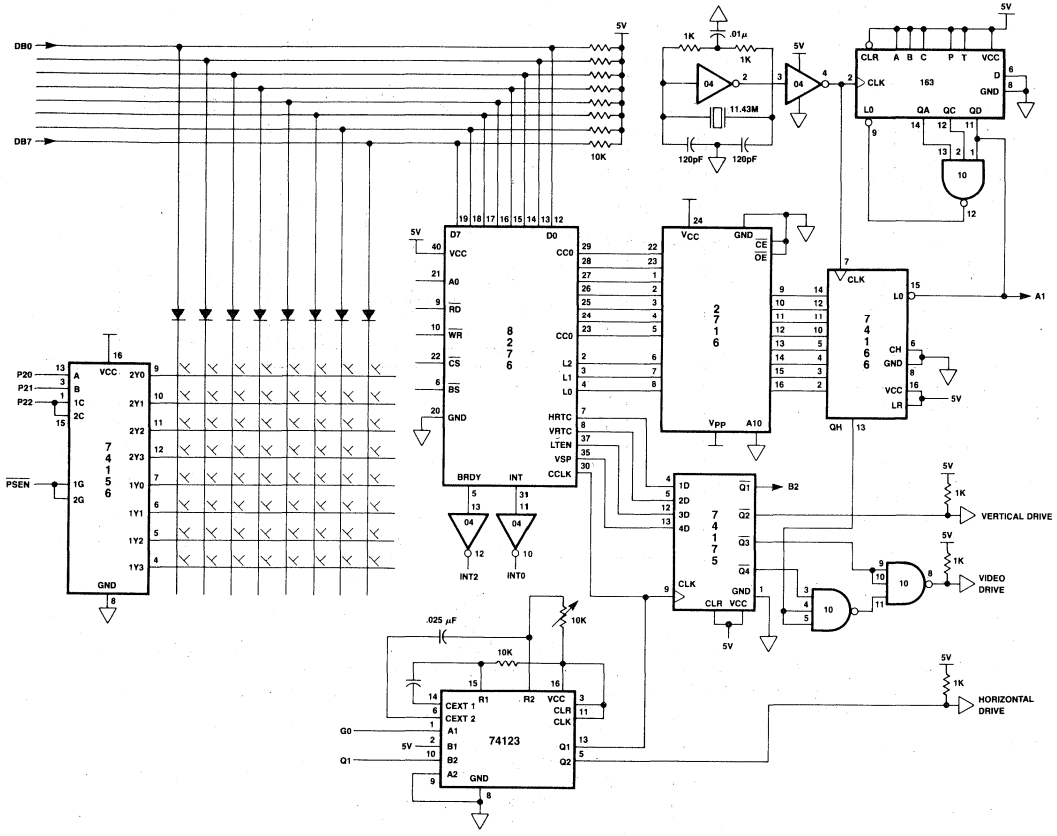
Following the system reset, the 8051 initializes all on-chip peripherals along with the 8276 and display ram. After initialization, the processor waits until the fifo has a character to process or is flagged that it is time to scan the keyboard. This foreground program is interrupted once every 617 microseconds to service the 8276 row buffers. The 8051 is also interrupted each 16.67 milliseconds to re-initialize LINE0 and to flag the foreground program to read the keyboard.

As discussed earlier, a special technique of rapidly moving the contents of the display RAM to the 8276 row buffers without the need of a DMA device was employed. The characters are then synchronously transferred to the character generator via CC0-CC6 and LC0-LC2 which are used to display one line at a time. Following the transfer of the first line to the dot timing logic, the line count is incremented and the second line is selected. This process continues until the last line of the character is transferred.

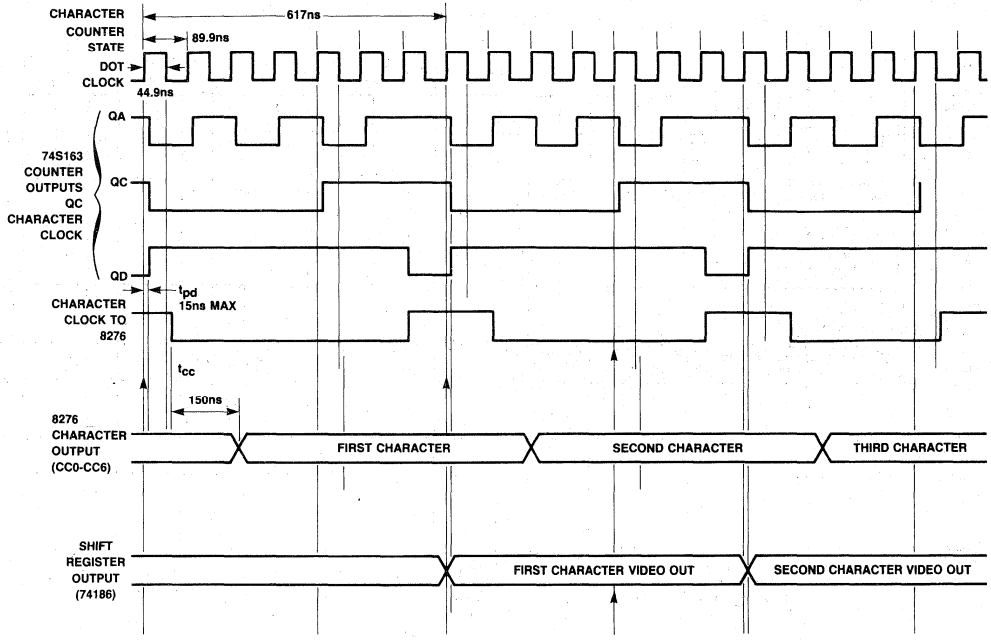
The dot timing logic latches the ouput of the character ROM in a parallel in, serial out synchronous shift register. The shift register's output constitutes the video information to the CRT.

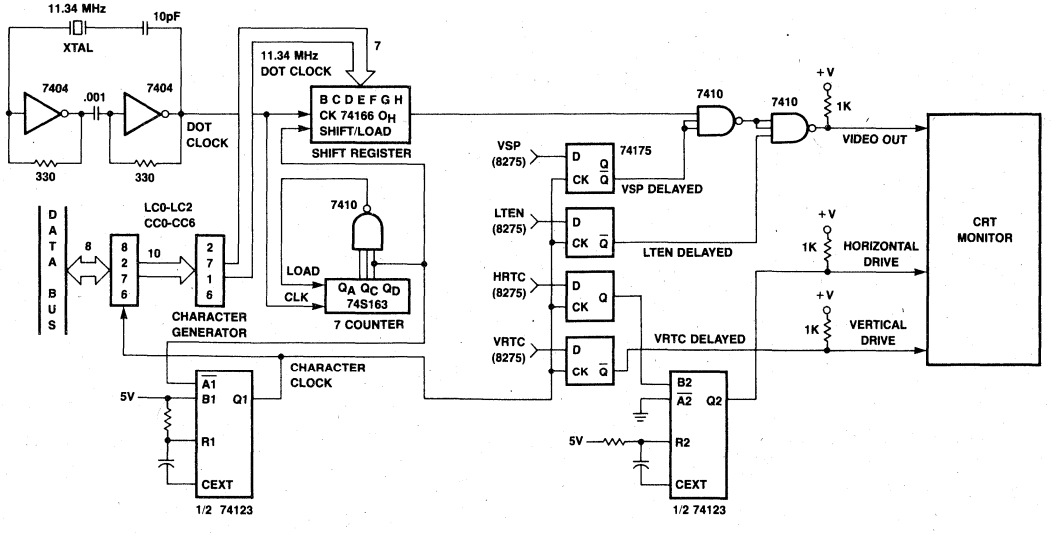
Appendix 7.1 CRT Schematics



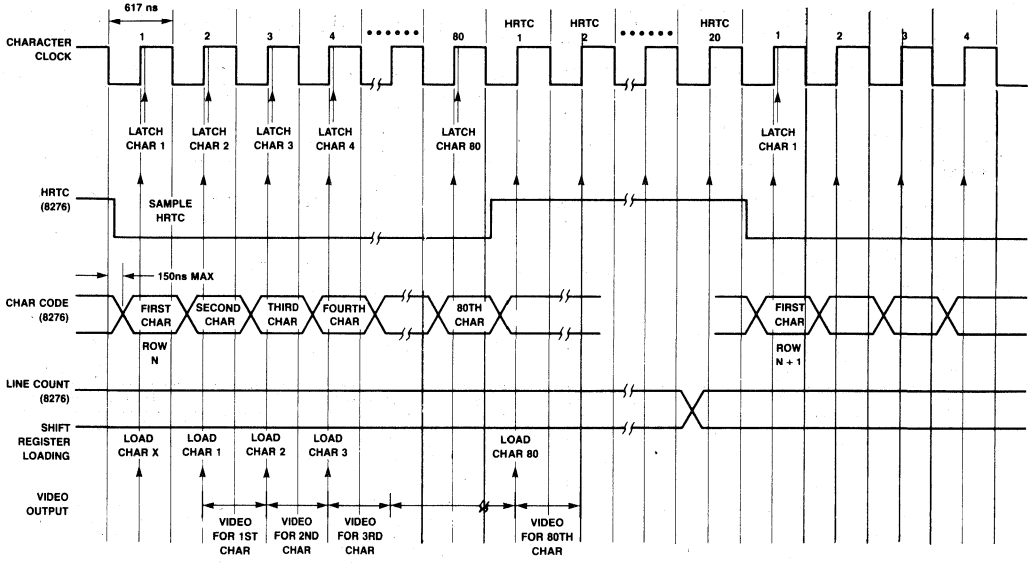

DB0
DB7
5V
10K
1K
.01μ
11.43M
120pF
120pF
04
163
CLR
A B C
P T
VCC
CLK
GND
QA QC QD
L0
D
74166
CH
VCC
LR
QH
A1
8276
D7
D0
VCC
GND
A0
RD
WR
CS
BS
CC0
L2
L1
L0
HRTC
VRTC
LTEN
VSP
CCLK
BRDY
INT
INT2
INT0
2716
VCC
GND
CE
OE
VPP
A10
74156
P20
P21
P22
PSEN
1G
2G
1C
2C
2Y0
2Y1
2Y2
2Y3
1Y0
1Y1
1Y2
1Y3
74175
1D
2D
3D
4D
Q1
Q2
Q3
Q4
CLR
B2
VERTICAL DRIVE
VIDEO DRIVE
HORIZONTAL DRIVE
.025 μF
10K
74123
CEXT 1
CEXT 2
R1
R2
A1
B1
B2
A2
G0
Q1

Appendix 7.2 Dot Timing





Appendix 7.3 CRT System Timing



Appendix 7.4 Escape/Control/Display Character Summary

	CONTROL CHARACTERS				DISPLAYABLE CHARACTER						ESCAPE SEQUENCE			
BIT	000	001	010	011	100	101	110	111	010	011	100	101	110	111
0000	NUL @	DLE P	SP	ø	@	P		P						
0001	SOH A	DC1 Q	!	|	A	Q	A	Q			↑ A		
0010	STX B	DC2 R	"	2	B	R	B	R			↓ B			
0011	ETX C	DC3 S	=	3	C	S	C	S			→ C			
0100	EOT D	DC4 T	$	4	D	T	D	T			← D			
0101	ENQ E	NAK U	%	5	E	U	E	U			CLR E			
0110	ACK F	SYN V	&	6	F	V	F	V						
0111	BEL G	ETB W	'	7	G	W	G	W						
1000	BS H	CAN X	(	8	H	X	H	X			HOME H			
1001	HT I	EM Y	)	9	I	Y	I	Y						
1010	LF J	SUB Z	*	:	J	Z	J	Z			EOS I			
1011	VT K	ESC [	+	;	K	[	K				EL J			
1100	FF L	FS	,		L		L							
1101	CR M	GS	–	=	M	]	M							
1110	SO N	RS \	.		N	^	N							
1111	SI O	US –	/	?	O	–	O							

NOTE: Shaded blocks — functions terminal will react to. Others can be generated but are ignored upon receipt.

Appendix 7.5 Character Generator

As previously mentioned, the character generator used in this terminal is a 2716 EPROM. A 1K by 8 device would have been sufficient since a 128 character 5 by 7 dot matrix only requires 8K of memory. A custom character set could have been stored in the second 1K bytes of the 2716. Any of the free I/0 pins on the 8051 could have been used to switch between the character sets.

The three low-order line count outputs (LC0–LC2) from the 8276 are connected to the three low-order address lines of the character generator. The CC0–CC6 output lines are connected to the A3–A9 lines of the character generator.

The output of the character generator is loaded into the shift register. The serial output of the shift register is the video output to the CRT.

Let's assume that the letter "E" is to be displayed. The ASCII code for "E" (45H) is presented to the address lines A2–A9 of the character generator. The scan lines (LC0–LC2) will now count from 0 to seven to form the character as shown in Figure 7.5.0. The same procedure is used to form all 128 possible characters. For reference Appendix 7.6 contains the HEX dump of the character generator used in this terminal.

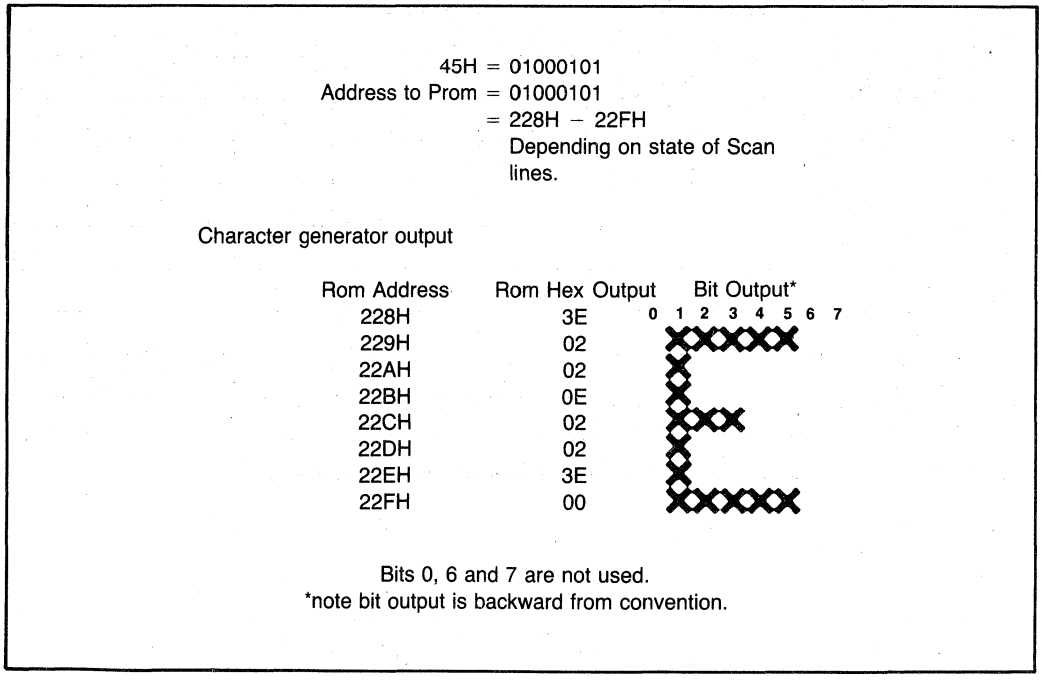
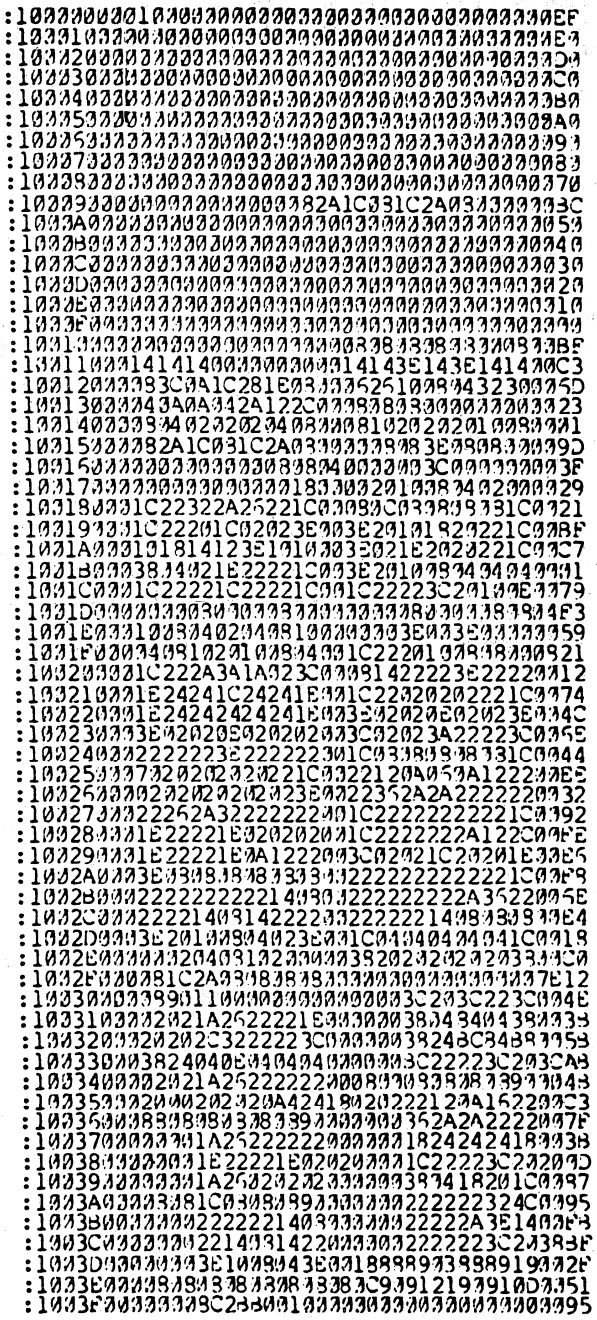


Figure 7.5.0 Character Generator

Appendix 7.6 Hex Dump of the Character Generator



Appendix 7.7 Composite Video

In this design it was assumed that the CRT monitor required a separate horizontal drive, vertical drive, and video input. Many monitors require a composite video signal. The schematic shown in Figure 7.7.0 illustrate how to generate a composite video from the output of the 8276.

The dual one-shots are used to provide a small delay and the proper horizontal and vertical pulse to the composite video monitor. The delay introduced in the horizontal and vertical timing is used to center the display. The 7486 is used to mix the vertical and horizontal retrace. Q1 mix the video and retrace signals along with providing the proper D.C. levels.

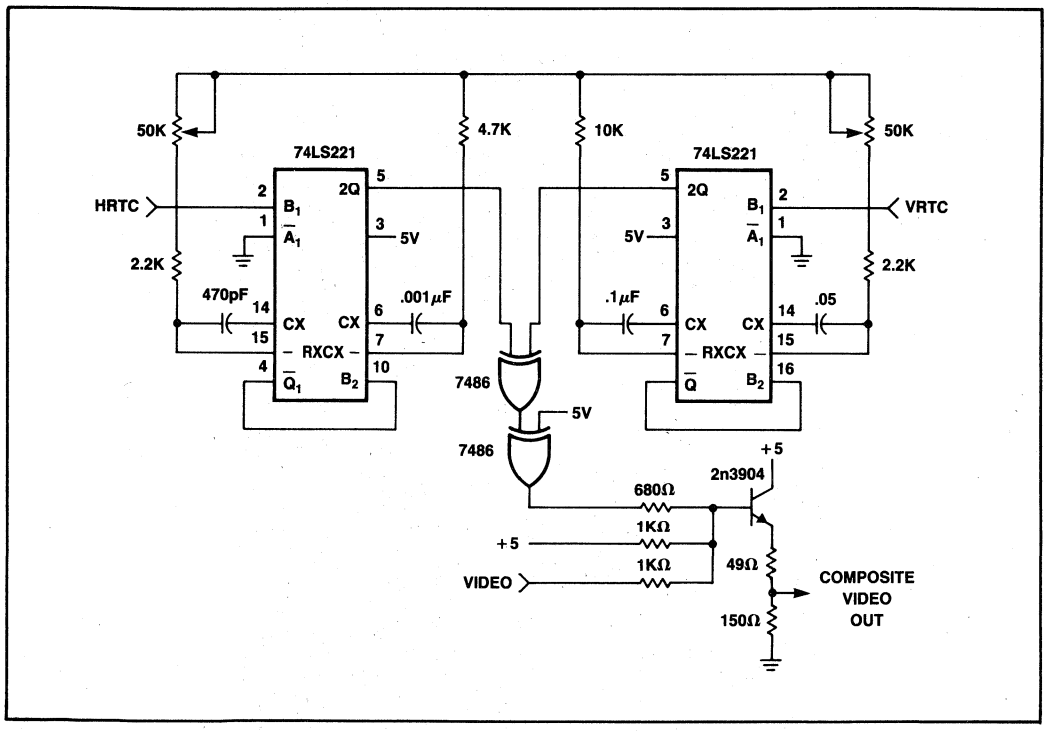


Figure 7.7.0 Composite Video

Appendix 7.8 Software Documentation

```
/*************************************************************************
*************************************************************************
*******                                                           *******
*******            SOFTWARE DOCUMENTATION FOR THE 8051            *******
*******            TERMINAL CONTROLLER APPLICATION NOTE           *******
*******                                                           *******
*************************************************************************
*************************************************************************

        MEMORY MAP ASSOCIATED WITH PERIPHERAL DEVICES (USING MOVX):

        8051 WR AND READ DISPLAY RAM-    ADDRESS 1000H TO 17CFH
        8051 WR DISPLAY RAM TO THE 8276- ADDRESS 1800H TO 1FCFH
        8276 COMMAND ADDRESS-            ADDRESS 0001H
        8276 PARAMETER ADDRESS-                  ADDRESS 0000H
        8276 STATUS REGISTER-                    ADDRESS 0001H


              MEMORY MAP FOR READING THE KEYBOARD (USING MOVC):

        KEYBOARD ADDRESS-                              ADDRESS 10FFH TO 17FFH



    /******************** START MAIN PROGRAM ***************************/

    /* BEGIN BY PUTTING THE ASCII CODE FOR BLANK IN THE DISPLAY RAM*/

    INIT:
    {FILL 2000 LOCATIONS IN THE DISPLAY RAM WITH SPACES (ASCII 20H)}

    /*        INITIALIZE POINTERS, RAM BITS, ETC.     */

    {INITIALIZE POINTERS AND FLAGS}
    {INITIALIZE TOP OF THE CRT DISPLAY "LINE0"=1800H}
    {INITIALIZE 8276 BUFFER POINTER "RASTER" =1800H}
    {INITIALIZE DISPLAY$RAM$POINTER=0000H}

            /* INITIALIZE THE 8276 */

    { RESET THE 8276}
    {INITIALIZE 8276 TO 80 CHARACTER/ROW }
    {INITIALIZE 8276 TO 25 ROWS PER FRAME}
    {INITIALIZE 8276 TO 10 LINES PER ROW}
    {INITIALIZE 8276 TO NON-BLINKING UNDERLINE CURSER}
    {INITIALIZE CURSER TO HOME POSITION (00,00)(UPPER LEFT HAND CORNER)}
    {START DISPLAY}
    {ENABLE 8276 INTERRUPT}

            /* SET UP 8051 INTERRUPTS AND PRIORITIES */

    {SERIAL PORT HAS HIGHEST INTERRUPT PRIORITY}
    {EXTERNAL INTERRUPTS ARE EDGE SENSITIVE}
    {ENABLE EXTERNAL INTERRUPTS}
```

```
/*PROCEDURE SCANNER: THIS PROCEDURE SCANS THE KEYBOARD AND DETERMINES IF A
  SINGLE VALID KEY HAS BEEN PUSHED. IF TRUE THEN THE ASCII EQUIVALENT
  WILL BE TRANSMITTED TO THE HOST COMPUTER.*/

SCANNER:

{ENABLE 8051 GLOBAL INTERRUPT BIT}


/*      PROGRAMMABLE DELAY FOR THE CURSER BLINK     */

IF {30 VERTICAL RETRACE INTERRUPTS HAVE OCCURRED (CURSER$COUNT=1FH)} THEN
DO;
   {COMPLEMENT CURSER$ON}
   {CLEAR CURSER$COUNT}
   IF {CURSER IS TO BE OFF (CURSER$ON=0)} THEN {MOVE CURSER OFF THE SCREEN}
   CALL LOAD$CURSER;
END;

IF {THE LOCAL$LINE SWITCH HAS CHANGED STATE} THEN
DO;
   IF {IN LOCAL MODE} THEN {DISABLE SERIAL PORT INTERRUPT}
   ELSE CALL CHECK$BAUD$RATE;
END;

DO WHILE {INBETWEEN VERTICAL REFRESHES}
   IF {THE FIFO HAS A CHARACTER TO PROCESS (SERIAL$INT=1)} THEN CALL DECIPHER;
END;

CALL READER;

IF {THE PRESENT PRESSED KEY IS EQUAL TO THE LAST KEY PRESSED AND VALID=1} THEN
   CALL AUTO$REPEAT;
ELSE
DO;
   IF {A KEY IS PRESSED BUT NOT THE SAME ONE AS THE LAST KEYBOARD SCAN} THEN
   DO;
      IF {ONLY ONE KEY IS PRESSED} THEN
           {GET THE ASCII CODE FOR IT}
           {SET NEW$KEY AND VALID FLAGS}
      ELSE {RESET VALID AND NEW$KEY FLAGS}
   END;
   ELSE {THE KEYBOARD MUST NOT HAVE A KEY PRESSED SO RESET VALID$KEY AND NEW$KEY FLAGS}
END;

GOTO SCANNER;
END;


/*    PROCEDURE AUTO$REPEAT: THIS PROCEDURE WILL PERFORM AN AUTO REPEAT FUNCTION
      BY TRANSMITTING A CHARACTER EVERY OTHER TIME THIS ROUTINE IS CALLED.
      THE AUTO REPEAT FUNCTION IS ACTIVATED AFTER A FIXED DELAY PERIOD AFTER THE
      FIRST CHARACTER IS SENT*/


AUTO$REPEAT:

IF {THE KEY PRESSED IS NEW (NEW$KEY=1} THEN
DO;
   {CLEAR THE DIVIDE BY TWO COUNTER "TRANSMIT$TOGGLE"}
   {INITIALIZE THE DELAY COUNTER "TRANSMIT$COUNT" TO 0D0H}
   CALL TRANSMIT;                                          /* FIRST CHARACTER */
   {CLEAR NEW$KEY}
END;
```

```
ELSE
DO;
   IF {TRANSMIT$COUNT IS NOT EQUAL TO 0} THEN
   DO;
      {INCREMENT TRANSMIT$COUNT}
      IF TRANSMIT$COUNT=0FFH THEN                    /*DELAY BETWEEN FIRST CHARACTER AND THE SECOND */
      DO;
         CALL TRANSMIT;                              /*SECOND CHARACTER */
         {CLEAR TRANSMIT$COUNT}
      END;
   END;
   ELSE
   DO;
      {TURN THE CURSER ON DURING THE AUTO REPEAT FUNCTION}
      IF TRANSMIT$TOGGLE = 1 THEN                    /* 2 VERT FRAMES BETWEEN 3RD TO NTH CHARACTER */
         CALL TRANSMIT;                              /* 3RD THROUGH NTH CHARACTER */
      {COMPLEMENT TRANSMIT$TOGGLE}
   END;
END;

END AUTO$REPEAT;


/* PROCEDURE TRANSMIT- ONCE THE HOST COMPUTER SIGNALS THE 8051H BY BRINGING
   THE CLEAR-TO-SEND LINE LOW, THE ASCII CHARACTER IS PUT INTO THE SERIAL PORT.*/


TRANSMIT:
PROCEDURE;
IF {THE TERMINAL IS ON-LINE} THEN
DO;
   {WAIT UNTIL THE CLEAR$TO$SEND LINE IS LOW AND UNTIL THE 8051 SERIAL PORT TX IS NOT BUSY (TRANSMIT$INT=1)}
   {TRANSMIT THE ASCII CODE}
   {CLEAR THE FLAG "TRANSMIT$INT". THE SERIAL PORT SERVICE ROUTINE WILL SET THE FLAG
   {WHEN THE SERIAL PORT IS FINISHED TRANSMITTING}
END;
ELSE {THE TERMINAL IS IN THE LOCAL MODE}
DO;
   {PUT THE ASCII CODE IN THE FIFO}
   {INCREMENT THE FIFO POINTER}
   {SET SERIAL$INT}
END;
END TRANSMIT;
```

```
/*      PROCEDURE DECIPHER: THIS PROCEDURE DECODES THE HOST COMPUTER'S MESSAGES AND DETERMINES
WHETHER IT IS A DISPLAYABLE CHARACTER, CONTROL SEQUENCE, OR AN ESCAPE SEQUENCE
THE PROCEDURE THEN ACTS ACCORDINGLY */


DECIPHER:
START$DECIPHER:

VALID$RECEPTION=0;
DO WHILE {THE FIFO IS NOT EMPTY AND THE CHARACTER IS DISPLAYABLE}
   RECEIVE={ASCII CODE}
   CALL DISPLAY;
   {NEXT CHARACTER}
END;

IF {CHARACTERS WERE DISPLAYED} THEN
   {DISABLE SERIAL PORT INTERRUPT}
   {MOVE THE REMAINING CONTENTS OF THE FIFO UP TO THE BEGINNING OF THE FIFO}
   {ENABLE SERIAL PORT INTERRUPT}
   {SET THE VALID$RECEPTION FLAG}

IF {THE FIFO IS EMPTY} THEN {CLEAR THE "SERIAL$INT FLAG AND RETURN}

IF {THE NEXT CHARACTER IS AN "ESC" CODE } THEN
DO:
   {LOOK AT THE CHARACTER IN THE FIFO AFTER THE ESC CODE AND CALL THE CORRECT SUBROUTINE}
         ;
         CALL UP$CURSER;                                  /* ESC A */
         CALL DOWN$CURSER;                                /* ESC B */
         CALL RIGHT$CURSER;                               /* ESC C */
         CALL LEFT$CURSER;                                /* ESC D */
         CALL CLEAR$SCREEN;                               /* ESC E */
         CALL MOV$CURSER;                                 /* ESC F */
         ;
         CALL HOME;                                       /* ESC H */
         ;
         CALL ERASE$FROM$CURSER$TO$END$OF$SCREEN;         /* ESC J */
         CALL BLINE;                                      /* ESC K */

   {DISABLE THE SERIAL PORT INTERRUPT}
   {MOVE THE REMAINING CONTENTS OF THE FIFO UP TO THE BEGINNING OF THE FIFO}
   {ENABLE THE SERIAL PORT INTERRUPT}
   {SET THE "VALID$RECEPTION" FLAG}

   IF {THE FIFO IS EMPTY} THEN {CLEAR THE SERIAL$INT FLAG AND RETURN}
END;
```

```
IF {THE NEXT CHARACTER IS A CONTROL CODE} THEN
DO;
   {CALL THE RIGHT SUBROUTINE}

      CALL LEFT$CURSER;                          /* CTL H */
      ;
      CALL LINE$FEED;                            /* CTL J */
      ;
      CALL CLEAR$SCREEN;                         /* CTL L */
      CALL CARRIAGE$RETURN;                       /* CTL M */

   {DISABLE THE SERIAL PORT INTERRUPT}
   {MOVE THE REMAINING CONTENTS OF THE FIFO UP TO THE BEGINNING OF THE FIFO}
   {ENABLE THE SERIAL PORT INTERRUPT}
   {SET THE "VALID$RECEPTION" FLAG}
END;

IF {NO VALID CODE WAS RECEIVED ("VALID$RECEPTION" IS 0)} THEN
  {THROW THE CHARACTER OUT AND MOVE THE REMAINING CONTENTS OF THE FIFO}
  {UP TO THE BEGINNING}

IF {THE FIFO IS EMPTY} THEN {CLEAR THE SERIAL$INT FLAG AND RETURN}

END DECIPHER;



/*        PROCEDURE DISPLAY: THIS PROCEDURE WILL TAKE THE BYTE IN RAM LABELED
        RECEIVE AND PUT IT INTO THE DISPLAY RAM. */


DISPLAY:

{PUT INTO THE DISPLAY RAM LOCATION POINTED TO BY "DISPLAY$RAM$POINTER
 THE CONTENTS OF RECEIVE}

IF {THE END OF THE DISPLAY MEMORY HAS BEEN REACHED} THEN
   {RESET "DISPLAY$RAM$POINTER" TO THE BEGINNING OF THE RAM}
ELSE
   {INCREMENT "DISPLAY$RAM$POINTER"}

IF {THE CURSER IS IN THE LAST COLUMN OF THE CRT DISPLAY} THEN
DO;
   {MOVE THE CURSER BACK TO THE BEGINNING OF THE LINE}
   IF {THE NEW DISPLAY RAM LOCATION HAS A END-OF-LINE CHARACTER IN IT} THEN
      CALL FILL;

   IF {THE CURSER IS ON THE LAST LINE OF THE CRT DISPLAY} THEN
      CALL SCROLL;
   ELSE
      {MOVE THE CURSER TO THE NEXT LINE}
END;
ELSE
   {INCREMENT THE CURSER TO THE NEXT LOCATION}

{TURN THE CURSER ON }
CALL LOADCURSER;
END DISPLAY;
```

```
/*        PROCEDURE LINE$FEED      */

LINE$FEED:

IF {THE CURSER IS IN THE LAST LINE OF THE CRT DISPLAY} THEN
   CALL SCROLL;
ELSE
DO;
   {MOVE THE CURSER TO THE NEXT LINE}
   {TURN THE CURSER ON}
   CALL LOAD$CURSER;
END;

IF {THE DISPLAY$RAM$POINTER IS ON THE LAST LINE IN THE DISPLAY RAM} THEN
   {MOVE THE DISPLAY$RAM$POINTER TO THE FIRST LINE IN THE DISPLAY RAM}
ELSE
   {MOVE THE DISPLAY$RAM$POINTER TO THE NEXT LINE IN THE DISPLAY RAM}

IF {THE FIRST CHARACTER IN THE NEW LINE CONTAINS AN END-OF-LINE CHARACTER } THEN
   CALL FILL;

END LINE$FEED;




/*        PROCEDURE SCROLL         */

SCROLL:

CALL BLANK;
{DISABLE VERTICAL RETRACE INTERRUPT}

IF {THE FIRST LINE OF THE CRT CONTAINS THE LAST LINE OF THE DISPLAY MEMORY} THEN
   { MOVE THE POINTER "LINE0" TO THE BEGINNING OF THE DISPLAY MEMORY}
ELSE
   {MOVE "LINE0" TO THE NEXT LINE IN THE DISPLAY MEMORY}

{ENABLE VERTICAL RETRACE INTERRUPT}

END SCROLL;




/*        PROCEDURE CLEAR SCREEN      */

CLEAR$SCREEN:

CALL HOME;
CALL ERASE$FROM$CURSER$TO$END$OF$SCREEN;

END CLEAR$SCREEN;
```

```
/*        PROCEDURE HOME: THIS PROCEDURE MOVES THE CURSER TO THE 0,0 POSITION */

HOME:

{MOVE THE CURSER POSITION TO THE UPPER LEFT HAND CORNER OF THE CRT}
{TURN THE CURSER ON}
CALL LOAD$CURSER;
{MOVE THE DISPLAY$RAM$POINTER TO THE CORRECT LOCATION IN THE DISPLAY RAM}

END HOME;



/*    PROCEDURE ERASE FROM CURSER TO END OF SCREEN:  */

ERASE$FROM$CURSER$TO$END$OF$SCREEN:

CALL BLINE;                                  /* ERASE CURRENT LINE */

IF {THE CURSER IS NOT ON THE LAST LINE OF THE CRT DISPLAY} THEN
    STARTING WITH THE NEXT LINE,PUT AN END-OF-LINE CHARACTER (0F1H)
    IN THE DISPLAY RAM LOCATIONS THAT CORRESPOND TO THE BEGINNING OF
    THE CRT DISPLAY LINES UNTIL THE BOTTOM OF THE CRT SCREEN HAS BEEN REACHED}
END;

END ERASE$FROM$CURSER$TO$END$OF$SCREEN;



/*PROCEDURE MOV$CURSER: THIS PROCEDURE IS USED IN CONJUNCTION WITH WORDSTAR
  IF A ESC F IS RECEIVED FROM THE HOST COMPUTER, THE TERMINAL CONTROLLER WILL
  READ THE NEXT TWO BYTE TO DETERMINE WHERE TO MOVE THE CURSER. THE FIRST BYTE
  IS THE ROW INFORMATION FOLLOWED BY THE COLUMN INFORMATION */


MOV$CURSER:

{WAIT UNTIL THE FIFO HAS RECEIVED THE NEXT TWO CHARACTERS}
{MOVE THE CURSER TO THE LOCATION SPECIFIED IN THE ESCAPE SEQUENCE}
{MOVE THE DISPLAY$RAM$POINTER TO THE CORRECT LOCATION}

IF THE FIRST CHARACTER IN THE NEW LINE HAS AN END-OF-LINE CHARACTER} THEN
   CALL FILL;
END;

{DISABLE THE SERIAL PORT INTERRUPT}
{MOVE THE REMAIN CONTENTS OF THE FIFO UP TWO LOCATIONS IN MEMORY}
{DECREMENT THE FIFO BY TWO}
{ENABLE THE SERIAL PORT INTERRUPT}

END MOV$CURSER;



/*        PROCEDURE LEFT CURSER: THIS PROCEDURE MOVES THE CURSER LEFT ONE COLUMN
  BY SUBTRACTING 1 OF THE CURSER COLUMN RAM LOCATION THEN CALL LOAD CURSER */


LEFT$CURSER:

IF {THE CURSER IS NOT IN THE FIRST LOCATION OF A LINE} THEN
DO;
   {MOVE THE CURSER LEFT BY ONE LOCATION}
   {TURN THE CURSER ON}
   CALL LOAD$CURSER;
   {DECREMENT THE DISPLAY$RAM$POINTER BY ONE}
END;

END LEFT$CURSER;
```

```
/*        PROCEDURE RIGHT CURSER: THIS PROCEDURE MOVES THE CURSER RIGHT ONE COLUMN
  BY ADDING 1 TO THE CURSER COLUMN RAM LOCATION THEN CALL LOAD CURSER */

RIGHT$CURSER:

IF {THE CURSER IS NOT IN THE LAST POSITION OF THE CRT LINE} THEN
DO;
   {MOVE THE CURSER RIGHT BY ONE LOCATION}
   {TURN THE CURSER ON}
   CALL LOAD$CURSER;
   {INCREMENT THE DISPLAY$RAM$POINTER BY ONE}
END;

END RIGHT$CURSER;



/*        PROCEDURE UP CURSER: THIS PROCEDURE MOVES THE CURSER UP ONE ROW
  BY SUBTRACTING 1 TO THE CURSER ROW RAM LOCATION THEN CALL LOAD CURSER */

UP$CURSER:

IF {THE CURSER IS NOT ON THE FIRST LINE OF THE CRT DISPLAY} THEN
DO;
   {MOVE THE CURSER UP ONE LINE}
   {TURN ON THE CURSER}
   CALL LOAD$CURSER;

   IF {THE DISPLAY$RAM$POINTER IS IN THE FIRST LINE OF DISPLAY MEMORY} THEN
      {MOVE THE DISPLAY$RAM$POINTER TO THE LAST LINE OF DISPLAY MEMORY}
   ELSE
      {MOVE THE DISPLAY$RAM$POINTER UP ONE LINE IN DISPLAY MEMORY}

   IF {THE FIRST LOCATION OF THE NEW LINE CONTAINS AN END-OF-LINE CHARACTER} THEN
      CALL FILL;
END;
END  UP$CURSER;



/*        PROCEDURE DOWN CURSER: THIS PROCEDURE MOVES THE CURSER DOWN ONE ROW
  BY ADDING 1 TO THE CURSER ROW RAM LOCATION THEN CALL LOAD CURSER */


DOWN$CURSER:

IF {THE CURSER IS NOT ON THE LAST LINE OF THE CRT DISPLAY} THEN
DO;
   {TURN THE CURSER ON}
   {MOVE THE CURSER TO THE NEXT LINE}
   CALL LOAD$CURSER;

   IF {THE DISPLAY$RAM$POINTER IS NOT ON THE LAST LINE OF THE DISPLAY MEMORY} THEN
      {MOVE THE DISPLAY$RAM$POINTER TO THE NEXT LINE IN THE DISPLAY MEMORY}
   ELSE
      {MOVE THE DISPLAY$RAM$POINTER TO THE FIRST LINE IN THE DISPLAY MEMORY}

   IF {THE FIRST CHARACTER IN THE NEW LINE IS AN END-OF-LINE CHARACTER} THEN
      CALL FILL;
END;

END DOWN$CURSER;
```

```
/*        PROCEDURE CARRIAGE$RETURN        */

CARRIAGE$RETURN:

{MOVE THE DISPLAY$RAM$POINTER TO THE BEGINNING OF THE CURRENT LINE IN THE DISPLAY MEMORY}
{MOVE THE CURSER TO THE BEGINNING OF THE CURRENT LINE OF THE CRT DISPLAY}
{TURN THE CURSER ON}
CALL LOAD$CURSER;

END CARRIAGE$RETURN;


/*        PROCEDURE LOAD CURSER: LOAD CURSER TAKES THE VALUE HELD IN RAM AND
  LOADS IT INTO THE 8276 CURSER REGISTER. */


LOAD$CURSER:
PROCEDURE;
IF {THE CURSER IS ON} THEN
   {MOVE THE CURSER BACK ONTO THE CRT DISPLAY}
{DISABLE BUFFER INTERRUPT}
{WRITE TO THE 8276 CURSER REGISTERS THE X,Y LOCATIONS}
{ENABLE BUFFER INTERRUPT}

END LOAD$CURSER;


/*        PROCEDURE CHECK BAUD RATE: THIS PROCEDURE READS THE THREE PORT PINS ON P1 AND SETS UP
          THE SERIAL PORT FOR THE SPECIFIED BAUD RATE */


CHECK$BAUD$RATE:

{SET TIMER 1 TO MODE 1 AND AUTO RELOAD}
{TURN TIMER ON}
{ENABLE SERIAL PORT INTERRUPT}
{READ BAUD RATE SWITCHES AND SET UP RELOAD VALUE}

   ;                          /* 00 IS NOT ALLOWED */
   TH1=040H;                  /*  150 BAUD */
   TH1=0A0H;                  /*  300 BAUD */
   TH1=0D0H;                  /*  600 BAUD */
   TH1=0E8H;                  /* 1200 BAUD */
   TH1=0F4H;                  /* 2400 BAUD */
   TH1=0FAH;                  /* 4800 BAUD */
   TH1=0FDH;                  /* 9600 BAUD */

END CHECK$BAUD$RATE;
```

```
/*        PROCEDURE READER: THIS PROCEDURE IS WRITTEN IS ASSEMBLY LANGUAGE. THE
  EXTERNAL PROCEDURE SCANS THE 8 LINES OF THE KEYBOARD AND READS THE RETURN
  LINES. THE STATUS OF THE 8 RETURN LINES ARE THEN STORED IN INTERNAL
  MEMORY ARRAY CALLED CURRENT$KEY */


READER:

{INITIALIZE FLAGS "KEY0"=0, "SAME"=1, 0 COUNTER=0}

DO UNTIL {ALL 8 KEYBOARD SCAN LINES ARE READ}
   {READ KEYBOARD SCAN}
   IF {NO KEY WAS PRESSED} THEN
      {INCREMENT 0 COUNTER}
   ELSE
   IF {THE KEY PRESSED WAS NOT THE SAME KEY THAT WAS PRESSED THE LAST TIME
       THE KEYBOARD WAS READ} THEN
      {CLEAR "SAME" AND WRITE NEW SCAN RESULT TO CURRENT$KEY RAM ARRAY}
END;

IF {ALL 8 SCANS DIDN'T HAVE A KEY PRESSED (0 COUNTER=8)} THEN
   {SET KEY0, AND CLEAR SAME}

END READER;



/*        PROCEDURE BLANK: THIS EXTERNAL PROCEDURE FILLS LINE0 WITH SPACES (20H ASCII)
  DURING THE SCROLL ROUTINES.*/


BLANK:

DO I= {BEGINNING OF THE CRT DISPLAY (LINE0)} TO {LINE0 + 50H}
   {DISPLAY RAM POINTED TO BY "I" = SPACE (ASCII 20H)}
   NEXT I
END;

END BLANK;



/*        PROCEDURE BLINE: THIS EXTERNAL PROCEDURE BLANKS FROM THE CURSER TO THE END OF
                  THE DISPLAY LINE */


BLINE:

DO I= {CURRENT CURSER POSITION ON CRT DISPLAY} TO {END OF ROW}
   {DISPLAY RAM POINTED TO BY "I" = SPACE (ASCII 20H)}
   NEXT I
END;

END BLINE;



/*        PROCEDURE FILL: THIS EXTERNAL PROCEDURE FILLS A DISPLAY LINE WITH SPACES*/


FILL:

DO I= {BEGINNING OF THE LINE THAT THE CURSER IS ON} TO {END OF THE ROW}
   {DISPLAY RAM POINTED TO BY "I" = SPACE (ASCII 20H)}
   NEXT I
END;

END FILL;
```

Appendix 7.9 Software Listings

```
PL/M-51 COMPILER

ISIS-II PL/M-51 V1.1
COMPILER INVOKED BY:  PLM51 :F1:CRTPLM.SRC


            $OPTIMIZE(1)
            $NOINITVECTOR
            $ROM(LARGE)

            /*****************************************************************************
            *****************************************************************************
            *******                                                               ********
            *******            PLM51 SOFTWARE FOR THE 8051 TERMINAL             ********
            *******            CONTROLLER APPLICATION NOTE                      ********
            *******                                                               ********
            *****************************************************************************
            *****************************************************************************

                  MEMORY MAP ASSOCIATED WITH PERIPHERAL DEVICES (USING MOVX):

                  8051 WR AND READ DISPLAY RAM-    ADDRESS 1000H TO 17CFH
                  8051 WR DISPLAY RAM TO THE 8276- ADDRESS 1800H TO 1FCFH
                  8276 COMMAND ADDRESS-            ADDRESS 0001H
                  8276 PARAMETER ADDRESS-          ADDRESS 0000H
                  8276 STATUS REGISTER-            ADDRESS 0001H


                  MEMORY MAP FOR READING THE KEYBOARD (USING MOVC):

                  KEYBOARD ADDRESS-                ADDRESS 10FFH TO 17FFH

               THE FOLLOWING SOFTWARE SWITCHES MUST BE SET ACCORDING TO THE TYPE OF
            KEYBOARD THAT IS GOING TO BE USED.

               SW1- SET WHEN USING AN UNDECODED KEYBOARD IS TO BE USED
               SW2- SET WHEN USING A DECODED OR A SERIAL TYPE OF KEYBOARD


               PROGRAMS TO LINK TOGETHER FOR WORKING SYSTEMS:

               UNDECODED KEYBOARD- CRTPLM.OBJ,CRTASM.OBJ,KEYBD.OBJ,PLM51.LIB
               DECODED KEYBOARD-CRTPLM.OBJ,CRTASM.OBJ,DECODE.OBJ,PLM51.LIB
               DETACHED KEYBOARD-CRTPLM.OBJ,CRTASM.OBJ,DETACH.OBJ,PLM51.LIB
            */
            $SET (SW1)
            $RESET (SW2)
```

```
PL/M-51 COMPILER

                $EJECT

                CRT$CONTROLLER:
  1   1         DO;

                    /***************** DECLARE LITERALS ************************/

  2   1         DECLARE LLC LITERALLY 'LOCAL$LINE$CHANGE';
  3   1         DECLARE REG  LITERALLY 'REGISTER';
  4   1         DECLARE CURRENT$KEY LITERALLY 'CURKEY';
  5   1         DECLARE SERIAL$SERVICE LITERALLY 'SERBUF';
  6   1         DECLARE DISPLAY$RAM$POINTER LITERALLY 'POINT';
  7   1         DECLARE SERIAL$INT LITERALLY 'SERINT';
  8   1         DECLARE TRANSMIT$INT LITERALLY 'TRNINT';
  9   1         DECLARE CURSER$COLUMN LITERALLY 'CURSER';
 10   1         DECLARE LAST$KEY LITERALLY 'LSTKEY';
 11   1         DECLARE CURSER$COUNT LITERALLY 'COUNT';
 12   1         DECLARE SCAN$INT LITERALLY 'SCAN';


                    /********* REGISTER DECLARATIONS FOR THE 8051 *****************/


                /********* BYTE REGISTERS ********/

 13   1         DECLARE
                    P0   BYTE  AT(80H)  REG,
                    P1   BYTE  AT(90H)  REG,
                    P2   BYTE  AT(0A0H) REG,
                    P3   BYTE  AT(0B0H) REG,
                    PSW  BYTE  AT(0D0H) REG,
                    ACC  BYTE  AT(0E0H) REG,
                    B    BYTE  AT(0F0H) REG,
                    SP   BYTE  AT(81H)  REG,
                    DPL  BYTE  AT(82H)  REG,
                    DPH  BYTE  AT(83H)  REG,
                    PCON BYTE  AT(87H)  REG,
                    TCON BYTE  AT(88H)  REG,
                    TMOD BYTE  AT(89H)  REG,
                    TL0  BYTE  AT(8AH)  REG,
                    TL1  BYTE  AT(8BH)  REG,
                    TH0  BYTE  AT(8CH)  REG,
                    TH1  BYTE  AT(8DH)  REG,
                    IE   BYTE  AT(0A8H) REG,
                    IP   BYTE  AT(0B8H) REG,
                    SCON BYTE  AT(98H)  REG,
                    SBUF BYTE  AT(99H)  REG;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

            $EJECT
            /********* BIT REGISTERS ********/

              /********* PSW  BITS ********/
 14   1       DECLARE
               CY    BIT  AT(0D7H) REG,
               AC    BIT  AT(0D6H) REG,
               F0    BIT  AT(0D5H) REG,
               RS1   BIT  AT(0D4H) REG,
               RS0   BIT  AT(0D3H) REG,
               OV    BIT  AT(0D2H) REG,
               P     BIT  AT(0D0H) REG,

              /********* TCON BITS ********/
               TF1   BIT  AT(8FH)  REG,
               TR1   BIT  AT(8EH)  REG,
               TF0   BIT  AT(8DH)  REG,
               TR0   BIT  AT(8CH)  REG,
               IE1   BIT  AT(8BH)  REG,
               IT1   BIT  AT(8AH)  REG,
               IE0   BIT  AT(89H)  REG,
               IT0   BIT  AT(88H)  REG,

              /*********  IE  BITS ********/
               EA    BIT  AT(0AFH) REG,
               ES    BIT  AT(0ACH) REG,
               ET1   BIT  AT(0ABH) REG,
               EX1   BIT  AT(0AAH) REG,
               ET0   BIT  AT(0A9H) REG,
               EX0   BIT  AT(0A8H) REG,

              /*********  IP  BITS ********/
               PS    BIT  AT(0BCH) REG,
               PT1   BIT  AT(0BBH) REG,
               PX1   BIT  AT(0BAH) REG,
               PT0   BIT  AT(0B9H) REG,
               PX0   BIT  AT(0B8H) REG,

              /*********  P3  BITS ********/
               RD    BIT  AT(0B7H) REG,
               WR    BIT  AT(0B6H) REG,
               T1    BIT  AT(0B5H) REG,
               T0    BIT  AT(0B4H) REG,
               INT1  BIT  AT(0B3H) REG,
               INT0  BIT  AT(0B2H) REG,
               TXD   BIT  AT(0B1H) REG,
               RXD   BIT  AT(0B0H) REG,

              /********* SCON BITS ********/
               SM0   BIT  AT(9FH)  REG,
               SM1   BIT  AT(9EH)  REG,
               SM2   BIT  AT(9DH)  REG,
               REN   BIT  AT(9CH)  REG,
               TB8   BIT  AT(9BH)  REG,
               RB8   BIT  AT(9AH)  REG,
               TI    BIT  AT(99H)  REG,
               RI    BIT  AT(98H)  REG;
```

```
PL/M-51 COMPILER    CRTCONTROLLER


            $EJECT
            $IF SW1
                /*************** DECLARE CONSTANTS**********************/

 15   1     DECLARE LOW$SCAN(16) STRUCTURE
                (KEY(8) BYTE) CONSTANT

                ('890-',5CH,5EH,08H,00H,
            /* SCAN 0, SHIFT KEY =0; 8,9,0,-,\,^, BACK SPACE */

                'uiop',5BH,'@',0AH,7FH,
            /* SCAN 1, SHIFT =0; u,i,o,p,[,@, LINE FEED, DELETE */

                'jkl;:',00H,0DH,'7',
            /* SCAN 2, SHIFT =0; j,k,l,;,:, RETURN, 7 */

                'm',2CH,'.',00H,'/',00H,00H,00H,
            /* SCAN 3, SHIFT =0; m,COMMA,./ */

                00H,'azxcvbn',
            /* SCAN 4, SHIFT =0; a,z,x,c,v,b,n */

                'y',00H,00H,' dfgh',
            /* SCAN 5, SHIFT =0; y, SPACE, d,f,g,h */

                09H,'qwsert',00H,
            /* SCAN 6, SHIFT =0; TAB,q,w,s,e,r,t */

                1BH,'123456',00H,
            /* SCAN 7, SHIFT =0;ESC,1,2,3,4,5,6 */

                28H,29H,00H,'=',7CH,7EH,08H,00H,
            /* SCAN 0, SHIFT =1; (,),=,|,~, BACK SPACE */

                'UIOP',00H,00H,0AH,7FH,
            /* SCAN 1, SHIFT =1; U,I,O,P, LINE FEED, DELETE */

                'JKL+*',00H,0DH,27H,
            /* SCAN 2, SHIFT =1; J,K,L,+,*, RETURN, ' */

                'M<>',00H,3FH,00H,00H,00H,
            /* SCAN 3, SHIFT =1; M,<,>,? */

                00H,'AZXCVBN',
            /* SCAN 4, SHIFT =1; A,Z,X,,C,V,B,N */

                'Y',00H,00H,' DFGH',
            /* SCAN 5, SHIFT =1; Y, SPACE, D,F,G,H */

                09H,'QWSERT',00H,
            /* SCAN 6, SHIFT =1; TAB, Q,W,S,E,R,T */

                1BH,'!"#$%&',00H);
            /* SCAN 7, SHIFT =1;ESC,!,",#,$,%,& */
            $ENDIF
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                $EJECT
                    /******************DECLARE VARIABLES********************/


  16    1       DECLARE

                $IF SW2

INPUT                   BIT AT(0B4H)    REG,
                $ENDIF
                $IF SW1
                    CAP$LOCK            BIT AT(095H)    REG,
                    SHIFT$KEY           BIT AT(096H)    REG,
                    CONTROL$KEY         BIT AT(097H)    REG,
                $ENDIF
                    LOCAL$LINE          BIT AT(0B5H)    REG,
                    CLEAR$TO$SEND       BIT AT(093H)    REG,
                    DATA$TERMINAL$READY BIT AT(094H)    REG;

  17    1       DECLARE (

                $IF SW1
                    SAME,
                    VALID$KEY,
                    KEY0,
                    LAST$SHIFT$KEY,
                    LAST$CONTROL$KEY,
                    LAST$CAP$LOCK,
                $ENDIF

                $IF SW2
                    RCVFLG,
                    SYNC,
                    BYFIN,
                    KBDINT,
                    ERROR,
                $ENDIF

                    NEW$KEY,
                    TRANSMIT$TOGGLE,
                    CURSER$ON,
                    SERIAL$INT,
                    SCAN$INT,
                    TRANSMIT$INT,
                    ESCSEQ,
                    VALID$RECEPTION,
                    LLC,
                    ENSP)       BIT PUBLIC;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

            $EJECT

 18   1     DECLARE (

                I,
                J,
                K,
                ASCII$KEY,
                TRANSMIT$COUNT,
                TEMP,
                SHIFT,
                CURSER$COL,
                CURSER$COLUMN,
                CURSER$ROW,
                CURSER$COUNT,
                FIFO,
                RECEIVE)        BYTE PUBLIC;

            $IF SW1
 19   1     DECLARE LAST$KEY(8) BYTE PUBLIC;
            $ENDIF

            $IF SW2
            DECLARE LAST$KEY(2) BYTE PUBLIC;
            $ENDIF

 20   1     DECLARE SERIAL(16)  BYTE PUBLIC;


 21   1     DECLARE DISPLAY$RAM(7CFH) BYTE  AT(1000H)   AUXILIARY;


 22   1     DECLARE

                PARAMETER$ADDRESS   BYTE    AT(0000H)   AUXILIARY,
                COMMAND$ADDRESS     BYTE    AT(0001H)   AUXILIARY;


 23   1     DECLARE (

                DISPLAY$RAM$POINTER,
                RASTER,
                LINE0,
                L)          WORD PUBLIC;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                    $EJECT

                    /*  PROCEDURE READER: THIS PROCEDURE IS WRITTEN IS ASSEMBLY LANGUAGE. THE
                        EXTERNAL PROCEDURE SCANS THE 8 LINES OF THE KEYBOARD AND READS THE RETURN
                        LINES. THE STATUS OF THE 8 RETURN LINES ARE THEN STORED IN INTERNAL
                        MEMORY ARRAY CALLED CURRENT$KEY. THE PROCEEDURE CONTROLS 2 STATUS FLAGS;
                            KEY0 AND SAME. KEY0 IS SET IF ALL 8 SCANS READ NO KEY WAS PRESSED.
                            IF ALL 8 SCANS ARE THE SAME AS THE LAST READING OF THE KEYBOARD, THEN
                            SAME IS SET. */

 24   2     READER: PROCEDURE EXTERNAL;
 25   1     END READER;



                    /*  PROCEDURE BLANK: THIS EXTERNAL PROCEDURE FILLS LINE0 SCAN WITH SPACES (20H ASCII)
                        DURING THE SCROLL ROUTINES.*/

 26   2     BLANK: PROCEDURE EXTERNAL;
 27   1     END BLANK;

                    /*  PROCEDURE BLINE: THIS EXTERNAL PROCEDURE BLANKS FROM THE CURSER TO THE END OF
                                THE DISPLAY LINE */

 28   2     BLINE: PROCEDURE EXTERNAL;
 29   1     END BLINE;



                    /*  PROCEDURE FILL: THIS EXTERNAL PROCEDURE FILLS THE CURSER LINE
                            WITH SPACES*/

 30   1     FILL:
              PROCEDURE EXTERNAL;
 31   1     END FILL;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                $EJECT

                /*  PROCEDURE CHECK BAUD RATE: THIS PROCEDURE READS THE THREE PORT PINS ON P1 AND SETS UP
                    THE SERIAL PORT FOR THE SPECIFIED BAUD RATE */

 32   1         CHECK$BAUD$RATE:
                PROCEDURE;
 33   2         SCON=70H;                    /* MODE 1
                                                ENABLE RECEPTION*/
 34   2         TMOD=TMOD OR 20H;            /* TIMER 1 AUTO RELOAD */
 35   2         TR1=1;                       /* TIMER 1 ON */
 36   2         ES=1;                        /* ENABLE SERIAL INTERRUPT*/
 37   2         ENSP=1;                      /* SERIAL INTERRUPT MASK FLAG */
 38   3         DO CASE (P1 AND 07H);
 39   3            ;                         /* 00 IS NOT ALLOWED */
 40   3            TH1=040H;                    /*  150 BAUD */
 41   3            TH1=0A0H;                    /*  300 BAUD */
 42   3            TH1=0D0H;                    /*  600 BAUD */
 43   3            TH1=0E8H;                    /* 1200 BAUD */
 44   3            TH1=0F4H;                    /* 2400 BAUD */
 45   3            TH1=0FAH;                    /* 4800 BAUD */
 46   3            TH1=0FDH;                    /* 9600 BAUD */
 47   3         END;
 48   1         END CHECK$BAUD$RATE;



                /*  PROCEDURE LOAD CURSER: LOAD CURSER TAKES THE VALUE HELD IN RAM AND
                    LOADS IT INTO THE 8276 CURSER REGISTERS. */

 49   1         LOAD$CURSER:
                PROCEDURE;
 50   2         IF CURSER$ON=1 THEN
 51   2            CURSER$COL=CURSER$COLUMN;
 52   2         EX1=0;                       /* DISABLE BUFFER INTERRUPT */
 53   2         COMMAND$ADDRESS=80H;         /* INITIALIZE CURSER COMMAND */
 54   2         PARAMETER$ADDRESS=CURSER$COL;
 55   2         PARAMETER$ADDRESS=CURSER$ROW;
 56   2         EX1=1;                       /* ENABLE BUFFER INTERRUPT */
 57   1         END LOAD$CURSER;



                /*  PROCEDURE CARRIAGE$RETURN   */

 58   1         CARRIAGE$RETURN:
                PROCEDURE;
 59   2         DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER-CURSER$COLUMN;
 60   2         CURSER$COLUMN=0;
 61   2         CURSER$ON=1;
 62   2         CALL LOAD$CURSER;
 63   1         END CARRIAGE$RETURN;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                $EJECT

                /*  PROCEDURE DOWN CURSER: THIS PROCEDURE MOVES THE CURSER DOWN ONE ROW
                    BY ADDING 1 TO THE CURSER ROW RAM LOCATION THEN CALL LOAD CURSER */


  64   1        DOWN$CURSER:
                PROCEDURE;
  65   2        IF CURSER$ROW < 18H THEN
  66   3        DO;
  67   3           CURSER$ON=1;
  68   3           CURSER$ROW=CURSER$ROW + 1;
  69   3           CALL LOAD$CURSER;
  70   3           IF DISPLAY$RAM$POINTER < 780H THEN
  71   3              DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER +50H;
  72   3           ELSE
                      DISPLAY$RAM$POINTER=(DISPLAY$RAM$POINTER-780H);
  73   3           L=DISPLAY$RAM$POINTER-CURSER$COLUMN;
  74   3           IF DISPLAY$RAM(L)=0F1H THEN                    /* LOOK FOR END OF*/
  75   4           DO;                                            /*   LINE CHARACTER */
  76   4              CALL FILL;                                  /*IF TRUE FILL LINE*/
  77   4              DISPLAY$RAM(L)=20H;                         /*WITH SPACES */
  78   4           END;
  79   3        END;
  80   1        END DOWN$CURSER;



                /*  PROCEDURE UP CURSER: THIS PROCEDURE MOVES THE CURSER UP ONE ROW
                BY SUBTRACTING 1 TO THE CURSER ROW RAM LOCATION THEN CALL LOAD CURSER */

  81   1        UP$CURSER:
                PROCEDURE;
  82   2        IF CURSER$ROW >0 THEN
  83   3        DO;
  84   3           CURSER$ROW=CURSER$ROW - 1;
  85   3           CURSER$ON=1;
  86   3           CALL LOAD$CURSER;
  87   3           IF DISPLAY$RAM$POINTER<50H THEN
  88   3              DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER+780H;
  89   3           ELSE
                      DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER - 50H;
  90   3           L=DISPLAY$RAM$POINTER-CURSER$COLUMN;
  91   3           IF DISPLAY$RAM(L)=0F1H THEN                    /* LOOK FOR END OF LINE*/
  92   4           DO;                                            /*     CHARACTER */
  93   4              CALL FILL;                                  /* IF TRUE FILL WITH */
  94   4              DISPLAY$RAM(L)=20H;                         /* SPACES */
  95   4           END;
  96   3        END;
  97   1        END UP$CURSER;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                    $EJECT

                    /*  PROCEDURE RIGHT CURSER: THIS PROCEDURE MOVES THE CURSER RIGHT ONE COLUMN
                        BY ADDING 1 TO THE CURSER COLUMN RAM LOCATION THEN CALL LOAD CURSER */

 98   1             RIGHT$CURSER:
                    PROCEDURE;
 99   2             IF CURSER$COLUMN < 4FH THEN
100   3             DO;
101   3                CURSER$COLUMN=CURSER$COLUMN + 1;
102   3                CURSER$ON=1;
103   3                CALL LOAD$CURSER;
104   3                DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER +1;
105   3             END;
106   1             END RIGHT$CURSER;




                    /*  PROCEDURE LEFT CURSER: THIS PROCEDURE MOVES THE CURSER LEFT ONE COLUMN
                        BY SUBTRACTING 1 TO THE CURSER COLUMN RAM LOCATION THEN CALL LOAD CURSER */

107   1             LEFT$CURSER:
                    PROCEDURE;
108   2             IF CURSER$COLUMN >0 THEN
109   3             DO;
110   3                CURSER$COLUMN=CURSER$COLUMN - 1;
111   3                CURSER$ON=1;
112   3                CALL LOAD$CURSER;
113   3                DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER -1;
114   3             END;
115   1             END LEFT$CURSER;
```

PL/M-51 COMPILER CRTCONTROLLER

```
                $EJECT

                /*  PROCEDURE MOV$CURSER: THIS PROCEDURE IS USED IN CONJUNCTION WITH WORDSTAR
                    IF A ESC F IS RECEIVED FROM THE HOST COMPUTER, THE TERMINAL CONTROLLER WILL
                    READ THE NEXT TWO BYTE TO DETERMINE WHERE TO MOVE THE CURSER. THE FIRST BYTE
                    IS THE ROW INFORMATION FOLLOWED BY THE COLUMN INFORMATION */


 116   1        MOV$CURSER:
                PROCEDURE;
 117   3        DO WHILE FIFO<4;          /* WAIT UNTILL THE MOV$CURSER PARAMETERS*/
 118   3        END;                   /* ARE RECEIVED INTO THE FIFO */
 119   2        TEMP=CURSER$ROW;
 120   2        CURSER$ROW=SERIAL(2);
 121   2        IF CURSER$ROW>TEMP THEN
 122   3        DO;
 123   3           L=DISPLAY$RAM$POINTER+((CURSER$ROW-TEMP)*50H);
 124   3           IF L>7CFH THEN                                  /* IF OUT OF RAM RANGE */
 125   3              DISPLAY$RAM$POINTER=L-7D0H;                  /* RAP AROUND TO BEGINNING */
 126   3           ELSE                                            /* OF RAM */
                       DISPLAY$RAM$POINTER=L;
 127   3        END;
 128   2        ELSE
                DO;
 129   3           IF CURSER$ROW<TEMP THEN
 130   4           DO;
 131   4              L=(TEMP-CURSER$ROW)*50H;
 132   4              IF DISPLAY$RAM$POINTER<L THEN                          /* IF OUT OF RAM RANGE*/
 133   4                 DISPLAY$RAM$POINTER=(7D0H-(L-DISPLAY$RAM$POINTER));/* RAP AROUND TO END OF RAM*/
 134   4              ELSE
                          DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER-L;
 135   4           END;
 136   3        END;
 137   2        TEMP=CURSER$COLUMN;
 138   2        CURSER$COLUMN=SERIAL(3);
 139   2        IF CURSER$COLUMN>TEMP THEN
 140   2           DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER+(CURSER$COLUMN-TEMP);
 141   2        ELSE
                   DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER-(TEMP-CURSER$COLUMN);
 142   2        CURSER$ON=1;
 143   2        CALL LOAD$CURSER;
 144   2        L=DISPLAY$RAM$POINTER-CURSER$COLUMN;
 145   2        IF DISPLAY$RAM(L)=0F1H THEN                     /* LOOK FOR END FO LINE CHARACTER*/
 146   3        DO;
 147   3           CALL FILL;                                   /* IF TRUE FILL WITH SPACES */
 148   3           DISPLAY$RAM(L)=20H;
 149   3        END;
 150   2        ES=0;
 151   3        DO I=2 TO FIFO-2;
 152   3           SERIAL(I)=SERIAL(I+2);
 153   3        END;
 154   2        FIFO=FIFO-2;
 155   2        ES=ENSP;
 156   1        END MOV$CURSER;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                $EJECT

                /*    PROCEDURE ERASE FROM CURSER TO END OF SCREEN:  */

157   1         ERASE$FROM$CURSER$TO$END$OF$SCREEN:
                PROCEDURE;
158   2         CALL BLINE;                                        /* ERASE CURRENT LINE */
159   2         IF CURSER$ROW < 18H THEN
160   3         DO;
161   3            L=DISPLAY$RAM$POINTER-CURSER$COLUMN+50H;     /* GET NEXT LINE */
162   4            DO WHILE (L < 7D0H) AND (L <> (LINE0 AND 7FFH));
163   4               DISPLAY$RAM(L)=0F1H;          /* ERASE UNTIL LINE0 OR */
164   4               L=L+50H;                   /* END OF DISPLAY RAM*/
165   4            END;
166   3            L=0;
167   4            DO WHILE L <>(LINE0 AND 7FFH);       /* ERASE UNTIL LINE0 */
168   4               DISPLAY$RAM(L)=0F1H;
169   4               L=L+50H;
170   4            END;
171   3         END;
172   1         END ERASE$FROM$CURSER$TO$END$OF$SCREEN;




                /*  PROCEDURE HOME: THIS PROCEDURE MOVES THE CURSER TO THE 0,0 POSITION */

173   1         HOME:
                PROCEDURE;
174   2         CURSER$ROW=00;
175   2         CURSER$COLUMN=00;
176   2         CURSER$ON=1;
177   2         CALL LOAD$CURSER;
178   2         DISPLAY$RAM$POINTER=(LINE0 AND 7FFH);
179   1         END HOME;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                $EJECT

                /*  PROCEDURE CLEAR SCREEN     */

180   1         CLEAR$SCREEN:
                PROCEDURE;
181   2         CALL HOME;
182   2         CALL ERASE$FROM$CURSER$TO$END$OF$SCREEN;
183   1         END CLEAR$SCREEN;



                /*      PROCEDURE SCROLL    */


184   1         SCROLL:
                PROCEDURE;
185   2         CALL BLANK;
186   2         EX0=0;                    /* DISABLE VERTICAL REFRESH INTERRUPT */
187   2         IF LINE0= 1F80H THEN
188   2            LINE0= 1800H;
189   2         ELSE
                   LINE0= LINE0+50H;
190   2         EX0=1;                    /* ENABLE VERTICAL REFRESH INTERRUPT */
191   1         END SCROLL;



                /*  PROCEDURE LINE$FEED */

192   1         LINE$FEED:
                PROCEDURE;
193   2         IF CURSER$ROW=18H THEN
194   2            CALL SCROLL;
195   2         ELSE
                DO;
196   3            CURSER$ROW= CURSER$ROW+1;
197   3            CURSER$ON=1;
198   3            CALL LOAD$CURSER;
199   3         END;
200   2         IF DISPLAY$RAM$POINTER >77FH THEN
201   2            DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER-780H;
202   2         ELSE
                   DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER+50H;
203   2         L=DISPLAY$RAM$POINTER-CURSER$COLUMN;
204   2         IF DISPLAY$RAM(L)=0F1H THEN                    /* LOOK FOR END OF LINE CHARACTER*/
205   3         DO;
206   3            CALL FILL;                                  /* IF TRUE FILL WITH SPACES */
207   3            DISPLAY$RAM(L)=20H;
208   3         END;
209   1         END LINE$FEED;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                $EJECT

                /*  PROCEDURE DISPLAY: THIS PROCEDURE WILL TAKE THE BYTE IN RAM LABELED
                        RECEIVE AND PUT IT INTO THE DISPLAY RAM. */


210   1         DISPLAY:
                PROCEDURE;
211   2         DISPLAY$RAM(DISPLAY$RAM$POINTER)=RECEIVE;
212   2         IF DISPLAY$RAM$POINTER=7CFH THEN            /* IF END OF RAM */
213   2            DISPLAY$RAM$POINTER=000H;                /* RAP AROUND TO BEGINNING */
214   2         ELSE
                   DISPLAY$RAM$POINTER=DISPLAY$RAM$POINTER+1;
215   2         IF CURSER$COLUMN=4FH THEN
216   3         DO;
217   3            CURSER$COLUMN=00H;
218   3            L=DISPLAY$RAM$POINTER;
219   3            IF DISPLAY$RAM(L)=0F1H THEN
220   4            DO;
221   4               CALL FILL;
222   4               DISPLAY$RAM(L)=20H;
223   4            END;
224   3            IF CURSER$ROW=18H THEN
225   3               CALL SCROLL;
226   3            ELSE
                      CURSER$ROW=CURSER$ROW+1;
227   3         END;
228   2         ELSE
                   CURSER$COLUMN=CURSER$COLUMN+1;
229   2         CURSER$ON=1;
230   2         CALL LOADCURSER;
231   1         END DISPLAY;
```

PL/M-51 COMPILER CRTCONTROLLER

```
                $EJECT

                /*  PROCEDURE DECIPHER: THIS PROCEDURE DECODES THE HOST COMPUTER'S MESSAGES AND DETERMINES
                    WHETHER IT IS A DISPLAYABLE CHARACTER, CONTROL SEQUENCE, OR AN ESCAPE SEQUENCE
                    THE PROCEDURE THEN ACTS ACCORDINGLY */


 232   1        DECIPHER:
                PROCEDURE;
 233   2        START$DECIPHER:
                VALID$RECEPTION=0;
 234   2        I=0;
 235   3        DO WHILE (I<FIFO) AND (SERIAL(I)>1FH) AND (SERIAL(I)<7FH);
 236   3           RECEIVE=SERIAL(I);
 237   3           CALL DISPLAY;
 238   3           I=I+1;
 239   3        END;
 240   2        IF I>0 THEN
 241   3        DO;
 242   3           ES=0;                        /* DISABLE SERIAL INTERRUPT WHILE MOVING FIFO */
 243   3           K=FIFO-I;
 244   4           DO J=0 TO K;                 /* MOVE FIFO */
 245   4              SERIAL(J)=SERIAL(I);
 246   4              I=I+1;
 247   4           END;
 248   3           FIFO=K;
 249   3           ES=ENSP;                     /* ENABLE SERIAL INTERRUPT */
 250   3           VALID$RECEPTION=1;
 251   3        END;
 252   2        IF FIFO=0 THEN
 253   3        DO;
 254   3           SERIAL$INT=0;
 255   3           GOTO END$DECIPHER;
 256   3        END;
 257   2        IF (SERIAL(0)=1BH) THEN
 258   3        DO;
 259   3           IF (ESC$SEQ=1) AND (FIFO<2) THEN
 260   3              GOTO END$DECIPHER;
 261   3           K=(SERIAL(1) AND 5FH)-40H;
 262   3           IF (K >00H) AND (K<0CH) THEN
 263   4           DO;
 264   5              DO CASE K;
 265   5                 ;
 266   5                 CALL UP$CURSER;                              /* ESC A */
 267   5                 CALL DOWN$CURSER;                            /* ESC B */
 268   5                 CALL RIGHT$CURSER;                           /* ESC C */
 269   5                 CALL LEFT$CURSER;                            /* ESC D */
 270   5                 CALL CLEAR$SCREEN;                           /* ESC E */
 271   5                 CALL MOV$CURSER;                             /* ESC F */
 272   5                 ;
 273   5                 CALL HOME;                                   /* ESC H */
 274   5                 ;
 275   5                 CALL ERASE$FROM$CURSER$TO$END$OF$SCREEN;     /* ESC J */
 276   5                 CALL BLINE;                                  /* ESC K */
 277   5              END;
 278   4           END;
 279   3           ES=0;                        /* DISABLE SERIAL INTERRUPTS WHILE MOVING FIFO */
```

PL/M-51 COMPILER CRTCONTROLLER

```
280   4          DO I=0 TO (FIFO-2);
281   4             SERIAL(I)=SERIAL(I+2);     /* MOVE FIFO */
282   4          END;
283   3          FIFO=FIFO-2;
284   3          ES=ENSP;                      /* ENABLE SERIAL INTERRUPTS */
285   3          VALID$RECEPTION=1;
286   3          IF FIFO=0 THEN
287   4          DO;
288   4             SERIAL$INT=0;
289   4             GOTO END$DECIPHER;
290   4          END;
291   3       END;
292   2       IF (SERIAL(0)> 07H) AND (SERIAL(0)<0EH) THEN
293   3       DO;
294   4          DO CASE (SERIAL(0) -08H);
295   4             CALL LEFT$CURSER;                 /* CTL H */
296   4             ;
297   4             CALL LINE$FEED;                   /* CTL J */
298   4             ;
299   4             CALL CLEAR$SCREEN;                /* CTL L */
300   4             CALL CARRIAGE$RETURN;             /* CTL M */
301   4          END;
302   3          ES=0;                                /* DISABLE SERIAL INTERRUPTS WHILE MOVING FIFO */
303   4          DO I=0 TO (FIFO-1);
304   4             SERIAL(I)=SERIAL(I+1);            /* MOVE FIFO */
305   4          END;
306   3          FIFO=FIFO-1;
307   3          ES=ENSP;                             /* ENABLE SERIAL INTERRUPTS */
308   3          VALID$RECEPTION=1;
309   3       END;
310   2       IF VALID$RECEPTION=0 THEN
311   3       DO;
312   3          ES=0;
313   4          DO I=0 TO (FIFO-1);              /* IF CHARACTER IS UNRECOGNIZED THEN */
314   4             SERIAL(I)=SERIAL(I+1);        /* TRASH IT */
315   4          END;
316   3          FIFO=FIFO-1;
317   3          ES=ENSP;
318   3       END;
319   2       IF FIFO=0 THEN
320   2          SERIAL$INT=0;
321   2       END$DECIPHER:
             END DECIPHER;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                $EJECT

                /* PROCEDURE TRANSMIT- THIS PROCEDURE LOOKS AT THE CLEAR TO SEND PIN FOR AN ACTIVE
                   LOW SIGNAL. ONCE THE MAIN COMPUTER SIGNALS THE 8051 THE ASCII CHARACTER IS PUT
                   INTO THE SERIAL PORT.*/


 322   1        TRANSMIT:
                PROCEDURE;
 323   2        IF LOCAL$LINE =1 THEN
 324   3        DO;
 325   4           DO WHILE (CLEAR$TO$SEND=1) OR (TRANSMIT$INT=0);
 326   4           END;
 327   3           SBUF=ASCII$KEY;
 328   3           TRANSMIT$INT=0;
 329   3        END;
 330   2        ELSE
                DO;
 331   3           SERIAL(FIFO)=ASCII$KEY;
 332   3           FIFO=FIFO+1;
 333   3           SERIAL$INT=1;
 334   3        END;
 335   1        END TRANSMIT;




                /*  PROCEDURE AUTO$REPEAT: THIS PROCEDURE WILL PERFORM AN AUTO REPEAT FUNCTION
                    AFTER A FIXED DELAY PERIOD */


 336   1        AUTO$REPEAT:
                PROCEDURE;
 337   2        IF NEW$KEY=1 THEN
 338   3        DO;
 339   3           TRANSMIT$TOGGLE=0;
 340   3           TRANSMIT$COUNT=0D0H;
 341   3           CALL TRANSMIT;                    /* FIRST CHARACTER */
 342   3           NEW$KEY=0;
 343   3        END;
 344   2        ELSE
                DO;
 345   3           IF TRANSMIT$COUNT <> 00H THEN
 346   4           DO;
 347   4              TRANSMIT$COUNT=TRANSMIT$COUNT+1;
 348   4              IF TRANSMIT$COUNT=0FFH THEN   /*DELAY BETWEEN FIRST CHARACTER AND THE SECOND */
 349   5              DO;
 350   5                 CALL TRANSMIT;             /*SECOND CHARACTER */
 351   5                 TRANSMIT$COUNT=00;
 352   5              END;
 353   4           END;
 354   3           ELSE
                   DO;
 355   4              CURSER$ON=1;
 356   4              CURSER$COUNT=0;
 357   4              IF TRANSMIT$TOGGLE = 1 THEN       /* 2 VERT FRAMES BETWEEN 3RD TO NTH CHARACTER */
 358   4                 CALL TRANSMIT;                 /* 3RD THROUGH NTH CHARACTER */
 359   4              TRANSMIT$TOGGLE= NOT TRANSMIT$TOGGLE;
 360   4           END;
 361   3        END;
 362   1        END AUTO$REPEAT;
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                $EJECT

                /******************** START MAIN PROGRAM ***************************/
                /*  BEGIN BY PUTTING ASCII CODE FOR BLANK IN THE DISPLAY RAM;*/


 363   1        INIT:
                DO L=0 TO 7CFH;
 364   2           DISPLAY$RAM(L)=20H;
 365   2        END;

                /*  INITIALIZE POINTERS, RAM BITS, ETC.     */


 366   1        ESC$SEQ=0;
 367   1        SCAN$INT=0;
 368   1        SERIAL$INT=0;
 369   1        FIFO=0;
 370   1        CURSER$COUNT=0;
 371   1        LLC=0;
 372   1        DATA$TERMINAL$READY=1;
 373   1        TCON=05H;
 374   1        LINE0=1800H;
 375   1        RASTER=1800H;
 376   1        DISPLAY$RAM$POINTER=0000H;
 377   1        TRANSMIT$INT=1;

                $IF SW1

 378   2        DO I=0 TO 7;
 379   2           LAST$KEY(I)=00H;
 380   2        END;

 381   1        VALID$KEY=0;
 382   1        LAST$SHIFT$KEY=1;
 383   1        LAST$CONTROL$KEY=1;
 384   1        LAST$CAP$LOCK=1;
                $ENDIF

                $IF SW2
                RCVFLG=0;
                SYNC=0;
                BYFIN=0;
                KBDINT=0;
                ERROR=0;
                $ENDIF


                      /* INITIALIZE THE 8276 */

 385   1        COMMAND$ADDRESS=00H;              /* RESET THE 8276 */
 386   1        PARAMETER$ADDRESS=4FH;            /* NORMAL ROWS, 80 CHARACTER/ROW */
 387   1        PARAMETER$ADDRESS=58H;            /* 2 ROW COUNTS PER VERTICAL RETRACE
                                                     25 ROWS PER FRAME */
 388   1        PARAMETER$ADDRESS=89H;            /* LINE 9 IS THE UNDERLINE POSITION
                                                     10 LINES PER ROW  */
 389   1        PARAMETER$ADDRESS=0F9H;           /* OFFSET LINE COUNTER, NON-TRANSPARENT FIELD ATTRIBUTE
```

```
PL/M-51 COMPILER    CRTCONTROLLER

                                        NON-BLINKING UNDERLINE CURSER, 20 CHARACTER COUNTS PER
                                        HORIZONTAL RETRACE */
390   1     TEMP=COMMAND$ADDRESS;

391   1     CURSER$COLUMN=00H;
392   1     CURSER$ROW=00H;
393   1     CURSER$COL=00H;
394   1     CALL LOAD$CURSER;
395   1     TEMP=COMMAND$ADDRESS;

396   1     COMMAND$ADDRESS=0E0H;           /* PRESET 8276 COUNTERS */
397   1     TEMP=COMMAND$ADDRESS;

398   1     COMMAND$ADDRESS=23H;            /* START DISPLAY */
399   1     COMMAND$ADDRESS=0A0H;           /* ENABLE INTERRUPTS */
400   1     TEMP=COMMAND$ADDRESS;

            /* SET UP INTERRUPTS AND PRIORITIES */

            $IF SW1
401   1     IP=10H;                         /* SERIAL PORT HAS HIGHEST PRIORITY */
402   1     IE=85H;                         /* ENABLE 8051 EXTERNAL INTERRUPTS */
            $ENDIF

            $IF SW2
            IP=10H;                         /* SERIAL PORT HAS HIGHEST PRIORITY */
            IE=87H;                         /* ENABLE TIMER0 INTERRUPT*/
            TMOD=05H;                       /* TIMER 0 =EVENT COUNTER */
            TL0=0FFH;
            TH0=0FFH;                       /* INITIALIZE COUNTER TO FFFFH*/
            TR0=1;
            $ENDIF

            /*  PROCEDURE SCANNER: THIS PROCEDURE SCANS THE KEYBOARD AND DETERMINES IF A
                SINGLE VALID KEY HAS BEEN PUSHED. IF TRUE THEN THE ASCII EQUIVALENT
                    WILL BE TRANSMITTED TO THE HOST COMPUTER.*/

403   1     SCANNER:
            EA=1;
404   1     DATA$TERMINAL$READY=0;
405   1     IF CURSER$COUNT=1FH THEN        /* PROGRAMMABLE CURSER BLINK */
406   2     DO;
407   2        CURSER$ON=NOT CURSER$ON;
408   2        CURSER$COUNT=00;
409   2        IF CURSER$ON=0 THEN
410   2           CURSER$COL=7FH;
411   2        CALL LOAD$CURSER;
412   2     END;
413   1     IF LLC<>LOCAL$LINE THEN         /* IF LOCAL/LINE HAS CHANGED STATUS */
414   2     DO;
415   2        IF LOCAL$LINE=0 THEN
416   3        DO;
417   3           ENSP=0;
418   3           ES=0;
419   3        END;
420   2        ELSE
               CALL CHECK$BAUD$RATE;
421   2        LLC=LOCAL$LINE;
422   2     END;
            $IF SW1
423   2     DO WHILE SCAN$INT=0;            /* WAIT UNITL VERTICAL RETRACE BEFORE */
424   2        IF SERIAL$INT=1 THEN         /* SCANNING THE KEYBOARD*/
425   2           CALL DECIPHER;
426   2     END;
```

PL/M-51 COMPILER CRTCONTROLLER

```
                $EJECT

427   1         CALL READER;
428   1         IF VALID$KEY =1 AND SAME=1 AND (LAST$SHIFT$KEY=SHIFT$KEY) AND
                   (LAST$CAP$LOCK=CAP$LOCK) AND (LAST$CONTROL$KEY=CONTROL$KEY) THEN
429   1            CALL AUTO$REPEAT;
430   1         ELSE
                DO;
431   2            IF KEY0=0 AND SAME=0 THEN
432   3            DO;
433   3               TEMP =0;
434   3               K=0;
435   4               DO WHILE LAST$KEY(K)=0;
436   4                  K=K+1;
437   4               END;
438   3               TEMP=LAST$KEY(K);
439   4               DO I=(K+1) TO 7;
440   4                  TEMP=TEMP+LAST$KEY(I);
441   4               END;
442   3               IF TEMP=LAST$KEY(K) THEN
443   4               DO;
444   4                  J=0;
445   5                  DO WHILE (TEMP AND 01H)=0;
446   5                     TEMP=SHR (TEMP,1);
447   5                     J=J+1;
448   5                  END;
449   4                  IF TEMP >1 THEN
450   5                  DO;
451   5                     VALID$KEY=0;
452   5                     NEW$KEY=0;
453   5                  END;
454   4                  ELSE
                           DO;
455   5                     IF CONTROL$KEY=0 THEN
456   5                        ASCII$KEY=(LOW$SCAN(K).KEY(J)) AND 1FH;
457   5                     ELSE
                              DO;
458   6                        IF SHIFT$KEY=0 THEN
459   6                           ASCII$KEY=LOW$SCAN(K+08H).KEY(J);
460   6                        ELSE
                                 DO;
461   7                           ASCII$KEY=LOW$SCAN(K).KEY(J);
462   7                           IF (CAP$LOCK=0) AND (ASCII$KEY>60H) AND (ASCII$KEY<7BH) THEN
463   7                              ASCII$KEY=ASCII$KEY-20H;
464   7                           IF LLC=0 THEN
465   8                           DO;
466   8                              IF ASCII$KEY=1BH THEN
467   8                                 ESC$SEQ=1;
468   8                              ELSE
                                       ESC$SEQ=0;
469   8                           END;
470   7                        END;
471   6                     END;
472   5                     LAST$SHIFT$KEY=SHIFT$KEY;
473   5                     LAST$CAP$LOCK=CAP$LOCK;
474   5                     LAST$CONTROL$KEY=CONTROL$KEY;
475   5                     VALID$KEY=1;
476   5                     NEW$KEY=1;
477   5                  END;
478   4               END;
479   3               ELSE
                        DO;
480   4                  VALID$KEY=0;
481   4                  NEW$KEY=0;
482   4               END;
483   3            END;
484   2         END;

                $ENDIF
```

```
PL/M-51 COMPILER    CRTCONTROLLER

            $EJECT

            $IF SW2
            IF SERIAL$INT=1 THEN
               CALL DECIPHER;
            IF KBDINT =1 THEN
            DO;
               IF ERROR =0 THEN
               DO;
                  ASCII$KEY=LST$KEY(1);
                  NEW$KEY=1;
                  CALL AUTO$REPEAT;
                  KBDINT=0;
               END;
            ERROR=0;
            KBDINT=0;
            END;
            $ENDIF

 485   1    GOTO SCANNER;
 486   1    END;



MODULE INFORMATION:                (STATIC+OVERLAYABLE)
    CODE SIZE                     = 08E6H      2278D
    CONSTANT SIZE                 = 0080H       128D
    DIRECT VARIABLE SIZE          =   2DH+00H    45D+  0D
    INDIRECT VARIABLE SIZE        =   00H+00H     0D+  0D
    BIT SIZE                      =   10H+00H    16D+  0D
    BIT-ADDRESSABLE SIZE          =   00H+00H     0D+  0D
    AUXILIARY VARIABLE SIZE       = 0000H         0D
    MAXIMUM STACK SIZE            = 000CH        12D
    REGISTER-BANK(S) USED:          0
    1056 LINES READ
    0 PROGRAM ERROR(S)
END OF PL/M-51 COMPILATION
```

```
MCS-51 MACRO ASSEMBLER    CRTASM


ISIS-II MCS-51 MACRO ASSEMBLER V2.1
OBJECT MODULE PLACED IN :F1:CRTASM.OBJ
ASSEMBLER INVOKED BY:  ASM51 :F1:CRTASM.SRC


LOC  OBJ        LINE  SOURCE

                   1
                   2
                   3
                   4  ;
                   5  ;
                   6
                   7          PUBLIC BLANK
                   8          PUBLIC BLINE
                   9          PUBLIC FILL
                  10          EXTRN DATA (LINE0,RASTER,POINT,SERIAL,FIFO,CURSER,COUNT,L)
                  11          EXTRN BIT (SERINT,ESCSEQ,TRNINT,SCAN)
                  12
                  13
----              14          CSEG AT(03H)
0003 8020         15          SJMP    VERT              ;RESET RASTER TO LINE0 AND SCAN KEYBOARD
                  16
                  17  ;       EXTRN CODE (DETACH)
                  18  ;       CSEG AT(0BH)
                  19  ;       LJMP    DETACH            ;NEEDED IF DECODED KEYBOARD IS USED
                  20
----              21          CSEG AT(013H)
0013 802A         22          SJMP    BUFFER            ;FILL 8276 ROW BUFFER
                  23
----              24          CSEG AT(023H)
0023 802D         25          SJMP    SERBUF            ;STICK SERIAL INFORMATION INTO THE FIFO
                  26
----              27          CSEG
                  28
0025 C0D0         29  VERT:   PUSH    PSW               ;PUSH REG USED BY PLM51
0027 C0E0         30          PUSH    ACC
0029 C000         31          PUSH    00H
002B 850000   F   32          MOV     RASTER,LINE0      ;REINITIALIZE RASTER TO LINE0
002E 850000   F   33          MOV     RASTER+1,LINE0+1
0031 7801         34          MOV     R0,#01H           ;CLR 8276 INTERRUPT FLAG
0033 E2           35          MOVX    A,@R0
0034 0500     F   36          INC     COUNT             ;INCR CURSER COUNT REGISTER
0036 D200     F   37          SETB    SCAN              ;FOR DEBOUNCE ROUTINE
0038 D000         38          POP     00H               ;POP REGISTERS
003A D0E0         39          POP     ACC
003C D0D0         40          POP     PSW
003E 32           41          RETI
                  42
                  43
003F C0D0         44  BUFFER: PUSH    PSW               ;PUSH ALL REG USED BY PLM51 CODE
0041 C0E0         45          PUSH    ACC
0043 C082         46          PUSH    DPL
0045 C083         47          PUSH    DPH
0047 11FA         48          ACALL   DMA               ;FILL 8276 ROW BUFFER
0049 D083         49          POP     DPH               ;POP REGISTERS
004B D082         50          POP     DPL
004D D0E0         51          POP     ACC
004F D0D0         52          POP     PSW
0051 32           53          RETI
                  54
                  55 +1  $EJECT
```

```
MCS-51 MACRO ASSEMBLER    CRTASM


LOC  OBJ       LINE  SOURCE

                 56
0052 309904      57  SERBUF: JNB   099H,OVER  ;IF TRANSMIT BIT NOT SET THEN CHECK RECEIVE
0055 C299        58          CLR   099H               ;CLR TRANSMISSION INTERRUPT FLAG
0057 D200    F   59          SETB  TRNINT             ;SETB TRANS INT FOR PLM51 STATUS CHECK
0059 209828      60  OVER:   JB    98H,GOBACK ;IF RI NOT SET GOBACK
005C C001        61      PUSH      01
005E A999        62          MOV   R1,SBUF            ;READ SBUF
0060 C298        63          CLR   098H               ;CLEAR RI BIT
0062 C0D0        64          PUSH  PSW                ;PUSH REGISTERS USED BY PLM51
0064 C0E0        65          PUSH  ACC
0066 C000        66          PUSH  00H
0068 C200    F   67          CLR   ESCSEQ             ;CLR ESC SEQUENCE FLAG
006A 7400    F   68          MOV   A,#SERIAL          ;GET SERIAL FIFO RAM START LOCATION
006C 2500    F   69          ADD   A,FIFC             ;AND FIND HOW FAR INTO THE FIFO WE ARE
006E F8          70          MOV   R0,A               ;PUT IT INTO R0
006F E9          71          MOV   A,R1
0070 C2E7        72          CLR   0E7H               ;CLR BIT 7 OF ACC
0072 F6          73          MOV   @R0,A              ;PUT DATA IN FIFO
0073 B41B02      74          CJNE  A,#1BH,OVER1       ;IF DATA IS NOT A ESC KEY THEN GO OVER
0076 D200    F   75          SETB  ESCSEQ             ;SET ESC SEQUENCE FLAG
0078 0500    F   76  OVER1:  INC   FIFC               ;MOV FIFO TO NEXT LOCATION
007A D200    F   77          SETB  SERINT             ;SET SERIAL INT BIT FOR PLM51 STATUS CHECK
007C D000        78          POP   00H                ;POP REGISTERS
007E D0E0        79          POP   ACC
0080 D0D0        80          POP   PSW
0082 D001        81          POP   01H
0084 32          82  GOBACK: RETI
                 83
0085 C0D0        84  BLANK:  PUSH  PSW               ;PUSH REG USED BY PLM51
0087 C0E0        85          PUSH  ACC
0089 C082        86          PUSH  DPL
008B C083        87          PUSH  DPH
008D C000        88          PUSH  00H
008F 850082  F   89          MOV   DPL,LINE0+1        ;GET LINE0 INFO
0092 850083  F   90          MOV   DPH,LINE0          ;AND PUT IT INTO DPTR
0095 7850        91          MOV   R0,#50H            ;NUMBER OF CHARACTERS IN A LINE
0097 7420        92  NOTYET: MOV   A,#20H             ;ASCII SPACE CHARACTER
0099 F0          93          MOVX  @DPTR,A            ;MOV TO DISPLAY RAM
009A A3          94          INC   DPTR               ;INCR TO NEXT DISPLAY RAM LOCATION
009B D8FA        95          DJNZ  R0,NOTYET          ;IF ALL 50H LOCATIONS ARE NOT FILLED
                 96                                   ;GO DO MORE
009D D000        97          POP   00H                ;POP REGISTERS
009F D083        98          POP   DPH
00A1 D082        99          POP   DPL
00A3 D0E0       100          POP   ACC
00A5 D0D0       101          POP   PSW
00A7 22         102          RET
                103 +1  $EJECT
```

```
MCS-51 MACRO ASSEMBLER    CRTASM

LOC  OBJ          LINE  SOURCE

                   104
00A8 C0D0          105  BLINE:   PUSH  PSW          ;PUSH REGISTERS USED BY PLM51
00AA C0E0          106           PUSH  ACC
00AC C082          107           PUSH  DPL
00AE C083          108           PUSH  DPH
00B0 C000          109           PUSH  00H
00B2 850083   F    110           MOV   DPH,PCINT    ;GET CURRENT DISPLAY RAM LOCATION
00B5 850082   F    111           MOV   DPL,PCINT+1
00B8 438310        112           ORL   DPH,#10H     ;SET BIT 15 FOR RAM ADDRESS DECODING
00BB A800     F    113           MOV   R0,CURSER    ;GET CURSER COLUMN INFO TO TELL HOW
                   114                              ;FAR INTO THE ROW YOU ARE
00BD 7420          115  CONT1:   MOV   A,#20H       ;ASCII SPACE CHARACTER
00BF F0            116           MOVX  @DPTR,A      ;MOV TO DISPLAY RAM
00C0 A3            117           INC   DPTR         ;INCR TO NEXT DISPLAY RAM LOCATION
00C1 08            118           INC   R0
00C2 B850F8        119           CJNE  R0,#50H,CONT1 ;IF NOT AT THE END OF THE LINE
                   120                              ; CONTINUE
00C5 D000          121           POP   00H          ;POP REGISTERS
00C7 D083          122           POP   DPH
00C9 D082          123           POP   DPL
00CB D0E0          124           POP   ACC
00CD D0D0          125           POP   PSW
00CF 22            126           RET
                   127
00D0 C0D0          128  FILL:    PUSH  PSW          ;PUSH REGISTERS USED BY PLM51
00D2 C0E0          129           PUSH  ACC
00D4 C082          130           PUSH  DPL
00D6 C083          131           PUSH  DPH
00D8 C000          132           PUSH  00H
00DA C3            133           CLR   C
00DB 850083   F    134           MOV   DPH,L        ;GET BEGINNING OF LINE RAM LOCATION
00DE 850082   F    135           MOV   DPL,L+1      ;CALCULATED BY PLM51
00E1 438310        136           ORL   DPH,#10H     ;SET BIT 15 FOR DISPLAY RAM ADDRESS DECODE
00E4 784F          137           MOV   R0,#4FH      ;SET UP COUNTER FOR 50H LOCATIONS
00E6 A3            138           INC   DPTR         ;GO PAST THE 0F1H
00E7 7420          139  CONT2:   MOV   A,#20H       ;ASCII SPACE CHARACTER
00E9 F0            140           MOVX  @DPTR,A      ;MOVE TO DISPLAY RAM
00EA A3            141           INC   DPTR         ;INCR TO NEXT DISPLAY RAM LOCATION
00EB D8FA          142           DJNZ  R0,CONT2     ;IF ALL 79 LOCATIONS HAVE NOT BEEN FILLED
                   143                              ;THEN CONTINUE
00ED D000          144           POP   00H          ;POP REGISTERS
00EF D083          145           POP   DPH
00F1 D082          146           POP   DPL
00F3 D0E0          147           POP   ACC
00F5 D0D0          148           POP   PSW
00F7 22            149           RET
                   150
                   151
                   152 +1   $EJECT
```

```
MCS-51 MACRO ASSEMBLER   CRTASM

LOC  OBJ        LINE  SOURCE

                 153
                 154  ;*************************************************************************
                 155  ;THIS ROUTINE MOVES DISPLAY RAM DATA TO ROW BUFFER OF 8276
                 156  ;*************************************************************************
                 157
0UF8 21BB        158  DDONE:  AJMP    DMADNE
                 159
0UFA 850083  F   160  DMA:    MOV     DPH,MASTER      ;LOAD XFER POINTER HIGH BYTE
0UFD 850082  F   161          MOV     DPL,MASTER+1    ;LOAD XFER POINTER LOW BYTE
0100 E0          162          MOVX    A,@DPTR
0101 A3          163          INC     DPTR
0102 20B3F3      164          JB      0B3H,DDONE      ;IF INT1 HIGH, THEN DMA IS OVER
0105 E0          165          MOVX    A,@DPTR
0106 A3          166          INC     DPTR
0107 E0          167          MOVX    A,@DPTR
0108 A3          168          INC     DPTR
0109 E0          169          MOVX    A,@DPTR
010A A3          170          INC     DPTR
010B E0          171          MOVX    A,@DPTR
010C A3          172          INC     DPTR
010D E0          173          MOVX    A,@DPTR
010E A3          174          INC     DPTR
010F E0          175          MOVX    A,@DPTR
0110 A3          176          INC     DPTR
0111 E0          177          MOVX    A,@DPTR
0112 A3          178          INC     DPTR
0113 E0          179          MOVX    A,@DPTR
0114 A3          180          INC     DPTR
0115 E0          181  TEN:    MOVX    A,@DPTR
0116 A3          182          INC     DPTR
0117 E0          183          MOVX    A,@DPTR
0118 A3          184          INC     DPTR
0119 E0          185          MOVX    A,@DPTR
011A A3          186          INC     DPTR
011B E0          187          MOVX    A,@DPTR
011C A3          188          INC     DPTR
011D E0          189          MOVX    A,@DPTR
011E A3          190          INC     DPTR
011F E0          191          MOVX    A,@DPTR
0120 A3          192          INC     DPTR
0121 E0          193          MOVX    A,@DPTR
0122 A3          194          INC     DPTR
0123 E0          195          MOVX    A,@DPTR
0124 A3          196          INC     DPTR
0125 E0          197          MOVX    A,@DPTR
0126 A3          198          INC     DPTR
0127 E0          199          MOVX    A,@DPTR
0128 A3          200          INC     DPTR
0129 E0          201  TWENTY: MOVX    A,@DPTR
012A A3          202          INC     DPTR
012B E0          203          MOVX    A,@DPTR
012C A3          204          INC     DPTR
012D E0          205          MOVX    A,@DPTR
012E A3          206          INC     DPTR
012F E0          207          MOVX    A,@DPTR
```

```
MCS-51 MACRO ASSEMBLER   CNTASK

LOC  OBJ              LINE     SOURCE

0130 A3               208              INC     DPTR
0131 E0               209              MOVX    A,@DPTR
0132 A3               210              INC     DPTR
0133 E0               211              MOVX    A,@DPTR
0134 A3               212              INC     DPTR
0135 E0               213              MOVX    A,@DPTR
0136 A3               214              INC     DPTR
0137 E0               215              MOVX    A,@DPTR
0138 A3               216              INC     DPTR
0139 E0               217              MOVX    A,@DPTR
013A A3               218              INC     DPTR
013B E0               219              MOVX    A,@DPTR
013C A3               220              INC     DPTR
013D E0               221     THIRTY:  MOVX    A,@DPTR
013E A3               222              INC     DPTR
013F E0               223              MOVX    A,@DPTR
0140 A3               224              INC     DPTR
0141 E0               225              MOVX    A,@DPTR
0142 A3               226              INC     DPTR
0143 E0               227              MOVX    A,@DPTR
0144 A3               228              INC     DPTR
0145 E0               229              MOVX    A,@DPTR
0146 A3               230              INC     DPTR
0147 E0               231              MOVX    A,@DPTR
0148 A3               232              INC     DPTR
0149 E0               233              MOVX    A,@DPTR
014A A3               234              INC     DPTR
014B E0               235              MOVX    A,@DPTR
014C A3               236              INC     DPTR
014D E0               237              MOVX    A,@DPTR
014E A3               238              INC     DPTR
014F E0               239              MOVX    A,@DPTR
0150 A3               240              INC     DPTR
0151 E0               241     FORTY:   MOVX    A,@DPTR
0152 A3               242              INC     DPTR
0153 E0               243              MOVX    A,@DPTR
0154 A3               244              INC     DPTR
0155 E0               245              MOVX    A,@DPTR
0156 A3               246              INC     DPTR
0157 E0               247              MOVX    A,@DPTR
0158 A3               248              INC     DPTR
0159 E0               249              MOVX    A,@DPTR
015A A3               250              INC     DPTR
015B E0               251              MOVX    A,@DPTR
015C A3               252              INC     DPTR
015D E0               253              MOVX    A,@DPTR
015E A3               254              INC     DPTR
015F E0               255              MOVX    A,@DPTR
0160 A3               256              INC     DPTR
0161 E0               257              MOVX    A,@DPTR
0162 A3               258              INC     DPTR
0163 E0               259              MOVX    A,@DPTR
0164 A3               260              INC     DPTR
0165 E0               261     FIFTY:   MOVX    A,@DPTR
0166 A3               262              INC     DPTR
```

```
MCS-51 MACRO ASSEMBLER   CNTASM

LOC  OBJ              LINE     SOURCE

0167 E0               263              MOVX    A,@DPTR
0168 A3               264              INC     DPTR
0169 E0               265              MOVX    A,@DPTR
016A A3               266              INC     DPTR
016B E0               267              MOVX    A,@DPTR
016C A3               268              INC     DPTR
016D E0               269              MOVX    A,@DPTR
016E A3               270              INC     DPTR
016F E0               271              MOVX    A,@DPTR
0170 A3               272              INC     DPTR
0171 E0               273              MOVX    A,@DPTR
0172 A3               274              INC     DPTR
0173 E0               275              MOVX    A,@DPTR
0174 A3               276              INC     DPTR
0175 E0               277              MOVX    A,@DPTR
0176 A3               278              INC     DPTR
0177 E0               279              MOVX    A,@DPTR
0178 A3               280              INC     DPTR
0179 E0               281      SIXTY:  MOVX    A,@DPTR
017A A3               282              INC     DPTR
017B E0               283              MOVX    A,@DPTR
017C A3               284              INC     DPTR
017D E0               285              MOVX    A,@DPTR
017E A3               286              INC     DPTR
017F E0               287              MOVX    A,@DPTR
0180 A3               288              INC     DPTR
0181 E0               289              MOVX    A,@DPTR
0182 A3               290              INC     DPTR
0183 E0               291              MOVX    A,@DPTR
0184 A3               292              INC     DPTR
0185 E0               293              MOVX    A,@DPTR
0186 A3               294              INC     DPTR
0187 E0               295              MOVX    A,@DPTR
0188 A3               296              INC     DPTR
0189 E0               297              MOVX    A,@DPTR
018A A3               298              INC     DPTR
018B E0               299              MOVX    A,@DPTR
018C A3               300              INC     DPTR
018D E0               301      SEVNTY: MOVX    A,@DPTR
018E A3               302              INC     DPTR
018F E0               303              MOVX    A,@DPTR
0190 A3               304              INC     DPTR
0191 E0               305              MOVX    A,@DPTR
0192 A3               306              INC     DPTR
0193 E0               307              MOVX    A,@DPTR
0194 A3               308              INC     DPTR
0195 E0               309              MOVX    A,@DPTR
0196 A3               310              INC     DPTR
0197 E0               311              MOVX    A,@DPTR
0198 A3               312              INC     DPTR
0199 E0               313              MOVX    A,@DPTR
019A A3               314              INC     DPTR
019B E0               315              MOVX    A,@DPTR
019C A3               316              INC     DPTR
019D E0               317              MOVX    A,@DPTR
```

```
MCS-51 MACRO ASSEMBLER    CRTASM

LOC  OBJ              LINE     SOURCE

019E A3                318             INC     DPTR
019F E0                319             MOVX    A,@DPTR
01A0 A3                320             INC     DPTR
01A1 E0                321     EIGHTY: MOVX    A,@DPTR
01A2 A3                322             INC     DPTR
                       323
01A3 E583              324     CHECK:  MOV     A,DPH
01A5 B41F0C            325             CJNE    A,#1FH,DONE
01A8 E582              326             MOV     A,DPL
01AA B4D007            327             CJNE    A,#0D0H,DONE
01AD 750018    F       328             MOV     RASTER,#18H
01B0 750000    F       329             MOV     RASTER+1,#00H
01B3 22                330             RET
                       331
01B4 858300    F       332     DONE:   MOV     RASTER,DPH
01B7 858200    F       333             MOV     RASTER+1,DPL
01BA 22                334             RET
                       335
01BB C3                336     DMADNE: CLR     C
01BC E582              337             MOV     A,DPL
01BE 244F              338             ADD     A,#79D          ;ADD 79 TO BUFFER POINTER
01C0 F582              339             MOV     DPL,A           ;TO GET TO NEXT DISPLAY LINE
01C2 D0DF              340             JNC     CHECK           ;IN THE DISPLAY MEMORY
01C4 0583              341             INC     DPH
01C6 80DB              342             SJMP    CHECK
                       343
                       344
                       345     END
```

```
MCS-51 MACRO ASSEMBLER    CKTASM

SYMBOL TABLE LISTING
------ ----- -------

N A M E     T Y P E   V A L U E      A T T R I B U T E S

ACC. . . .  D ADDR    00E0H    A
BLANK. . .  C ADDR    0085H    A PUB
BLINE. . .  C ADDR    00A8H    A PUB
BUFFER . .  C ADDR    003FH    A
CHECK. . .  C ADDR    01A3H    A
CNT1. . .   C ADDR    00BDH    A
CNT2. . .   C ADDR    00E7H    A
COUNT. . .  D ADDR    ----       EXT
CURSER . .  D ADDR    ----       EXT
DDONE. . .  C ADDR    00F8H    A
DMA. . . .  C ADDR    00FAH    A
DMADNE . .  C ADDR    01B8H    A
DONE . . .  C ADDR    01B4H    A
DPH. . . .  D ADDR    0083H    A
DPL. . . .  D ADDR    0082H    A
EIGHTY . .  C ADDR    01A1H    A
ESCSEQ . .  B ADDR    ----       EXT
FIFO . . .  D ADDR    ----       EXT
FIFTY. . .  C ADDR    0165H    A
FILL . . .  C ADDR    00D0H    A PUB
FORTY. . .  C ADDR    0151H    A
GOBACK . .  C ADDR    0084H    A
L. . . . .  D ADDR    ----       EXT
LINE0. . .  D ADDR    ----       EXT
NOTYET . .  C ADDR    0097H    A
OVER . . .  C ADDR    0059H    A
OVER1. . .  C ADDR    0078H    A
POINT. . .  D ADDR    ----       EXT
PSW. . . .  D ADDR    00D0H    A
RASIER . .  D ADDR    ----       EXT
SBUF . . .  D ADDR    0099H    A
SCAN . . .  B ADDR    ----       EXT
SERBUF . .  C ADDR    0052H    A
SERIAL . .  D ADDR    ----       EXT
SERINT . .  B ADDR    ----       EXT
SEVNTY . .  C ADDR    018DH    A
SIXTY. . .  C ADDR    0179H    A
TEN. . . .  C ADDR    0115H    A
THIRTY . .  C ADDR    013DH    A
TRNINT . .  B ADDR    ----       EXT
TWENTY . .  C ADDR    0129H    A
VERT . . .  C ADDR    0025H    A

REGISTER BANK(S) USED: 0

ASSEMBLY COMPLETE, NO ERRORS FOUND
```

```
MCS-51 MACRO ASSEMBLER    KEYBD

ISIS-II MCS-51 MACRO ASSEMBLER V2.1
OBJECT MODULE PLACED IN :F1:KEYBD.OBJ
ASSEMBLER INVOKED BY:  ASM51 :F1:KEYBD.SRC

LOC  OBJ  LINE     SOURCE

                     1
                     2
                     3
                     4     ;*************************************************************************
                     5     ;*************************************************************************
                     6     ;****                                                                 ****
                     7     ;****              SOFTWARE FOR READING AN UNDECODED                  ****
                     8     ;****                        KEYBOARD                                 ****
                     9     ;****                                                                 ****
                    10     ;*************************************************************************
                    11     ;*************************************************************************
                    12     ;
                    13     ;
                    14     ;
                    15     ;
                    16     ;       THIS CONTAINS THE SOFTWARE NEEDED TO SCAN AN UNDECODED KEYBOARD
                    17     ;       THIS PROGRAM MUST BE LINKED TO THE MAIN PROGRAMS TO FUNCTION
                    18     ;
                    19     ;
                    20     ;        MEMORY MAP FOR READING KEY BOARD (USING MOVC)
                    21     ;
                    22     ;       ADDRESS FOR KEY BOARD 10FFH TO 17FFH
                    23     ;
                    24     ;
                    25     ;
                    26     ;
                    27             PUBLIC READER
                    28             EXTRN DATA (LSTKEY)
                    29             EXTRN BIT (KEYD,SAME)
                    30     ;
                    31     ;*************************************************************************
                    32     ;*                                                                       *
                    33     ;*                          "READER"ROUTINE"                             *
                    34     ;*                                                                       *
                    35     ;*************************************************************************
                    36 +1  $EJECT
```

```
MCS-51 MACRO ASSEMBLER    KEY00


LOC  OBJ       LINE  SOURCE

                 37
                 38  UNDECODED_KEYBOARD SEGMENT CODE
----             39  RSEG UNDECODED_KEYBOARD
                 40
                 41
                 42
0000 C000        43  HEADER: PUSH  PSW           ;PUSH REG USED BY PLM51
0002 C0E0        44          PUSH  ACC
0004 C082        45          PUSH  DPL
0006 C083        46          PUSH  DPH
0008 C000        47          PUSH  00H
000A C001        48          PUSH  01H
000C C002        49          PUSH  02H
000E C003        50          PUSH  03H
0010 9010FF      51          MOV   DPTR,#10FFH   ;INITIALIZE DPTR TO KEYBOARD
                 52                              ;ADDRESS
0013 7900        53          MOV   R1,#00H       ;CLR ZERO COUNTER
0015 7800    F   54          MOV   R0,#LSTKEY    ;GET KEYBOARD RAM POINTER
0017 7808        55          MOV   R3,#08H       ;INITIALIZE LOOP COUNTER
0019 C200    F   56          CLR   KEY0          ;INITIALIZE PLM51 STATUS BITS
001B D200    F   57          SETB  SAME
001D 8602        58  MORE:   MOV   02H,@R0       ;MOV LAST KEYBOARD SCAN TO 02H
001F E4          59          CLR   A
0020 93          60          MOVC  A,@A+DPTR     ;SCAN KEYBOARD
0021 F4          61          CPL   A             ;INVERT
0022 6005        62          JZ    ZERO          ;IF SCAN WAS ZERO GO INCREMENT ZERO COUNTER
0024 B50224      63          CJNE  A,02H,NTSAME  ;COMPARE WITH LAST SCAN IF NOT THE SAME
                 64                              ;THEN CLR SAME BIT AND WRITE NEW INFORMATION
                 65                              ;TO RAM
0027 8005        66          SJMP  EQUAL         ;IF EQUAL JMP OVER INCR OF ZERO COUNTER
0029 0501        67  ZERO:   INC   01H           ;INCR ZERO COUNTER
002B B5021D      68          CJNE  A,02H,NTSAME
002E 08          69  EQUAL:  INC   R0            ;STEP TO NEXT SCAN RAM LOCATION
002F 0583        70          INC   DPH           ;NEXT KEYBOARD ADDRESS
0031 DBEA        71          DJNZ  R3,MORE       ;IF LOOP COUNTER NOT 0, SCAN AGAIN
0033 B90804      72          CJNE  R1,#08H,BACK  ;CHECK TO SEE IF ALL 8 SCANS WHERE 0
0036 D200    F   73          SETB  KEY0          ;IF YES SET KEY0 BIT
0038 C200    F   74          CLR   SAME
003A D003        75  BACK:   POP   03H
003C D002        76          POP   02H           ;POP REGISTERS
003E D001        77          POP   01H
0040 D000        78          POP   00H
0042 D083        79          POP   DPH
0044 D082        80          POP   DPL
0046 D0E0        81          POP   ACC
0048 D0D0        82          POP   PSW
004A 22          83          RET
                 84
004B F6          85  NTSAME: MOV   @R0,A         ;IF SCAN WAS NOT THE SAME THEN PUT NEW
                 86                              ;SCAN INFO INTO RAM
004C C200    F   87          CLR   SAME          ;CLR SAME BIT
004E 80DE        88          SJMP  EQUAL         ;GO DO MORE
                 89
                 90
                 91  END
```

```
MCS-51 MACRO ASSEMBLER    KEYBD

SYMBOL TABLE LISTING
------ ----- -------

N A M E              T Y P E   V A L U E       A T T R I B U T E S

ACC. . . . . .  D ADDR    00E0H   A
BACK . . . . . .  C ADDR    003AH   R       SEG=UNDECODED_KEYBOARD
DPH. . . . . .  D ADDR    0083H   A
DPL. . . . . .  D ADDR    0082H   A
EQUAL. . . . . .  C ADDR    002EH   R       SEG=UNDECODED_KEYBOARD
KEY0 . . . . . .  B ADDR    ----      EXT
LSTKEY . . . . . .  D ADDR    ----      EXT
MORE . . . . . .  C ADDR    001DH   R       SEG=UNDECODED_KEYBOARD
NTSAME . . . . . .  C ADDR    004BH   R       SEG=UNDECODED_KEYBOARD
PSW. . . . . .  D ADDR    00D0H   A
READER . . . . . .  C ADDR    0000H   R PUB   SEG=UNDECODED_KEYBOARD
SAME . . . . . .  B ADDR    ----      EXT
UNDECODED_KEYBOARD  C SEG     0050H           REL=UNIT
ZERO . . . . . .  C ADDR    0029H   R       SEG=UNDECODED_KEYBOARD

REGISTER BANK(S) USED: 0

ASSEMBLY COMPLETE, NO ERRORS FOUND
```

```
MCS-51 MACRO ASSEMBLER    DECODE


ISIS-II MCS-51 MACRO ASSEMBLER V2.1
OBJECT MODULE PLACED IN :F1:DECODE.OBJ
ASSEMBLER INVOKED BY:  ASM51 :F1:DECODE.SRC


LOC  OBJ  LINE     SOURCE

                     1
                     2
                     3
                     4      ;*****************************************************************
                     5      ;*****************************************************************
                     6      ;****                                                         ****
                     7      ;****          SOFTWARE FOR DECODED KEYBOARD                  ****
                     8      ;****                                                         ****
                     9      ;*****************************************************************
                    10      ;*****************************************************************
                    11      ;
                    12      ;
                    13      ;
                    14      ;
                    15              PUBLIC DETACH
                    16              EXTRN DATA (LSTKEY)
                    17              EXTRN BIT  (KBDINT)
                    18
                    19
                    20      ;
                    21      ;*****************************************************************
                    22      ;*                                                               *
                    23      ;*       "DECODE" INTERRUPT ROUTINE FOR DECODED KEYBOARDS        *
                    24      ;*                                                               *
                    25      ;*****************************************************************
                    26 +1   $EJECT
```

```
MCS-51 MACRO ASSEMBLER    DECODE


LOC  OBJ        LINE  SOURCE

                  27
                  28  DECODED_KEYBOARD SEGMENT CODE
----              29  RSEG DECODED_KEYBOARD
                  30
0000 C000         31  DETACH: PUSH    PSW             ;PUSH REGISTERS
0002 C082         32          PUSH    DPL             ;USED BY PLM51
0004 C083         33          PUSH    DPH
0006 C0E0         34          PUSH    ACC
0008 90B0FF       35          MOV     DPTR,#0B0FFH    ;ADDRESS FOR KEYBOARD
000B E4           36          CLR     A
000C 93           37          MOVC    A,@A+DPTR       ;FETCH ASCII BYTE
000D F500     F   38          MOV     LSTKEY+1,A      ;MOV TO MEMORY TO BE READ BY PLM51
000F D200     F   39          SETB    KBDINT          ;LET PLM51 KNOW THERE IS A BYTE
0011 758CFF       40          MOV     TH0,#0FFH       ;SET COUNTER TO FFFFH SO INTERRUPT
0014 758AFF       41          MOV     TL0,#0FFH       ;ON THE NEXT FALLING EDGE OF T0
0017 D0E0         42          POP     ACC
0019 D083         43          POP     DPH             ;POP REGISTERS
001B D082         44          POP     DPL
001D D000         45          POP     PSW
001F 32           46          RETI
                  47
                  48
                  49
                  50
                  51  END
```

```
MCS-51 MACRO ASSEMBLER    DECODE

SYMBOL TABLE LISTING
------ ----- -------

N A M E             T Y P E   V A L U E       A T T R I B U T E S

ACC. . . . . .      D ADDR    00E0H   A
DECODED_KEYBOARD    C SEG     0020H           REL=UNIT
DETACH . . . . .    C ADDR    0000H   R PUB   SEG=DECODED_KEYBOARD
DPH. . . . . .      D ADDR    0083H   A
DPL. . . . . .      D ADDR    0082H   A
KBDINT . . . . .    B ADDR    ----      EXT
LSTKEY . . . . .    D ADDR    ----      EXT
PSW. . . . . .      D ADDR    00D0H   A
TH0. . . . . .      D ADDR    008CH   A
TL0. . . . . .      D ADDR    008AH   A

REGISTER BANK(S) USED: 0

ASSEMBLY COMPLETE, NO ERRORS FOUND
```

```
MCS-51 MACRO ASSEMBLER    DETACH


ISIS-II MCS-51 MACRO ASSEMBLER V2.1
OBJECT MODULE PLACED IN :F1:DETACH.OBJ
ASSEMBLER INVOKED BY:  ASM51 :F1:DETACH.SRC


LOC  OBJ  LINE     SOURCE

                     1
                     2
                     3
                     4     ;************************************************************************
                     5     ;************************************************************************
                     6     ;****                                                                ****
                     7     ;****              SOFTWARE FOR A SERIAL OR DETACHABLE               ****
                     8     ;****                          KEYBOARD                              ****
                     9     ;****                                                                ****
                    10     ;************************************************************************
                    11     ;************************************************************************
                    12     ;
                    13     ;
                    14     ;
                    15     ;  THIS CONTAINS THE SOFTWARE NEEDED TO PERFORM A SOFTWARE SERIAL
                    16     ;  PORT FOR SERIAL KEYBOARDS AND DETACHABLE KEYBOARD. THIS PROGRAM MUST
                    17     ;  BE LINKED TO THE MAIN PROGRAMS FOR USE.
                    18     ;
                    19 +1  $EJECT
```

```
MCS-51 MACRO ASSEMBLER    DETACH

LOC  OBJ       LINE     SOURCE

                 20     ;
                 21     ;
                 22
  00B4           23             INPUT EQU  TO
                 24
                 25
                 26             PUBLIC DETACH
                 27             EXTRN DATA (LSTKEY)
                 28             EXTRN BIT (RCVFLG,SYNC,BYFIN)
                 29             EXTRN BIT (KBDINT,ERROR)
                 30
                 31     ;
                 32     ;
                 33     ;
                 34
                 35     ;       TIMER 0 LOAD VALUES FOR DIFFERENT BAUD RATES
                 36     ;       USED WITH DETACHABLE KEYBOARDS
                 37     ;
                 38     ;
                 39     ;
                 40     ;   BAUD      START BIT DETECT          MESSAGE DETECT
                 41     ;   110           0EFA2H                    0DF45H
                 42     ;   150           0F400H                    0E800H
                 43     ;
                 44     ;
                 45     ;
                 46     ;
  0000           47             START0          EQU     000H    ;LOW BYTE FOR 150 BAUD
  00F4           48             START1          EQU     0F4H    ;HIGH BYTE FOR 150 BAUD
  0000           49             MESSAGE0        EQU     000H    ;LOW BYTE FOR 150 BAUD
  00E8           50             MESSAGE1        EQU     0E8H    ;HIGH BYTE FOR 150 BAUD
                 51 +1  $EJECT
```

```
LOC  OBJ             LINE     SOURCE

                       52
                       53     ;
                       54     ;*****************************************************************************
                       55     ;*                                                                           *
                       56     ;*            "DETACH" INTERRUPT ROUTINE FOR DETACHABLE KEYBOARDS            *
                       57     ;*                                                                           *
                       58     ;*****************************************************************************
                       59
                       60
                       61
                       62     DETACHABLE_KEYBOARD SEGMENT CODE
----                   63     RSEG DETACHABLE_KEYBOARD
                       64
0000 C0D0              65     DETACH: PUSH    PSW                     ;PUSH REGISTERS USED BY PLM51
0002 C0E0              66             PUSH    ACC
0004 200013    F       67             JB      RCVFLG,VALID            ;IF RECEIVE FLAG SET GET NEXT BIT
0007 20B44A            68             JB      INPUT,RST               ;IF T0 IS A 1 THEN NOT A START BIT
000A D200      F       69             SETB    RCVFLG                  ;IF T0 IS 0 THEN IT  A  START BIT
000C 758CF4            70             MOV     TH0,#START1             ;SET TIMER TO INTERRUPT IN THE MIDDLE OF START BIT
000F 758A00            71             MOV     TL0,#START0
0012 E589              72             MOV     A,TMOD
0014 C2E2              73             CLR     0E2H
0016 F589              74             MOV     TMOD,A                  ;SET TIMER COUNTER TO TIMER MODE
0018 802B              75             SJMP    FINI                    ;GO BACK TO PROGRAM
                       76     ;
001A 200010    F       77     VALID:  JB      SYNC,NXTBIT             ;CHECK IF VALID START BIT HAS BEEN SEEN
001D 20B434            78             JB      INPUT,RST               ;IF NOT CHECK IF VALID START BIT
0020 D200      F       79             SETB    SYNC                    ;IF YES SET SYNC
0022 7500B0    F       80             MOV     LSTKEY,#80H             ; INIT LSTKEY
0025 758CE8            81             MOV     TH0,#MESSAGE1
0028 758A00            82             MOV     TL0,#MESSAGE0           ;SET TIMER FOR 1 BIT TIME
002B 8018              83             SJMP    FINI                    ;AND GO BACK TO MAIN PROGRAM
                       84     ;
002D 758CE8            85     NXTBIT: MOV     TH0,#MESSAGE1
0030 758A00            86             MOV     TL0,#MESSAGE0           ;SET TIMER FOR 1 BIT TIME
0033 200014    F       87             JB      BYFIN,STOP              ;CHECK TO SEE IF ALL 8 BITS HAVE BEEN RECEIVED
0036 E500      F       88             MOV     A,LSTKEY                ;GET WORKING REGISTER
0038 A2B4              89             MOV     C,INPUT                 ;GET NEXT BIT FROM T1
003A 13                90             RRC     A
003B F500      F       91             MOV     LSTKEY,A
003D 5006              92             JNC     FINI                    ;IF NO CARRY THEN NOT DONE
003F D200      F       93             SETB    BYFIN
0041 C2E7              94             CLR     0E7H                    ;CLR BIT 7
0043 F500      F       95             MOV     LSTKEY+1,A              ;MOV FINAL CODE TO LSTKY+1
0045 D0E0              96     FINI:   POP     ACC
0047 D0D0              97             POP     PSW
0049 32                98             RETI
```

```
MCS-51 MACRO ASSEMBLER    DETACH

LOC  OBJ            LINE     SOURCE

                      99     ;
004A 30B4D5           100     STOP:   JNB     RPLI,ERR        ;IF NOT 1 THEN NOT A VALID STOP BIT
004D D200      F      101             SETB    RBUINT          ;TELL PLM A BYTE IS READY
004F 020000    F      102             JMP     RST             ;AND GO BACK TO MAIN PROGRAM
                      103     ;
0052 D2D0      F      104     ERR:    SETB    ERRCK
0054 C200      F      105     RST:    CLR     RCVFLG          ;CLEAR FLAGS
0056 C200      F      106             CLR     SYNC
0058 C200      F      107             CLR     BYPIN
005A E589             108             MOV     A,IMOD
005C D2E2             109             SETB    0E2H            ;SET TIMER 0 TO COUNTER MODE
005E F589             110             MOV     IMOD,A
0060 758CFF           111             MOV     TH0,#0FFH       ;SET COUNTER TO FFFFH SO INTERRUPT
0063 758AFF           112             MOV     TL0,#0FFH       ;ON NEXT FALLING EDGE OF T0
0066 80DD             113             SJMP    FINI
                      114
                      115
                      116
                      117
                      118     END
```

```
MCS-51 MACRO ASSEMBLER    DETACH

SYMBOL TABLE LISTING
------ ----- -------

NAME              TYPE  VALUE      ATTRIBUTES

ACC . . . . . .   D ADDR   00E0H    A
BYFIN . . . . . .   B ADDR   ----      EXT
DETACH. . . . . .   C ADDR   0000H    R PUB    SEG=DETACHABLE_KEYBOARD
DETACHABLE_KEYBOARD   C SEG    0068H             REL=UNIT
ERR . . . . . .   C ADDR   0052H    R        SEG=DETACHABLE_KEYBOARD
ERROR . . . . . .   B ADDR   ----      EXT
FINI. . . . . .   C ADDR   0045H    R        SEG=DETACHABLE_KEYBOARD
INPUT . . . . . .   B ADDR   00B0H.4 A
KBDINT. . . . . .   B ADDR   ----      EXT
LSTKEY. . . . . .   D ADDR   ----      EXT
MESSAGE0. . . . . .   NUMB   0000H    A
MESSAGE1. . . . . .   NUMB   00E8H    A
NXTBIT. . . . . .   C ADDR   002DH    R        SEG=DETACHABLE_KEYBOARD
PSW . . . . . .   D ADDR   00D0H    A
RCVFLG. . . . . .   B ADDR   ----      EXT
RST . . . . . .   C ADDR   0054H    R        SEG=DETACHABLE_KEYBOARD
START0. . . . . .   NUMB   0000H    A
START1. . . . . .   NUMB   00F4H    A
STOP. . . . . .   C ADDR   004AH    R        SEG=DETACHABLE_KEYBOARD
SYNC. . . . . .   B ADDR   ----      EXT
TU. . . . . .   B ADDR   00B0H.4 A
TH0 . . . . . .   D ADDR   008CH    A
TL0 . . . . . .   D ADDR   008AH    A
TMOD. . . . . .   D ADDR   0089H    A
VALID . . . . . .   C ADDR   001AH    R        SEG=DETACHABLE_KEYBOARD

REGISTER BANK(S) USED: 0

ASSEMBLY COMPLETE, NO ERRORS FOUND
```

APPENDIX B
REFERENCES

1. John Murray and George Alexy, *CRT Terminal Design Using The Intel 8275 and 8279,* Intel Application Note AP-32, Nov., 1977.
2. John Katausky, *A Low Cost CRT Terminal Using The 8275,* Intel Application Note AP-62, Nov., 1979.

intel®

APPLICATION BRIEF

AB-38

August 1990

Interfacing the 82786 Graphics Coprocessor to the 8051

RICK SCHUE
REGIONAL APPLICATIONS SPECIALIST
INDIANAPOLIS, INDIANA

Order Number: 270528-003

INTERFACING THE 82786 GRAPHICS COPROCESSOR TO THE 8051

CONTENTS

Interfacing the 82786 to the 8051 presents some interesting challenges, but can be accomplished with a little additional logic and software. Since the 82786 looks like a DRAM controller to the host CPU, wait states are often required when accessing the coprocessor. Since wait states are not supported by the 8051, latching transceivers and dummy read and write cycles are used to communicate with the 82786. Byte swapping is also required in the external logic to allow the 8 bit 8051 to read and write the 16 bit graphics memory supported by the 82786. This byte swapping is accomplished with the latching transceivers as well. All of the control logic is implemented in an Intel 5C060 EPLD, allowing the entire interface to fit into three 24 pin DIPs.

HARDWARE

Figure 1 shows the interface between the 8051 bus and the 82786. Figure 2 shows a typical 8051 CPU design needed to complete the circuit. In this design the 82786 is mapped into an 8K byte window in 8051 data memory space. The upper address bits are used as a "page select" and are provided by I/O pins on the 8051. The 5C060 EPLD contains the control logic for the transceivers and address decoding for the 82786. An equivalent circuit for the EPLD is shown in Figure 3; the ".ADF" file is shown in Figure 4. The 82786 data memory is mapped into one 8K block (A000H–BFFEH), the 82786 registers are mapped into another (8000H–807EH), and the transceivers are mapped into a third block of memory (C000H–C001H).

OPERATION

Operation of the interface is as follows. For reading the graphics memory, the 8051 sets the upper address bits (PORT 1.0–1.3) and then performs a dummy read operation to the desired location in graphics memory (A000H thru BFFEH). The dummy read cycle provides the address and RD/WR information to the 82786, which runs a cycle and deposits the 16 bit result into the latching transceivers at the end of the read cycle, as indicated by SEN. This event clears the BUSY flip flop in the EPLD. When the BUSY signal goes inactive, the 8051 reads the low byte from the latching transceiver at address C000H and the high byte free address C001H.

For write cycles, the 8051 writes the low byte of the word into the latch at address C000H and the high byte into address C001H. Next the upper address bits are set with PORT1 and a dummy write cycle is performed in graphics memory at the desired address (A000H–BFFEH). Like in the read example, the 82786 runs a memory cycle at this point, enabling the outputs of the latching transceivers at the proper time in the write cycle, as indicated by SEN going active.

Accessing the registers inside the 82786 is done in exactly the same fashion, except that the 82786 is addressed in locations 8000H through 807EH. This causes the EPLD to drive the M/IO pin low during these cycles.

DESIGN NOTES

74F543's are used for the latching transceivers in this design, although 74HCT646's could be used to reduce the total power consumption. Some changes to the EPLD would be required in this case. The interface assumes that all memory accesses to the 82786 are word references; accordingly, BHE is grounded at the 82786. All addresses generated by the 8051 must be even byte addresses, the only byte operations allowed are the reads and writes to the latching transceivers. The design shown here incorporates hardware workarounds for the earlier "C-step" 82786; the current "D-step" part will work in the design as well. Additional information regarding the 82786 can be found in the "82786 Graphics Coprocessor User's Manual", Intel publication number 231933.

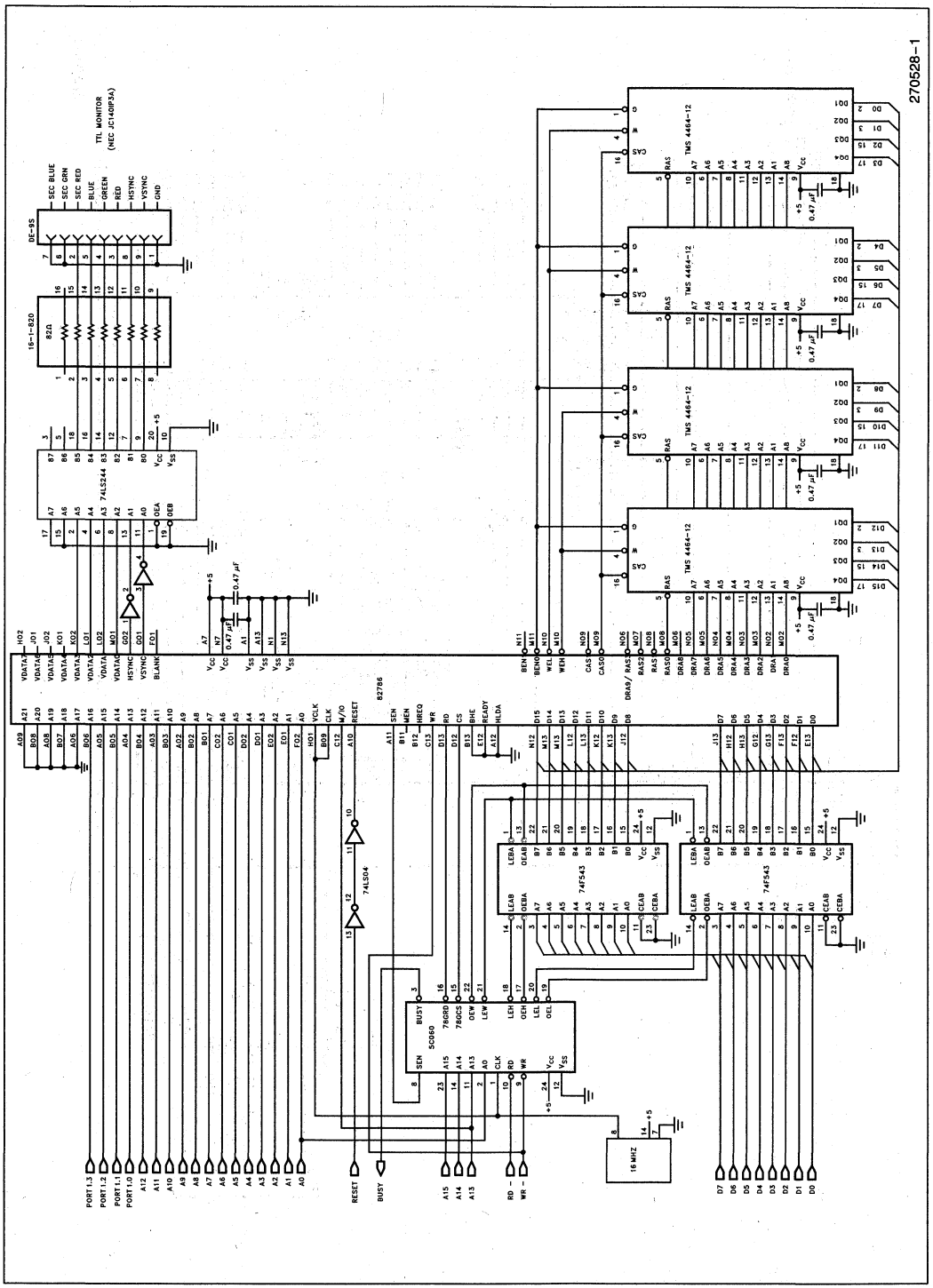

270528-1
TTL MONITOR
(NEC JC1402P3A)
SEC BLUE
SEC GRN
SEC RED
BLUE
GREEN
RED
HSYNC
VSYNC
GND
DE-9S
16-1-820
82S
74LS244
TMS 4464-12
0.47 µF
+5
82786
74LS04
74F543
5C060
16 MHZ
PORT 1.3
PORT 1.2
PORT 1.1
PORT 1.0
RESET
BUSY
RD –
WR –

Figure 1

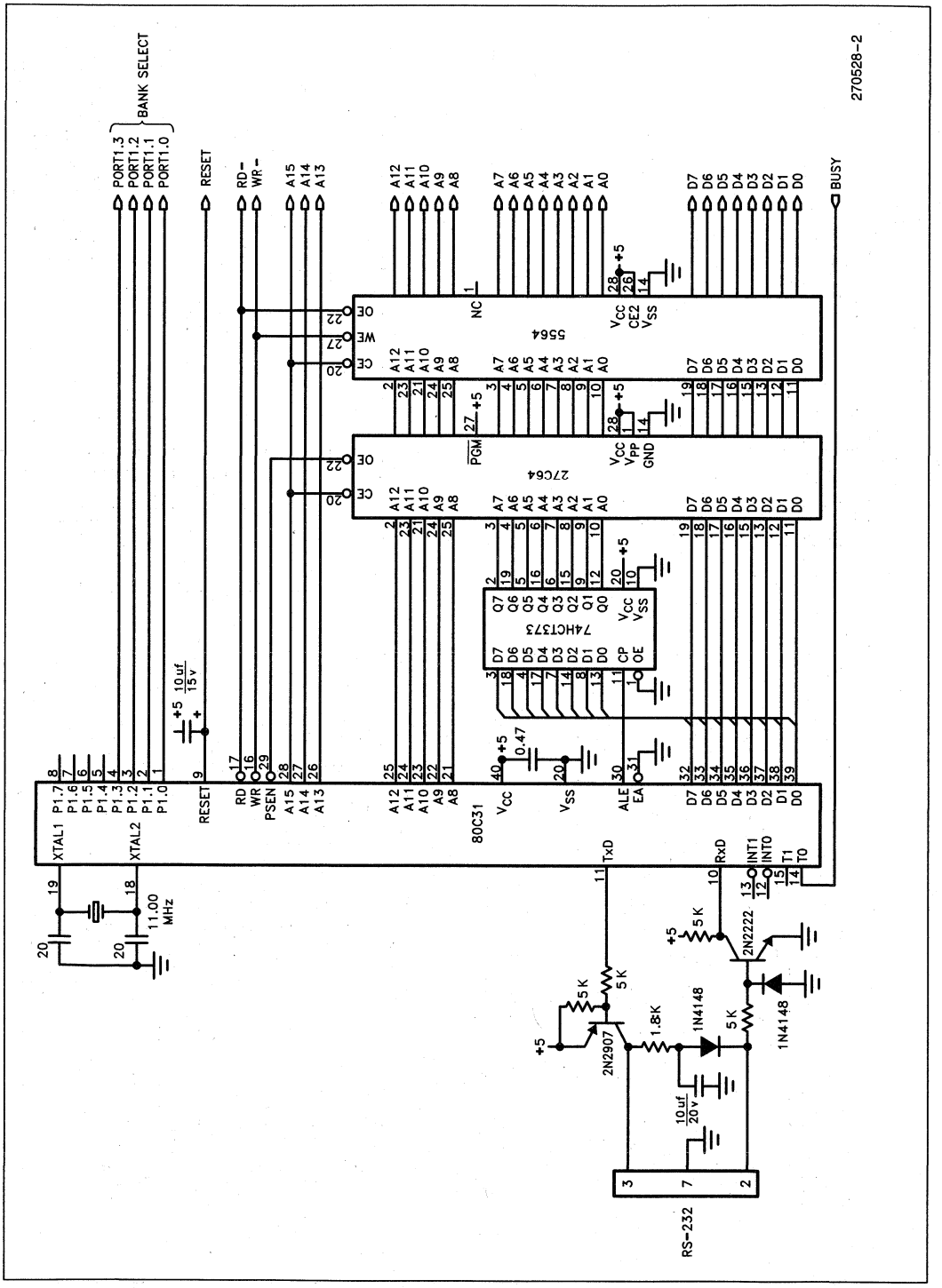

270528-2
BANK SELECT
PORT1.3
PORT1.2
PORT1.1
PORT1.0
RESET
RD-
WR-
A15
A14
A13
BUSY
5564
27C64
74HCT373
80C31
11.00 MHz
10 uf 15 v
0.47
5 K
1.8K
1N4148
2N2907
2N2222
10 uf 20 v
RS-232
XTAL1
XTAL2
TxD
RxD
INT1
INT0
T1
T0
ALE
EA
PSEN
PGM
NC
GND

Figure 2

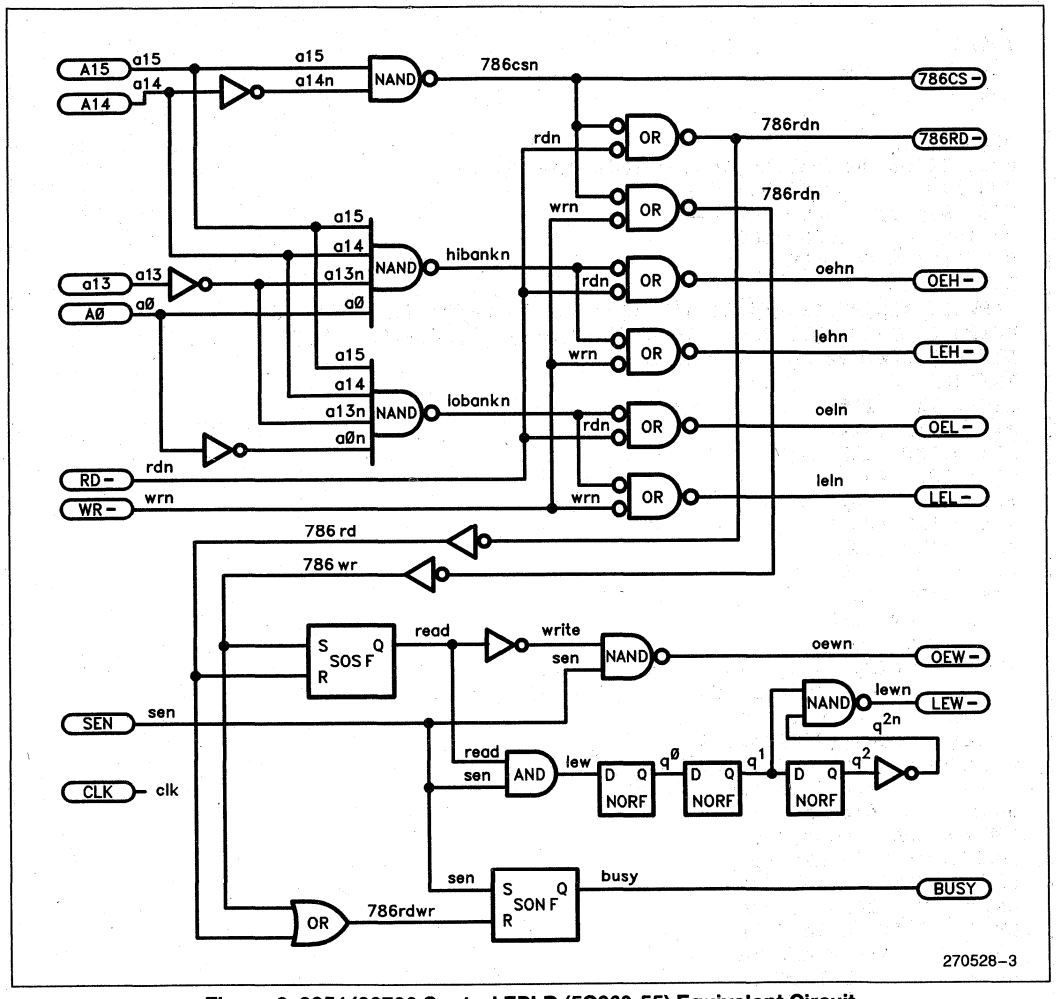


Figure 3. 8051/82786 Control EPLD (5C060-55) Equivalent Circuit

```
INTEL
August 11, 1987
1-003
0
5C060
8051/82786 Control Logic for 8051 Demo Board
786 I/O       8000H-807FH
786  Memory    A000H-BFFFH
Registers     C000H,C001H
OPTIONS: TURBO=ON
PART: 5C060
INPUTS: A15@23,A14@14,A13@11,A0@2,RD/@10,WR/@9,SEN@8,CKK
OUTPUTS: 786CS/@15,786RD/16,0EH/@17,LEH/@18,0EL/@19,LEL/@20,
LEW/@21,0EW/@22,READ@4,BUSY@3
NETWORK:
a15 = INP (A15)
a14 = INP (A14)
a13 = INP (A13)
a0 = INP (A0)
rdn = INP (RD/)
wrn = INP (WR/)
sen = INP (SEN)
clk = INP (CLK)
a14n = NOT (a14)
a13n = NOT (a13)
a0n = NOT (a0)
786csn = NAND (a15,a14n)
786CS/ = CONF (786csn,VCC)
786rdn = OR (786csn,rdn)
786RD/ = CONF (786rdn,VCC)
hibankn = NAND (a15,a14,a13n,a0)
lobankn = NAND (a15,a14,a13n,a0n)
oehn = OR (hibankn,rdn)
OEH/ = CONF (oehn,VCC)
lehn = OR (hibankn,wrn)
LEH/ = CONF (lehn,VCC)
oeln = OR (lobankn,rdn)
OEL/ = CONF (oeln,VCC)
leln = OR (lobankn,wrn)
LEL/ = CONF (leln,VCC)
oewn = NAND (sen,write)
OEW/ = CONF (oewn,VCC)
lew = AND (sen,read)
q0 = NORF (lew,clk,GND,GND)
q1 = NORF (q0,clk,GND,GND)
q2 = NORF (q1,clk,GND,GND)
q2n = NOT (q2)
lewn = NAND (q1,q2n)
LEW/ = CONF (lewn,VCC)
786wr = NOR (786csn,wrn)
786rd = NOT (786rdn)
READ,read = SOSF (786rd,clk,786wr,GND,GND,VCC)
write = NOT (read)
786rdwr = OR (786rd,786wr)
BUSY = SONF (786rdwr,clk,sen,GND,GND,VCC)
END$
```

Figure 4.

September 1990

Interfacing the Densitron LCD to the 8051

RICK SCHUE
REGIONAL APPLICATIONS SPECIALIST
INDIANAPOLIS, INDIANA

Order Number: 270529-003

INTERFACING THE DENSITRON LCD TO THE 8051

CONTENTS

INTRODUCTION

This application note details the interface between an 80C31 and a Densitron two row by 24 character LM23A2C24CBW display. This combination provides a very flexible display format (2x24) and a cost effective, low power consumption microcontroller suitable for many industrial control and monitoring functions.

Although this applications brief concentrates on the 80C31, the same software and hardware techniques are equally valid on other members of the 8051 family, including the 8031, 8751, and the 8044.

HARDWARE DESIGN

The LCD is mapped into external data memory, and looks to the 80C31 just like ordinary RAM. The register select (RS) and the read/write (R/W) pins are connected to the low order address lines A0 and A1. Connecting the R/W pin to an address line is a little unorthodox, but since the R/W line has the same set-up time requirements as the RS line, treating the R/W pin as an address kept this pin from causing any timing problems.

The enable (E) pin of the LCD is used to select the device, and is driven by the logical OR of the 80C31's RD and WR signals AND'ed with the MSB of the address bus. This maps the LCD into the upper half of the 64 KB external data space. If this seems a little wasteful, feel free to use a more elaborate address decoding scheme.

With the address decoding shown in the example, the LCD is mapped as follows:

Address	Function	Read/Write?
8000H	Write Command to LCD	Write Only
8001H	Write Data to LCD	Write Only
8002H	Read Status from LCD	Read Only
8003H	Read Data from LCD	Read Only
8004H to FFFFH	No Access	

Undefined results may occur if the software attempts to read address 8000H or 8001H, or write to address 8002H or 8003H.

TIMING REQUIREMENTS

The timing requirements of the Densitron LCD are a little slow for a full speed 80C31. The critical timing parameters are the enable pulse width (PW E) of 450 ns, and the data delay time during read cycles (tDDR) of 320 ns. The 80C31 is available at clock speeds up to 16 MHz, but at this speed these parameters are violated. Since the 80C31 lacks a READY pin, the only way to satisfy the LCD timing requirements is to slow the clock down to 10 MHz or lower. A convenient crystal frequency is 7.3728 MHz since it allows all standard baud rates to be generated with the internal timers.

SOFTWARE

The code consists of a main module and a set of utility procedures that talk directly to the LCD. This way the application code does not have to be concerned with where the LCD is mapped, or the exact bit patterns needed to control it. The mainline consists of a call to initialize the LCD, and then it writes a message to the screen, waits, and then erases it. It repeats this indefinitely.

The utility procedures include functions to initialize the display, send data and address to the LCD, home the cursor, clear the display, set the cursor to a given row and column, turn the cursor on and off, and print a string of characters to the display. Not all the functions are used in the software example.

REFERENCES

INTEL Embedded Controller Handbook, 210918

INTEL PL/M-51 User's Guide, 121966

DENSITRON Catalog LCDMD-C

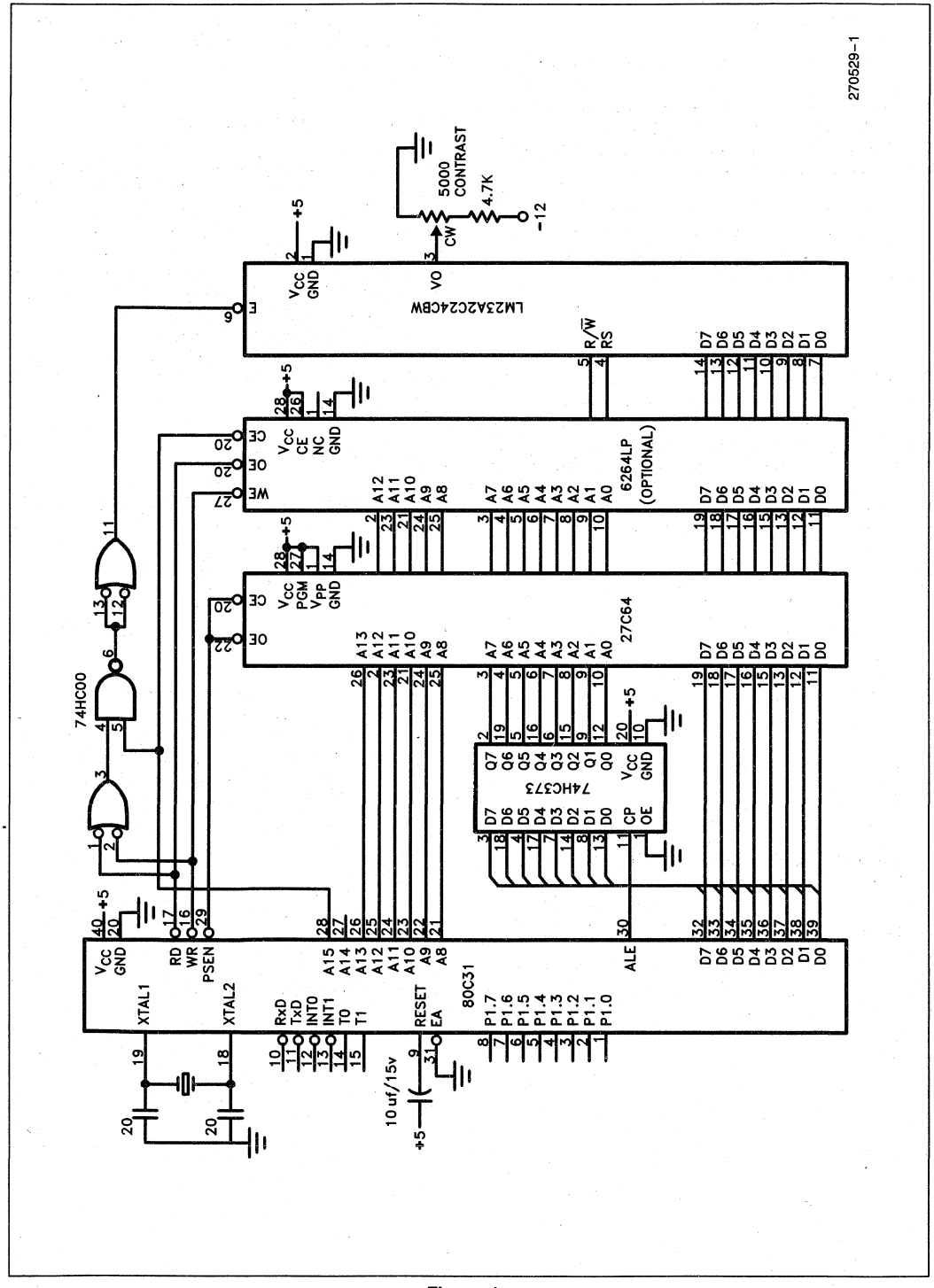

270529-1
5000 CONTRAST
4.7K
-12
CW
+5
LM23A2C24CBW
VCC GND
VO
R/W
RS
D7 D6 D5 D4 D3 D2 D1 D0
6264LP (OPTIONAL)
VCC CE NC GND
WE
OE
CE
A12 A11 A10 A9 A8
A7 A6 A5 A4 A3 A2 A1 A0
27C64
VCC PGM VPP GND
A13 A12 A11 A10 A9 A8
74HC00
74HC373
Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0
D7 D6 D5 D4 D3 D2 D1 D0
CP OE
80C31
XTAL1 XTAL2
RD WR PSEN
A15 A14 A13 A12 A11 A10 A9 A8
ALE
RxD TxD INT0 INT1 T0 T1
RESET EA
P1.7 P1.6 P1.5 P1.4 P1.3 P1.2 P1.1 P1.0
10 uf/15v

Figure 1.

```
Main_module:  DO;

Delay: PROCEDURE (count) EXTERNAL;
  DECLARE    count              WORD;
END Delay;

Initialize_LCD: PROCEDURE EXTERNAL;
END Initialize_LCD;

Clear display: PROCEDURE EXTERNAL;
END Clear_display;

LCD_print: PROCEDURE EXTERNAL;
END LCD_print;

DECLARE LCD_buffer                (48)   BYTE   PUBLIC,
        sign_on_message            (*)   BYTE   CONSTANT
                ('INTEL 8051 DRIVES LCD - '
                 '2 ROWS BY 24 CHARACTERS '),
        i                                BYTE;

/* This is the start of the program */

  /* Initialize the LCD */
  CALL Initialize_LCD;
  CALL Clear_display;

  /* Now enter an endless loop to display the message */
  DO WHILE 1;

    /* Copy the message to the buffer */
    DO i = 0 to 47;
      LCD_buffer(i) = sign_on_message(i);
    END;

    /* Now print out the buffer to the LCD */
    CALL LCD_print;

    /* wait a while */
    CALL Delay(2000);

    /* now clear the screen */
    CALL Clear_display;

END;         /* of DO WHILE */

END Main_module;
```

Main Module

```
LCD_IO_MODULE: DO;

DECLARE LCD_buffer  (48)    BYTE       EXTERNAL,
        LCD_command         BYTE       AT (08000H) AUXILIARY,
        LCD_data            BYTE       AT (08001H) AUXILIARY,
        LCD_status          BYTE       AT (08002H) AUXILIARY,
        LCD_busy            LITERALLY '1000$0000B',
        i                   BYTE;

Delay: PROCEDURE (msec) PUBLIC;

  /* This procedure causes a delay of n msec */

  DECLARE msec                WORD,
          i                    WORD;

  IF msec > 0 THEN DO;
    DO i = 0 to msec - 1;
      CALL Time(5);          /* .2 msec delay */
    END;

END Delay;


LCD_out: PROCEDURE (char) PUBLIC;

  DECLARE char BYTE;

  /* wait for LCD to indicate NOT busy */
  DO WHILE (LCD_status AND LCD_busy) <> 0;
  END;

  /* now send the data to the LCD */
  LCD_data = char;

END LCD out;
```

LCD Driver Module

```
LCD_command_out: PROCEDURE (char) PUBLIC;

  DECLARE char BYTE;

  /* wait for LCD to indicate NOT busy */
  DO WHILE (LCD_status AND LCD_busy) <> 0;
  END;

  /* now send the command to the LCD */
  LCD_command = char;

END LCD_command_out;


Home_cursor: PROCEDURE PUBLIC;

  CALL LCD_command_out(0000$0010B);

END Home_cursor;


Clear_display: PROCEDURE PUBLIC;

  CALL LCD_command_out (0000$0001B);

END Clear_display;


Set_cursor: PROCEDURE (position) PUBLIC;

  DECLARE   position            BYTE;

  IF position > 47 THEN position = 47;
  IF position < 24 THEN CALL LCD_command_out(080H + position);
  ELSE CALL LCD_command_out(0C0H + (position - 24));

END Set_cursor;


Cursor_on: PROCEDURE PUBLIC;

  CALL LCD_command_out(0000$1111B);

END Cursor_on;


Cursor_off: PROCEDURE PUBLIC;

  CALL LCD_command_out(0000$1100B);

END Cursor_off;
```

LCD Driver Module (Continued)

```
LCD_print: PROCEDURE PUBLIC;

  /* This procedure copies the contents of the LCD_buffer
     to the display */

  CALL Set_cursor(0) ;
  DO i = 0 to 23;
    CALL LCD_out(LCD_buffer(i));
  END;
  CALL Set_cursor(24);
  DO i = 24 to 47;
    CALL LCD_out(LCD_buffer(i));
  END;

END LCD_print;


Initialize_LCD: PROCEDURE PUBLIC;

  CALL Delay(100);
  CALL LCD_command_out(38H);   /* Function Set */
  CALL LCD_command_out(38H);
  CALL LCD_command_out(06H);   /* entry mode set */
  CALL Clear_display;
  CALL Home_cursor;
  CALL Cursor_off;
  CALL Set_cursor(0);

END Initialize_LCD;


END LCD_IO_Module;
```

LCD Driver Module (Continued)

September 1990

32-Bit Math Routines for the 8051

RICK SCHUE
REGIONAL APPLICATIONS SPECIALIST
INDIANAPOLIS, INDIANA

Order Number: 270530-002

32-BIT MATH ROUTINES FOR THE 8051

CONTENTS

Here are some easy to use 16- and 32-bit math routines that take the pain out of calculations such as PID loops, A/D calibration, linearization calculations and anything else that requires 32-bit accuracy.

The package is written to interface with PL/M-51. Parameters are passed as 16-bit words to the routines, which perform operations on a 32-bit "accumulator" resident in memory. The following functions are performed:

Load_16 (word_param)

Loads a 16-bit -RD into the low half of the 32-bit "accumulator", zeros upper 16 bits of accumulator.

Load_32 (word_hi,word_lo)

Loads word_hi into upper 16 bits of accumulator, word lo_into Lower 16 bits.

Low_16

Returns the lower 16 bits of the accumulator, bits 0 through 15.

Mid_16

Returns the middle 16 bits of the accumulator, bits 8 through 23.

High_16

Returns the upper 16 bits of the accumulator, bits 16 through 31.

Mul_16 (word_param)

Multiplies the 32-bit accumulator by the 16-bit word supplied, result left in accumulator.

Div_16 (word_param)

Divides the 32-bit accumulator by the 16-bit word supplied, result left in accumulator.

Add_16 (word_param)

Adds the 16-bit word supplied to the 32-bit accumulator.

Sub_16 (word_param)

Similar to Add_16 but for subtraction.

Add_32 (word_hi,word_lo)

Forms a 32-bit value for word_hi and word_lo and adds it to the accumulator.

Sub_32 (word_hi,word_lo)

Similar to Add_32 but for subtraction.

APPLICATION

Typical applications have 16-bit "input" values and produce 16-bit "output" values, but require 32-bit values for intermediate results. An example would be reading a 12-bit A/D, performing some gain and offset calculation on the raw A/D data to produce a calibrated 16 bit result. Doing this is a simple task with this math package.

```
CALL Load_16(AD_value);

CALL Add_16 (offset_value);

CALL Mul_16 (gain_factor);

/* gain is in units of 1/256 */

result = Mid_16;
```

In this example the accumulator was loaded with the raw A/D value and then the offset was applied. The gain_factor was "pre-multiplied" by 256 (8 bits), giving it a granularity of 1/256. The result was extracted from the "middle" 16 bits of the accumulator (bits 8 to 23) to account for the scaling factor of 256 introduced in the multiply step.

The package requires about 384 bytes of ROM and 30 bytes of RAM. Individual routines can be deleted to conserve RAM if they are not used.

CODE SOURCE LISTINGS

CODE SOURCE LISTINGS

```
NAME    Math_32_Module
;
PUBLIC    Load_16, ?Load_16?byte
PUBLIC    Load_32, ?Load_32?byte
PUBLIC    Mul_16, ?Mul_16?byte
PUBLIC    Div_16, ?Div_16?byte
PUBLIC    Add_16, ?Add_16?byte
PUBLIC    Sub_16, ?Sub_16?byte
PUBLIC    Add_32, ?Add_32?byte
PUBLIC    Sub_32, ?Sub_32?byte
PUBLIC    Low_16, Mid_16, High_16
;
Math_32_Data    SEGMENT    DATA
Math_32_Code    SEGMENT    CODE
;
RSEG    Math_32_Data
?Load_16?byte:  DS 2
?Load_32?byte:  DS 4
?Mul_16?byte:   DS 2
?Div_16?byte:   DS 2
?Add_16?byte:   DS 2
?Sub_16?byte:   DS 2
?Add_32?byte:   DS 4
?Sub_32?byte:   DS 4
OP_0:           DS 1
OP_1:           DS 1
OP_2:           DS 1
OP_3:           DS 1
TMP_0:          DS 1
TMP_1:          DS 1
TMP_2:          DS 1
TMP_3:          DS 1
;
RSEG    Math_32_Code
```

270530-1

```
Load_16:
    ;Load the lower 16 bits of the OP registers with the value supplied
    MOV     OP_3,#0
    MOV     OP_2,#0
    MOV     OP_1,?Load_16?byte
    MOV     OP_0,?Load_16?byte + 1
    RET

Load_32:
    ;Load all the OP registers with the value supplied
    MOV     OP_3,?Load_32?byte
    MOV     OP_2,?Load_32?byte + 1
    MOV     OP_1,?Load_32?byte + 2
    MOV     OP_0,?Load_32?byte + 3
    RET

Low_16:
    ;Return the lower 16 bits of the OP registers
    MOV     R6,OP_1
    MOV     R7,OP_0
    RET

Mid_16:
    ;Return the middle 16 bits of the OP registers
    MOV     R6,OP_2
    MOV     R7,OP_1
    RET

High_16:
    ;Return the high 16 bits of the OP registers
    MOV     R6,OP_3
    MOV     R7,OP_2
    RET

Add_16:
    ;Add the 16 bits supplied by the caller to the OP registers
    CLR     C
    MOV     A,OP_0
    ADDC    A,?Add_16?byte + 1      ;low byte first
    MOV     OP_0,A
    MOV     A,OP_1
    ADDC    A,?Add_16?byte          ;high byte + carry
    MOV     OP_1,A
    MOV     A,OP_2
    ADDC    A,#0                    ;propagate carry only
    MOV     OP_2,A
    MOV     A,OP_3
    ADDC    A,#0                    ;propagate carry only
    MOV     OP_3,A
    RET
```

270530-2

```
Add_32:
    ;Add the 32 bits supplied by the caller to the OP registers
    CLR     C
    MOV     A,OP_0
    ADDC    A,?Add_32?byte + 3      ;lowest byte first
    MOV     OP_0,A
    MOV     A,OP_1
    ADDC    A,?Add_32?byte + 2      ;mid-lowest byte + carry
    MOV     OP_1,A
    MOV     A,OP_2
    ADDC    A,?Add_32?byte + 1      ;mid-highest byte + carry
    MOV     OP_2,A
    MOV     A,OP_3
    ADDC    A,?Add_32?byte          ;highest byte + carry
    MOV     OP_3,A
    RET

Sub_16:
    ;Subtract the 16 bits supplied by the caller from the OP registers
    CLR     C
    MOV     A,OP_0
    SUBB    A,?Sub_16?byte + 1      ;low byte first
    MOV     OP_0,A
    MOV     A,OP_1
    SUBB    A,?Sub_16?byte          ;high byte + carry
    MOV     OP_1,A
    MOV     A,OP_2
    SUBB    A,#0                    ;propagate carry only
    MOV     OP_2,A
    MOV     A,OP_3
    SUBB    A,#0                    ;propagate carry only
    MOV     OP_3,A
    RET


Sub_32:
    ;Subtract the 32 bits supplied by the caller from the OP registers
    CLR     C
    MOV     A,OP_0
    SUBB    A,?Sub_32?byte + 3      ;lowest byte first
    MOV     OP_0,A
    MOV     A,OP_1
    SUBB    A,?Sub_32?byte + 2      ;mid-lowest byte + carry
    MOV     OP_1,A
    MOV     A,OP_2
    SUBB    A,?Sub_32?byte + 1      ;mid-highest byte + carry
    MOV     OP_2,A
    MOV     A,OP_3
    SUBB    A,?Sub_32?byte          ;highest byte + carry
    MOV     OP_3,A
    RET
```

270530-3

```
Mul_16:
    ;Multiply the 32 bit OP with the 16 value supplied
    MOV    TMP_3,#0        ;clear out upper 16 bits
    MOV    TMP_2,#0
    ;Generate the lowest byte of the result
    MOV    B,OP_0
    MOV    A,?Mul_16?byte+1
    MUL    AB
    MOV    TMP_0,A         ;low-order result
    MOV    TMP_1,B         ;high_order result
    ;Now generate the next higher order byte
    MOV    B,OP_1
    MOV    A,?Mul_16?byte+1
    MUL    AB
    ADD    A,TMP_1         ;low-order result
    MOV    TMP_1,A         ; save
    MOV    A,B             ; get high-order result
    ADDC   A,TMP_2         ; include carry from previous operation
    MOV    TMP_2,A         ; save
    JNC    Mul_loop1
    INC    TMP_3           ; propagate carry into TMP_3
Mul_loop1:
    MOV    B,OP_0
    MOV    A,?Mul_16?byte
    MUL    AB
    ADD    A,TMP_1         ;low-order result
    MOV    TMP_1,A         ; save
    MOV    A,B             ; get high-order result
    ADDC   A,TMP_2         ; include carry from previous operation
    MOV    TMP_2,A         ; save
    JNC    Mul_loop2
    INC    TMP_3           ; propagate carry into TMP_3
Mul_loop2:
    ; Now start working on the 3rd byte
    MOV    B,OP_2
    MOV    A,?Mul_16?byte+1
    MUL    AB
    ADD    A,TMP_2         ;low-order result
    MOV    TMP_2,A         ; save
    MOV    A,B             ; get high-order result
    ADDC   A,TMP_3         ; include carry from previous operation
    MOV    TMP_3,A         ; save
    ; Now the other half
    MOV    B,OP_1
    MOV    A,?Mul_16?byte
    MUL    AB
    ADD    A,TMP_2         ;low-order result
    MOV    TMP_2,A         ; save
    MOV    A,B             ; get high-order result
    ADDC   A,TMP_3         ; include carry from previous operation
    MOV    TMP_3,A         ; save
    ; Now finish off the highest order byte
    MOV    B,OP_3
    MOV    A,?Mul_16?byte+1
```

270530-4

```
MUL     AB
ADD     A,TMP_3         ;low-order result
MOV     TMP_3,A         ; save
; Forget about the high-order result, this is only 32 bit math!
MOV     B,OP_2
MOV     A,?Mul_16?byte
MUL     AB
ADD     A,TMP_3         ;low-order result
MOV     TMP_3,A         ; save
; Now we are all done, move the TMP values back into OP
MOV     OP_0,TMP_0
MOV     OP_1,TMP_1
MOV     OP_2,TMP_2
MOV     OP_3,TMP_3
RET
```

270530-5

```
Div_16:
    ;This divides the 32 bit OP register by the value supplied
    MOV    R7,#0
    MOV    R6,#0              ;zero out partial remainder
    MOV    TMP_0,#0
    MOV    TMP_1,#0
    MOV    TMP_2,#0
    MOV    TMP_3,#0
    MOV    R1,?Div_16?byte    ;load divisor
    MOV    R0,?Div_16?byte+1
    MOV    R5,#32             ;loop count
    ;This begins the loop
Div_loop:
    CALL   Shift_D        ;shift the dividend and return MSB in C
    MOV    A,R6           ;shift carry into LSB of partial remainder
    RLC    A
    MOV    R6,A
    MOV    A,R7
    RLC    A
    MOV    R7,A
    ;now test to see if R7:R6 >= R1:R0
    JC     Can_sub         ;Carry out of R7 shift means R7:R6 > R1:R0
    CLR    C
    MOV    A,R7            ;subtract R1 from R7 to see if R1 < R7
    SUBB   A,R1            ; A = R7 - R1, carry set if R7 < R1
    JC     Cant_sub
    ;at this point R7>R1 or R7=R1
    JNZ    Can_sub         ;jump if R7>R1
    ;if R7 = R1, test for R6>=R0
    CLR    C
    MOV    A,R6
    SUBB   A,R0            ; A = R6 - R0, carry set if R6 < R0
    JC     Cant_sub
Can_sub:
    ;subtract the divisor from the partial remainder
    CLR    C
    MOV    A,R6
    SUBB   A,R0         ; A = R6 - R0
    MOV    R6,A
    MOV    A,R7
    SUBB   A,R1         ; A = R7 - R1 - Borrow
    MOV    R7,A
    SETB   C            ; shift a 1 into the quotient
    JMP    Quot
Cant_sub:
    ;shift a 0 into the quotient
    CLR    C
Quot:
    ;shift the carry bit into the quotient
    CALL   Shift_Q
    ; Test for competion
    DJNZ   R5,Div_loop
    ; Now we are all done, move the TMP values back into OP
    MOV    OP_0,TMP_0
    MOV    OP_1,TMP_1
```

270530-6

```
    MOV     OP_2,TMP_2
    MOV     OP_3,TMP_3
    RET

Shift_D:
    ;shift the dividend one bit to the left and return the MSB in C
    CLR     C
    MOV     A,OP_0
    RLC     A
    MOV     OP_0,A
    MOV     A,OP_1
    RLC     A
    MOV     OP_1,A
    MOV     A,OP_2
    RLC     A
    MOV     OP_2,A
    MOV     A,OP_3
    RLC     A
    MOV     OP_3,A
    RET

Shift_Q:
    ;shift the quotent one bit to the left and shift the C into LSB
    MOV     A,TMP_0
    RLC     A
    MOV     TMP_0,A
    MOV     A,TMP_1
    RLC     A
    MOV     TMP_1,A
    MOV     A,TMP_2
    RLC     A
    MOV     TMP_2,A
    MOV     A,TMP_3
    RLC     A
    MOV     TMP_3,A
    RET

    END
```

270530-7

October 1989

Designing a Mailbox Memory for Two 80C31 Microcontrollers Using EPLDs

K. WEIGL & J. STAHL
INTEL CORPORATION
MUNICH, GERMANY

Order Number: 292016-004

DESIGNING A MAILBOX MEMORY FOR TWO 80C31 MICROCONTROLLERS USING EPLDs

CONTENTS

INTRODUCTION

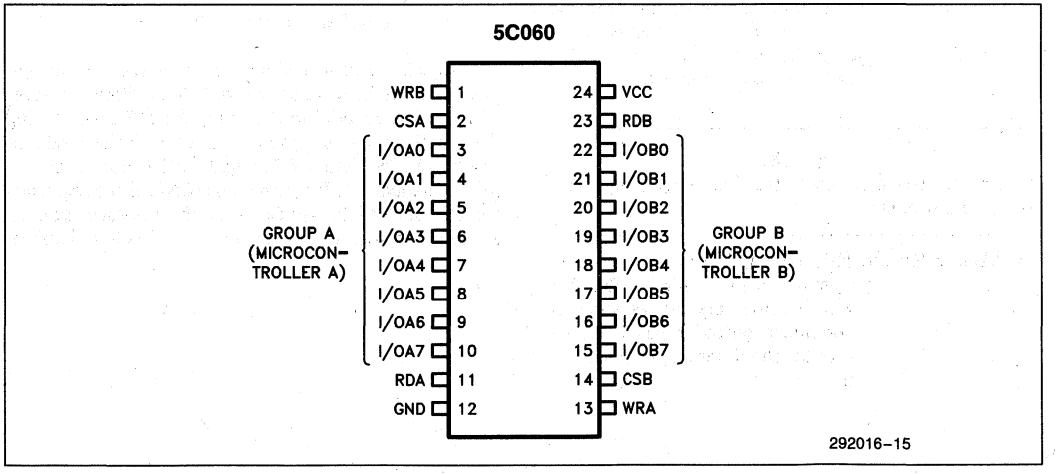
Very often, complex systems involve two or more microcontrollers to fulfill the requirements defined by a given objective. Since the nature of microcontrollers does not allow for easy dual-port memory design (no "READY" input; no "HOLD/HLDA" interface; port-oriented I/O etc.), design engineers are faced with the problem of interchanging information (data and status) between those microcontrollers. This application brief describes the design of a mailbox for exchanging information between two 80C31s, using a 5C060 EPLD as a "back-to-back" register, and a 5C032 EPLD as an arbitration vehicle to control the actions of the CPUs.

THE 5C060 MAILBOX

In this application, the 16 macrocells of the 5C060 are grouped into two sets of 8 so called "ROIF" (register output with input feedback) primitives to implement the two 8 bit bus interfaces needed. The grouping is done according to the following picture.

The 5C060 allows for independent clocking of 8 macrocells on each side of the chip, the two clock inputs are used to clock data from the microcontroller bus into the chip. To read the data written into the mailbox by one of the controllers, the RDA- (controller A is reading) or RDB- (controller B is reading) line must be pulled low by activating the read command (/RD). In order to avoid spurious read-cycles, the /RD commands from both microcontrollers are logically "ORed" together with an active high CS-signal (Chip Select) inside the 5C060. The CS-signal for both ports is derived from address line A15. Therefore, whenever A15 becomes a logic "1" (true), the mailbox is activated and ready to take or submit data.

Address range for the mailbox: F000 Hex to FFFF Hex
(Upper 12 kbyte)



THE 5C032 "MAILBOX CONTROLLER"

To keep the two microcontrollers informed about the status of their mailbox, the 5C032 is programmed to supply the following signals to both controllers:

```
/OBFA: "OUTPUT BUFFER FULL" FOR MC A

/OBFB: "OUTPUT BUFFER FULL" FOR MC B

/IBEA: "INPUT BUFFER EMPTY" FOR MC A

/IBEB: "INPUT BUFFER EMPTY" FOR MC B

/INTA: INTERRUPT TO MC A

/INTB: INTERRUPT TO MC B
```

The next section will discuss the meanings of these signals in more detail.

Output Buffer Full: This flag is set whenever the controller writes into its own output buffer. The flag remains valid, until the second controller has read the data. The flag is automatically reset to its inactive state when this read cycle is accomplished.

NOTE:
Both controllers can access (read or write) the mailbox simultaneously.

Input Buffer Empty: This flag indicates that there is no message in the mailbox. The flag will become inactive as soon as one microcontroller places a message for the other one (or vice versa).

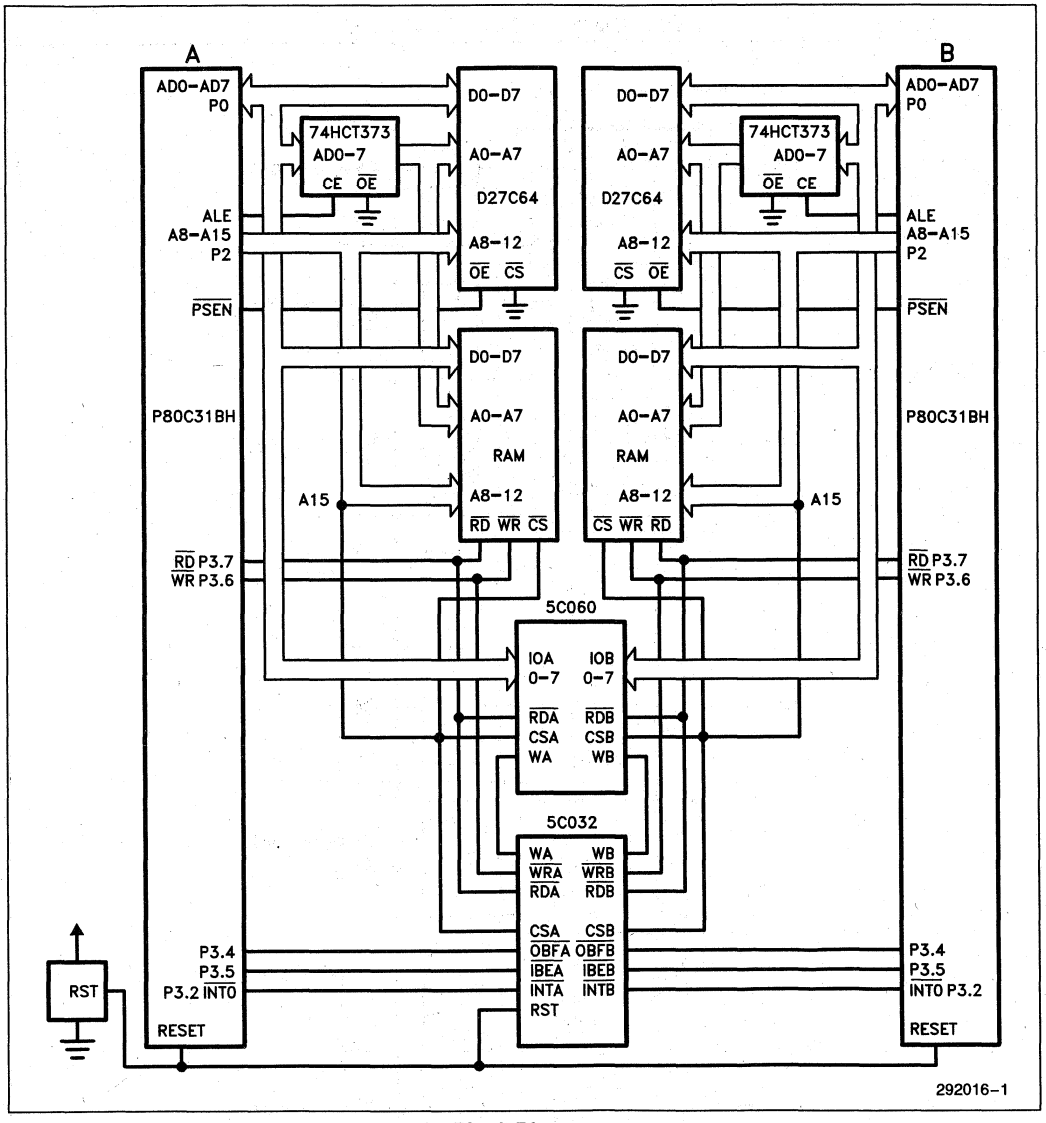
Example: /IBEA remains "LOW" until microcontroller B places a message for controller A into the mailbox for A. /IBEA will go "HIGH" as soon as controller B has accomplished its write cycle, and will not go "LOW" again until microcontroller A has read the message.

Interrupt: The 5C032 is programmed to supply interrupts to both microcontrollers involved, on one of the following events.

1. The /OBF flag of the opposite microcontroller becomes active; e.g. if controller A is placing a message for controller B, controller B receives an interrupt the same time as /OBFA becomes valid or vice versa.

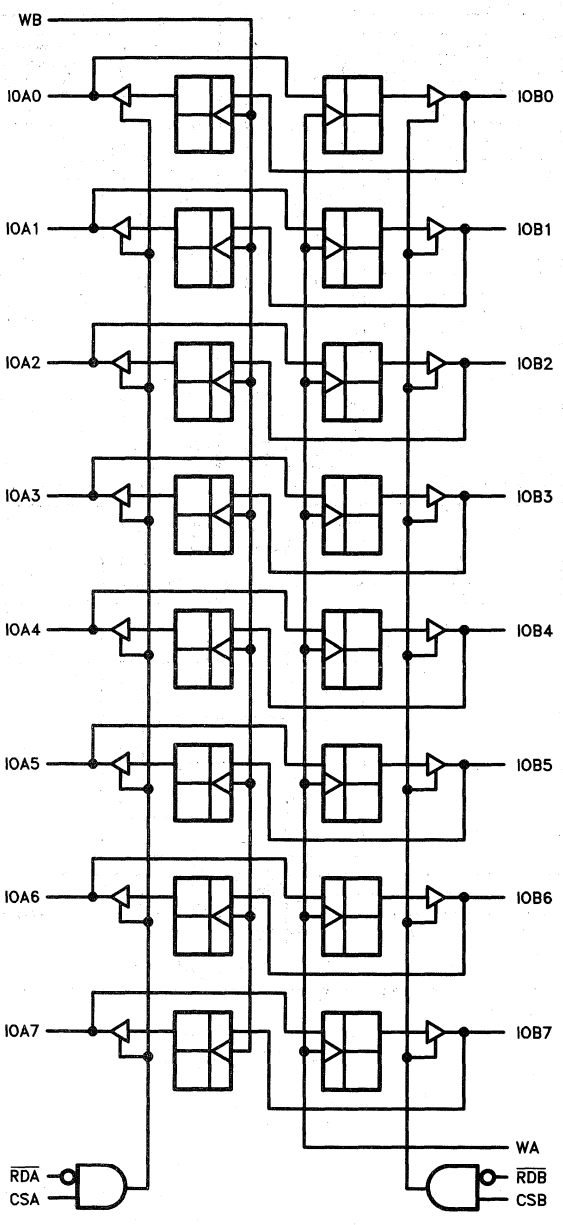
2. The /IBE flag of the opposite microcontroller goes active, indicating that this controller has received the message; e.g. if controller B reads the message stored by controller A, its /IBEB flag goes active and controller receives an interrupt indicating that the buffer is empty.

The signals described above are necessary to accomplish a secure handshake without overwriting messages accidentally. In addition to that, the 5C032 is issuing the actual write commands for the two register sets inside the 5C060. The /WRA and /WRB signals are results of logical "AND" functions between the appropriate CS- and /WR signals from the microcontrollers. Therefore, spurious write cycles are unlikely to happen.



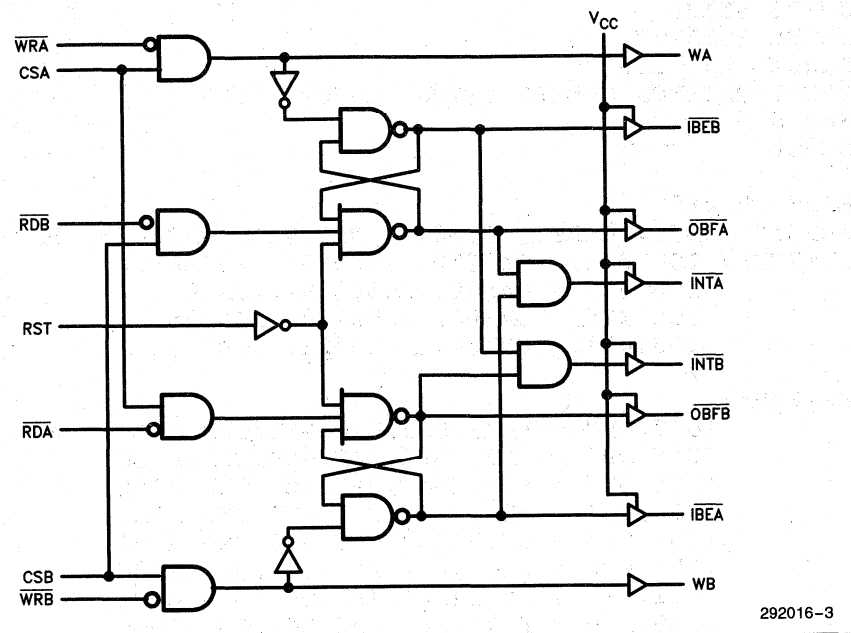
Block Diagram

5C060 "BACK TO BACK REGISTER"



292016-2

5C032 "MAILBOX CONTROLLER"



5C060 REGISTER ADF

```
JUERG STAHL
INTEL ZUERICH
August 28, 1989
80C31 MAILBOX MEMORY USING 5C060 / 5C032
REV 5
5C060

PART: 5C060
INPUTS: WB@1, CSA@2, CSB@14, nRDA@11, nRDB@23, WA@13
OUTPUTS: IOB7@15, IOA7@10, IOB6@16, IOA6@9,
         IOB5@17, IOA5@8, IOB4@18, IOA4@7,
         IOB3@19, IOA3@6, IOB2@20, IOA2@5,
         IOB1@21, IOA1@4, IOB0@22, IOA0@3

NETWORK:
        IOB7,DB7 = ROIF(DA7,WAC,GND,GND,RDBC)
        IOB6,DB6 = ROIF(DA6,WAC,GND,GND,RDBC)
        IOB5,DB5 = ROIF(DA5,WAC,GND,GND,RDBC)
        IOB4,DB4 = ROIF(DA4,WAC,GND,GND,RDBC)
        IOB3,DB3 = ROIF(DA3,WAC,GND,GND,RDBC)
        IOB2,DB2 = ROIF(DA2,WAC,GND,GND,RDBC)
        IOB1,DB1 = ROIF(DA1,WAC,GND,GND,RDBC)
        IOB0,DB0 = ROIF(DA0,WAC,GND,GND,RDBC)
        IOA7,DA7 = ROIF(DB7,WBC,GND,GND,RDAC)
        IOA6,DA6 = ROIF(DB6,WBC,GND,GND,RDAC)
        IOA5,DA5 = ROIF(DB5,WBC,GND,GND,RDAC)
        IOA4,DA4 = ROIF(DB4,WBC,GND,GND,RDAC)
        IOA3,DA3 = ROIF(DB3,WBC,GND,GND,RDAC)
        IOA2,DA2 = ROIF(DB2,WBC,GND,GND,RDAC)
        IOA1,DA1 = ROIF(DB1,WBC,GND,GND,RDAC)
        IOA0,DA0 = ROIF(DB0,WBC,GND,GND,RDAC)
        WAC = INP(WA)
        WBC = INP(WB)
        CSB = INP(CSB)
        CSA = INP(CSA)
        nRDB = INP(nRDB)
        nRDA = INP(nRDA)


EQUATIONS:

        RDBC = CSB * !nRDB;

        RDAC = CSA * !nRDA;



END$
```

292016-4

5C032 ARBITER ADF

```
JUERG STAHL
INTEL ZUERICH
August 28, 1989
80C31 MAILBOX MEMORY USING 5C060 / 5C032
REV 5
5C032

PART: 5C032
INPUTS: RST, nWRA, nRDB, CSA, nRDA, nWRB, CSB
OUTPUTS: WA, nOBFA, nIBEB, nINTA, nINTB, nOBFB, nIBEA, WB

NETWORK:
     nWRA = INP(nWRA)
     nRDA = INP(nRDA)
     CSA = INP(CSA)
     nWRB = INP(nWRB)
     nRDB = INP(nRDB)
     CSB = INP(CSB)
     RST = INP(RST)
     WA = CONF(WAd,VCC)
     WB = CONF(WBd,VCC)
     nOBFA,nOBFA = COIF(nOBFAd,VCC)
     nOBFB,nOBFB = COIF(nOBFBd,VCC)
     nIBEA,nIBEA = COIF(nIBEAd,VCC)
     nIBEB,nIBEB = COIF(nIBEBd,VCC)
     nINTA = CONF(nINTAd,VCC)
     nINTB = CONF(nINTBd,VCC)


EQUATIONS:

        nINTBd = nOBFB * nIBEB;
        nINTAd = nOBFA * nIBEA;
        nOBFBd = !(!(!nRDA * CSA) * nIBEA * !RST);
        nOBFAd = !(!(!nRDB * CSB) * nIBEB * !RST);
        nIBEBd = !(!(CSA * !nWRA) * nOBFA);
        nIBEAd = !(!(CSB * !nWRB) * nOBFB);
        WAd = CSA * !nWRA;
        WBd = CSB * !nWRB;


END$
```

292016-9

intel®

APPLICATION NOTE

AP-252

March 1985

Designing With The 80C51BH

TOM WILLIAMSON
MCO APPLICATIONS ENGINEER

Order Number: 270068-002

DESIGNING WITH THE 80C51BH

CONTENTS

2

CMOS EVOLVES

The original CMOS logic families were the 4000-series and the 74C-series circuits. The 74C-series circuits are functional equivalents to the corresponding numbered 74-series TTL circuits, but have CMOS logic levels and retain the other well known characteristics of CMOS logic.

These characteristics are: low power consumption, high noise immunity, and slow speed. The low power consumption is inherent to the nature of the CMOS circuit. The noise immunity is due partly to the CMOS logic levels, and partly to the slowness of the circuits. The slow speed is due to the technology used to construct the transistors in the circuit.

The technology used is called metal-gate CMOS, because the transistor gates are formed by metal deposition. More importantly, the gates are formed after the drain and source regions have been defined, and must overlap the source and drain somewhat to allow for alignment tolerances. This overlap plus the relatively large size of the transistors themselves result in high electrode capacitance, and that is what limits the speed of the circuit.

High speed CMOS became feasible with the development of the self-aligning silicon gate technology. In this process polysilicon gates are deposited **before** the source and drain regions are defined. Then the source and drain regions are formed by ion implantation using the gate itself as a mask for the implantation. This eliminates most of the overlap capacitance. In addition, the process allows smaller transistors. The result is a significant increase in circuit speed. The 74HC-series of CMOS logic circuits is based on this technology, and has speeds comparable to LS TTL, which is to say about 10 times faster than the 74C-series circuits.

The size reduction that contributes to the higher speed also demands an accompanying reduction in the maximum supply voltage. High-speed CMOS is generally limited to 6V.

WHAT IS CHMOS?

CHMOS is the name given to Intel's high-speed CMOS processes. There are two CHMOS processes, one based on an n-well structure and one based on a p-well structure. In the n-well structure, n-type wells are diffused into a p-type substrate. Then the n-channel transistors (nFETs) are built into the substrate and pFETs are built into the n-wells. In the p-well structure, p-type wells are diffused into an n-type substrate. Then the nFETs are built into the wells and pFETs, into the substrate. Both processes have their advantages and disadvantages, which are largely transparent to the user.

Lower operating voltages are easier to obtain with the p-well structure than with the n-well structure. But the p-well structure does not easily adapt to an EPROM which would be pin-for-pin compatible with HMOS EPROMs. On the other hand the n-well structure can be based on the solidly founded HMOS process, in which nFETs are built into a p-type substrate. This allows somewhat more than half of the transistors in a CHMOS chip to be constructed by processes that are already well characterized.

Currently Intel's CHMOS microcontrollers and memory products are n-well devices, whereas CHMOS microprocessors are p-well devices.

Further discussion of the CHMOS technology is provided in References 1 and 2 (which are reprinted in the Microcontroller Handbook).

THE MCS®-51 FAMILY IN CHMOS

The 80C51BH is the CHMOS version of Intel's original 8051. The 80C31BH is the ROMless 80C51BH, equivalent to the 8031. These CHMOS devices are architecturally identical with their HMOS counterparts, except that they have two added features for reduced power. These are the Idle and Power Down modes of operation.

In most cases, an 80C51BH can directly replace the 8051 in existing applications. It can execute the same code at the same speed, accept signals from the same sources, and drive the same loads. However, the 80C51BH covers a wider range of speeds, will emit CMOS logic levels to CMOS loads, and will draw about 1/10 the current of an 8051 (and less yet in the reduced power modes). Interchangeability between the HMOS and CHMOS devices is discussed in more detail in the final section of this Application Note.

It should be noted that the 80C51BH CPU is not static. That means if the clock frequency is too low, the CPU might forget what it was doing. This is because the circuitry uses a number of dynamic nodes. A dynamic node is one that uses the note-to-ground capacitance to form a temporary storage cell. Dynamic nodes are used to reduce the transistor count, and hence the chip area, thus to produce a more economical device.

This is not to say that the on-chip RAM in CHMOS microcontrollers is dynamic. It's not. It's the CPU that is dynamic, and that is what imposes the minimum clock frequency specification.

LATCHUP

Latchup is an SCR-type turn-on phenomenon that is the traditional nemesis of CMOS systems. The substrate, the wells, and the transistors form parasitic pnpn structures within the device. These parasitic structures turn on like an SCR if a sufficient amount of forward current is driven through one of the junctions. From the circuit designer's point of view it can happen whenever an input or output pin is externally driven a diode drop above V_{CC} or below V_{SS}, by a source that is capable of supplying the required trigger current.

However much of a problem latchup has been in the past, it is good to know that in most recently developed CMOS devices, and specifically in CHMOS devices, the current required to trigger latchup is typically well over 100 mA. The 80C51BH is virtually immune to latchup. (References 1 and 2 present a discussion of the latchup mechanisms and the steps that are taken on the chip to guard against it.) Modern CMOS is not absolutely immune to latchup, but with trigger currents in the hundreds of mA, latchup is certainly a lot easier to avoid than it once was.

A careless power-up sequence might trigger a latchup in the older CMOS families, but it's unlikely to be a major problem in high-speed CMOS or in CHMOS. There is still some risk incurred in inserting or removing chips or boards in a CMOS system while the power is on. Also, severe transients, such as inductive kicks or momentary short-circuits, can exceed the trigger current for latchup.

For applications in which some latchup risk seems unavoidable, you can put a small resistor (100Ω or so) in series with signal lines to ensure that the trigger current will never be reached. This also helps to control overshoot and RFI.

LOGIC LEVELS AND INTERFACING PROBLEMS

CMOS logic levels differ from TTL levels in two ways. First, for equal supply voltages, CMOS gives (and requires) a higher "logic 1" level than TTL. Secondly, CMOS logic levels are V_{CC} (or VDD) dependent, whereas guaranteed TTL logic levels are fixed when V_{CC} is within TTL specs.

Standard 74HC logic levels are as follows:

$V_{IH}MIN = 70\%$ of V_{CC}
$V_{IL}MAX = 20\%$ of V_{CC}
$V_{OH}MIN = V_{CC} - 0.1V$, $|I_{OH}| \leq 20\ \mu A$
$V_{OL}MAX = 0.1V$, $|I_{OL}| \leq 20\ \mu A$

Figure 1 compares 74HC, LS TTL, and 74HCT logic levels with those of the HMOS 8051 and the CHMOS 80C51BH for $V_{CC} = 5V$.

Output logic levels depend of course on load current, and are normally specified at several load currents. When CMOS and TTL are powered by the same V_{CC}, the logic levels guaranteed on the data sheets indicate that CMOS can drive TTL, but TTL can't drive CMOS. The incompatibility is that the TTL circuit's V_{OH} level is too low to reliably be recognized by the CMOS circuit as a valid V_{IH}.

Since HMOS circuits were designed to be TTL-compatible, they have the same incompatibility.

Fortunately, 74HCT-series circuits are available to ease these interfacing problems. They have TTL-compatible logic levels at the inputs and standard CMOS levels at the outputs.

The 80C51BH is designed to work with either TTL or CMOS. Therefore its logic levels are specified very much like 74HCT circuits. That is, its input logic levels are TTL-compatible, and its output characteristics are like standard high-speed CMOS.

NOISE CONSIDERATIONS

One of the major reasons for going to CMOS has traditionally been that CMOS is less susceptible to noise. As previously noted, its low susceptibility to noise is

Logic State	$V_{CC} = 5V$				
	74HC	74HCT	LS TTL	8051	80C51BH
V_{IH}	3.5V	2.0V	2.0V	2.0V	1.9V
V_{IL}	1.0V	0.8V	0.8V	0.8V	0.9V
V_{OH}	4.9V	4.9V	2.7V	2.4V	4.5V
V_{OL}	0.1V	0.1V	0.5V	0.45V	0.45V

Figure 1. Logic Level Comparison. (Output voltage levels depend on load current. Data sheets list guaranteed output levels for several load currents. The output levels listed here are for minimum loading.)

partly due to superior noise margins, and partly due to its slow speed.

Noise margin is the difference between V_{OL} and V_{IL}, or between V_{OH} and V_{IH}. If V_{OH} from a driving circuit is 2.7V and V_{IH} to the driven circuit is 2.0V, then the driven circuit has 0.7V of noise margin at the logic high level. These kinds of comparisons show that an all-CMOS system has wider noise margins than an all-TTL system.

Figure 2 shows noise margins in CMOS and LS TTL systems when both have V_{CC} = 5V. It can be seen that CMOS/CMOS and CMOS/CHMOS systems have an edge over LS TTL in this respect.

Noise margins can be misleading, however, because they don't say how much noise energy it takes to induce in the circuit a noise voltage of sufficient amplitude to cause a logic error. This would involve consideration of the width of the noise pulse as compared with the circuit's response speed, and the impedance to ground from the point of noise introduction in the circuit.

When these considerations are included, it is seen that using the slower 74C- and 4000-series circuits with a 12 or 15V supply voltage does offer a truly improved level of noise immunity, but that high-speed CMOS at 5V is not significantly better than TTL.

One should not mistake the wider supply voltage tolerance of high-speed CMOS for V_{CC} glitch immunity. Supply voltage tolerance is a DC rating, not a glitch rating.

For any clocked CMOS, and most especially for VLSI CMOS, V_{CC} decoupling is critical. CHMOS draws current in extremely sharp spikes at the clock edges. The VHF and UHF components of these spikes are not drawn from the power supply, but from the decoupling capacitor. If the decoupling circuit is not sufficiently low in inductance, V_{CC} will glitch at each clock edge. We suggest that a 0.1 μF decoupler cap be used in a minimum-inductance configuration with the microcontroller. A minimum-inductance configuration is one that minimizes the area of the loop formed by the chip (V_{CC} to V_{SS}), the traces to the decoupler cap, and the decoupler cap. PCB designers too often fail to understand that if the traces that connect the decoupler cap to the V_{CC} and V_{SS} pins aren't short and direct, the decoupler loses much of its effectiveness.

Interface	Noise Margin for V_{CC} = 5V	
	Logic Low $V_{IL}-V_{OL}$	Logic High $V_{OH}-V_{IH}$
74HC to 74HC	0.9V	1.4V
LSTTL to LSTTL	0.3V	0.7V
LSTTL to 74HCT	0.3V	0.7V
LSTTL to 80C51BH	0.3V	0.7V
74HC to 80C51BH	0.8V	3.0V
80C51BH to 74HC	0.8V	1.0V

Figure 2. Noise Margins for CMOS and LS TTL Circuits

Overshoot and ringing in signal lines are potential sources of logic upsets. These can largely be controlled by circuit layout. Inserting small resistors (about 100Ω) in series with signal lines that seem to need them will also help.

The sharp edges produced by high-speed CMOS can cause RFI problems. The severity of these problems is largely a function of the PCB layout. We don't mean to imply that all RFI problems can be solved by a better PCB layout. It may well be, for example, that in some RFI-sensitive designs high-speed CMOS is simply not the answer. But circuit layout is a critical factor in the noise performance of any electronic system, and more so in high-speed CMOS systems than others.

Circuit layout techniques for minimizing noise susceptibility and generation are discussed in References 3 through 6.

UNUSED PINS

CMOS input pins should not be left to float, but should always be pulled to one logic level or the other. If they float, they tend to float into the transition region between 0 and 1, where the pullup and pulldown devices in the input buffer are both conductive. This causes a significant increase in I_{CC}. A similar effect exists in HMOS circuits, but with less noticeable results.

In 80C51BH and 80C31BH designs, unused pins of Ports 1, 2, and 3 can be ignored, because they have internal pullups that will hold them at a valid Logic 1 level. Port 0 pins are different, however, in not having internal pullups (except during bus operations).

When the 80C51BH is in reset, the Port 0 pins are in a float state unless they are externally pulled up or down. If it's going to be held in reset for just a short time, the transient float state can probably be ignored. When it comes out of reset, the pins stay afloat unless

they are externally pulled either up or down. Alternatively, the software can internally write 0s to whatever Port 0 pins may be unused.

The same considerations are applicable to the 80C31BH with regards to reset. But when the 80C31BH comes out of reset, it commences bus operations, during which the logic levels at the pins are always well defined as high or low.

Consider the 80C31BH in the Power Down or Idle modes, however. In those modes it is not fetching instructions, and the Port 0 pins will float if not externally pulled high or low. The choice of whether to pull them high or low is the designer's. Normally it is sufficient to pull them up to V_{CC} with 10k resistors. But if power is going to be removed from circuits that are connected to the bus, it will be advisable to pull the bus pins down (normally with 10k resistors). Considerations involved in selecting pullup and pulldown resistor values are as follows.

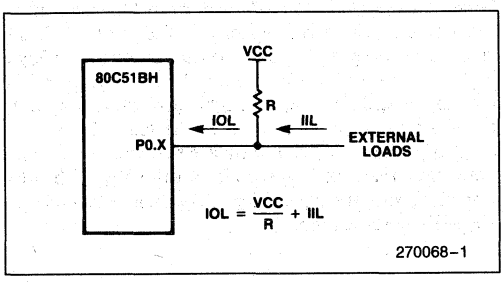


Figure 3a. Conditions defining the minimum value for R. P0.X is emitting a logic low. R must be large enough to not cause IOL to exceed data sheet specifications.

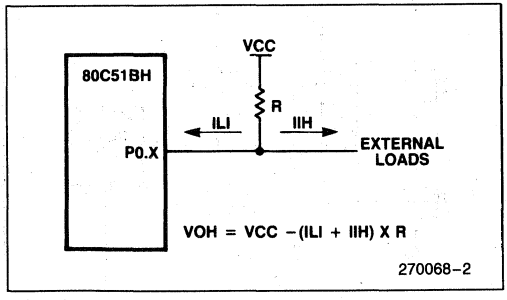


Figure 3b. Conditions defining the maximum value for R. P0.X is in a high impedance state. R must be small enough to keep V_{OH} acceptably high.

PULLUP RESISTORS

If a pullup resistor is to be used on a Port 0 pin, its minimum value is determined by I_{OL} requirements. If the pin is trying to emit a 0, then it will have to sink the current from the pullup resistor plus whatever other current may be sourced by other loads connected to the pin, as shown in Figure 3a, while maintaining a valid output low (V_{OL}). To guarantee that the pin voltage will not exceed 0.45V, the resistor should be selected so that I_{OL} doesn't exceed the value specified on the data sheet. In most CMOS applications, the minimum value would be about 2k Ω.

The maximum value you could use depends on how fast you want the pin to pull up after bus operations have ceased, and how high you want the V_{OH} level to be. The smaller the resistor the faster it pulls up. Its effect on the V_{OH} level is that $V_{OH} = V_{CC} - (ILI + IIH) \times R$. ILI is the input leakage current to the Port 0 pin, and IIH is the input high current to the external loads, as shown in Figure 3b. Normally V_{OH} can be expected to reach 0.9 V_{CC} if the pullup resistance does not exceed about 50k Ω.

Pulldown Resistors

If a pulldown resistor is to be used on a Port 0 pin, its minimum value is determined by V_{OH} requirements during bus operations, and its maximum value is in most cases determined by leakage current.

During bus operations the port uses internal pullups to emit 1s. The D.C. Characteristics in the data sheet list guaranteed V_{OH} levels for given I_{OH} currents. (The "-" sign in the I_{OH} value means the pin is sourcing that current to the external load, as shown in Figure 4.) To ensure the V_{OH} level listed in the data sheet, the resis-

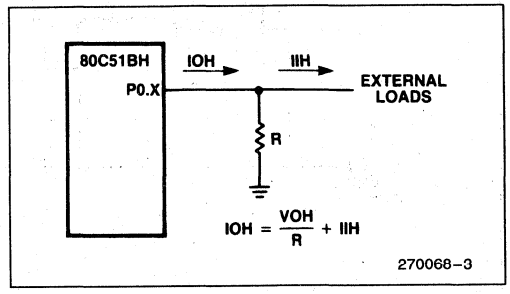


Figure 4a. Conditions defining the minimum value for R. P0.X is emitting a 1 in a bus operation. R must be large enough to not cause IOH to exceed data sheet specifications.

$$\frac{V_{OH}}{R} + I_{IH} \leq |I_{OH}|$$

tor has to satisfy where I_{IH} is the input high current to the external loads.

When the pin goes into a high impedance state, the pulldown resistor will have to sink leakage current from the pin, plus whatever other current may be sourced by other loads connected to the pin, as shown in Figure 4b. The Port 0 leakage current is I_{LI} on the data sheet. The resistor should be selected so that the voltage developed across it by these currents will be seen as a logic low by whatever circuits are connected to it (including the 80C51BH). In CMOS/CHMOS applications, 50k Ω is normally a reasonable maximum value.

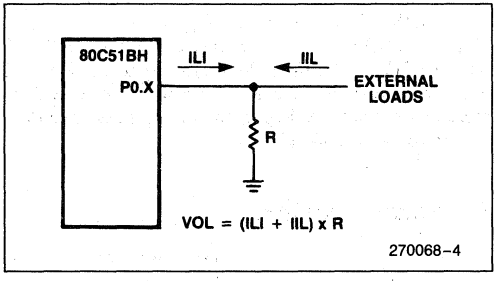


Figure 4b. Conditions defining the maximum value for R. P0.X is in a high impedance state. R must be small enough to keep VOL acceptably low.

DRIVE CAPABILITY OF THE INTERNAL PULLUPS

There's an important difference between HMOS and CHMOS port drivers. The pins of Ports 1, 2, and 3 of the CHMOS parts each have three pullups: strong, normal, and weak, as shown in Figure 5. The strong pullup (p1) is only used during 0-to-1 transitions, to hasten the transition. The weak pullup (p2) is on whenever the bit latch contains a 1. The "normal" pullup (p3) is controlled by the pin voltage itself.

The reason that p3 is controlled by the pin voltage is that if the pin is being used as an input, and the external source pulls it to a low, then turning off p3 makes for a lower I_{IL}. The data sheet shows an "I_{TL}" specification. This is the current that p3 will source during the time the pin voltage is making its 1-to-0 transition. This is what I_{IL} would be if an input low at the pin didn't turn p3 off.

Note, however, that this p3 turn-off mechanism puts a restriction on the drive capacity of the pin if it's being used as an output. If you're trying to output a logic high, and the external load pulls the pin voltage below the pin's V_{IH}MIN spec, p3 might turn off, leaving only the weak p2 to provide drive to the load. To prevent this happening, you need to ensure that the load doesn't draw more than the I_{OH} spec for a valid V_{OH}. The idea is to make sure the pin voltage never falls below its own V_{IH}MIN specification.

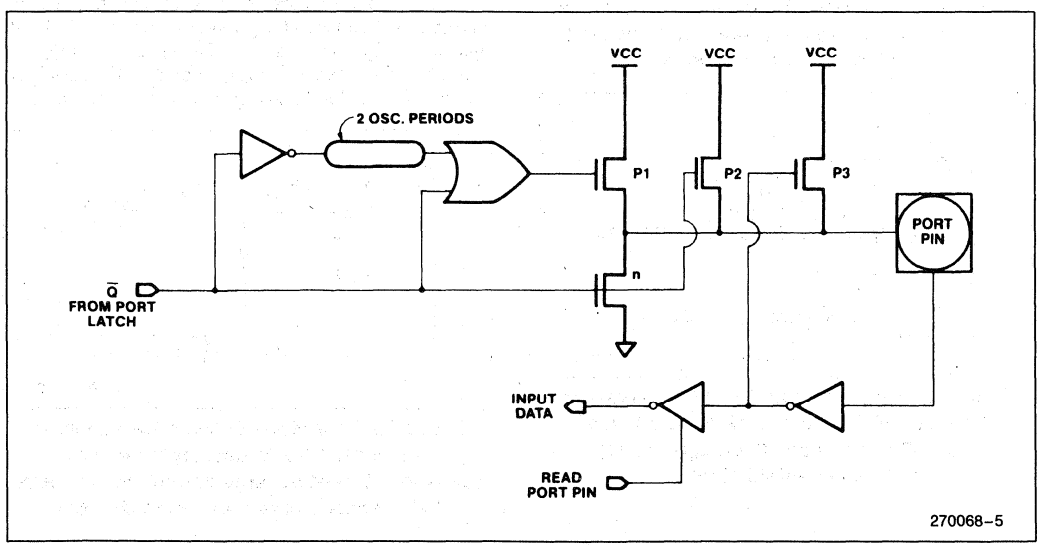


Figure 5. 80C51BH Output Drivers for Ports 1, 2 and 3

POWER CONSUMPTION

The main reason for going to CMOS, of course, is to conserve power. (There are other reasons, but this is the main one.) Conserving power doesn't mean just reducing your electric bill. Nor does it necessarily relate to battery operation, although battery operation without CMOS is pretty unhandy. The main reason for conserving power is to be able to put more functionality into a smaller space. The reduced power consumption allows the use of smaller and lighter power supplies, and less heat being generated allows denser packaging of circuit components. Expensive fans and blowers can usually be eliminated.

A cooler running chip is also more reliable, since most random and wearout failures relate to die temperature. And finally, the lower power dissipation will allow more functions to be integrated onto the chip.

The reason CMOS consumes less power than NMOS is that when it's in a stable state there is no path of conduction from V_{CC} to V_{SS} except through various leakage paths. CMOS does draw current when it's changing states. How much current it draws depends on how often and how quickly it changes states.

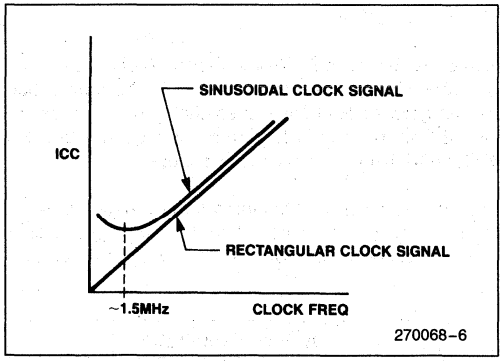


Figure 6. 80C51BH ICC vs. Clock Frequency

CMOS circuits draw current in sharp spikes during logical transitions. These current spikes are made up of two components. One is the current that flows during the transition time when pullup and pulldown FETs are both active. The average (DC) value of this component is larger when the transition times of the input signals are longer. For this reason, if the current draw is a critical factor in the design, slow rise and fall times should be avoided, even when the system speed doesn't seem to justify a need for nanosecond switching speeds.

The other component is the current that charges stray and load capacitance at the nodes of a CMOS logic gate. The average value of this current spike is its area (integral over time) multiplied by its rep rate. Its area is the amount of charge it takes to raise the node capacitance, C, to V_{CC}. That amount of charge is just C x V_{CC}. So the average value of the current spike is C x V_{CC} x f, where f is the clock frequency.

This component of current increases linearly with clock frequency. For minimal current draw, the 80C52BH-2 is spec'd to run at frequencies as low as 500 kHz.

Keep in mind, though, that other component of current that is due to slow rise and fall times. A sinusoid is not the optimal waveform to drive the XTAL1 pin with. Yet crystal oscillators, including the one on the 80C51BH, generate sinusoidal waveforms. Therefore, if the on-chip oscillator is being used, you can expect the device to draw more current at 500 kHz, than it does at 1.5 MHz, as shown in Figure 6. If you derive a good sharp square wave from an external oscillator, and use that to drive XTAL1, then the microcontroller will draw less current. But the external oscillator will probably make up the difference.

The 80C51BH has two power-saving features not available in the HMOS devices. These are the Idle and Power Down modes of operation. The on-chip hardware that implements these reduced power modes is shown in Figure 7. Both modes are invoked by software.

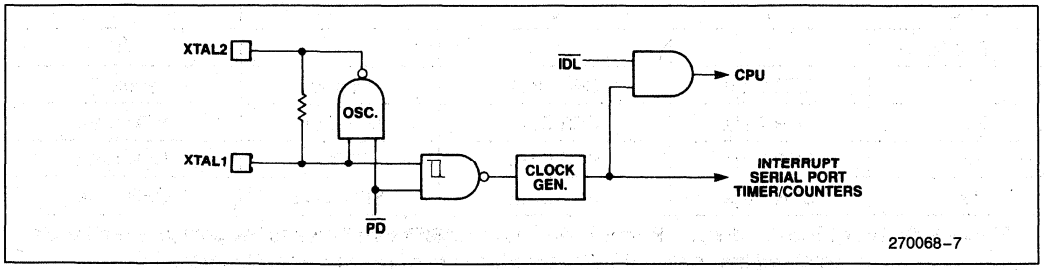


Figure 7. Oscillator and Clock Circuitry Showing Idle and Power Down Hardware

Idle: In the Idle Mode ($\overline{IDL}$ = 0 in Figure 7), the CPU puts itself to sleep by gating off its own clock. It doesn't stop the oscillator. It just stops the internal clock signal from getting to the CPU. Since the CPU draws 80 to 90 percent of the chip's power, shutting it off represents a fairly significant power savings. The on-chip periperals (timers, serial port, interrupts, etc.) and RAM continue to function as normal. The CPU status is preserved in its entirety: the Stack Pointer, Program Counter, Program Status Word, Accumulator, and all other registers maintain their data during Idle.

The Idle Mode is invoked by setting bit 0 (IDL) of the PCON register. PCON is not bit-addressable, so the bit has to be set by a byte operation, such as

```
ORL PCON,#1
```

The PCON register also contains flag bits GF0 and GF1, which can be used for any general purposes, or to give an indication if an interrupt occurred during normal operation or during Idle. In this application, the instruction that invokes Idle also sets one or both of the flag bits. Their status can then be checked in the interrupt routines.

While the device is in the Idle Mode, ALE and $\overline{PSEN}$ emit logic high (V_{OH}), as shown in Figure 8. This is so external EPROM can be deselected and have its output disabled.

The port pins hold the logical states they had at the time the Idle was activated. If the device was executing out of external program memory, Port 0 is left in a high impedance state and Port 2 continues to emit the high byte of the program counter (using the strong pullups to emit 1s). If the device was executing out of internal program memory, Ports 0 and 2 continue to emit whatever is in the P0 and P2 registers.

There are two ways to terminate Idle. Activation of any enabled interrupt will cause the hardware to clear bit 0 of the PCON register, terminating the Idle mode. The interrupt will be serviced, and following RETI the next instruction to be executed will be the one following the instruction that invoked Idle.

The other way is with a hardware reset. Since the clock oscillator is still running, RST only needs to be held active for two machine cycles (24 oscillator periods) to complete the reset. Note that this exit from Idle writes 1s to all the ports, initializes all SFRs to their reset values, and restarts program execution from location 0.

Power Down: In the Power Down Mode ($\overline{PD}$ = 0 in Figure 7), the CPU puts the whole chip to sleep by turning off the oscillator. In case it was running from an external oscillator, it also gates off the path to the internal phase generators, so no internal clock is generated even if the external oscillator is still running. The on-chip RAM, however, saves its data, as long as V_{CC} is maintained. In this mode the only I_{CC} that flows is leakage, which is normally in the micro-amp range.

The Power Down Mode is invoked by setting bit 1 in the PCON register, using a byte instruction such as

```
ORL   PCON,#2
```

While the device is in Power Down, ALE and $\overline{PSEN}$ emit lows (V_{OL}), as shown in Figure 8. The reason they are designed to emit lows is so that power can be removed from the rest of the circuit, if desired, while the 80CS51BH is in its Power Down mode.

The port pins continue to emit whatever data was written to them. Note that Port 2 emits its P2 register data even if execution was from external program memory.

Pin	Internal Execution		External Execution	
	Idle	Power Down	Idle	Power Down
ALE	1	0	1	0
PSEN/	1	0	1	0
P0	SFR Data	SFR Data	High-Z	High-Z
P1	SFR Data	SFR Data	SFR Data	SFR Data
P2	SFR Data	SFR Data	PCH	SFR Data
P3	SFR Data	SFR Data	SFR Data	SFR Data

Figure 8. Status of Pins in Idle and Power Down Modes. "SFR data" means the port pins emit their internal register data. "PCH" is the high byte of the Program Counter.

Port 0 also emits its P0 register data, but if execution was from external program memory, the P0 register data is FF. The oscillator is stopped, and the part remains in this state as long as V_{CC} is held, and until it receives an external reset signal.

The only exit from Power Down is a hardware reset. Since the oscillator was stopped, RST must be held active long enough for the oscillator to re-start and stabilize. Then the reset function initializes all the Special Function Registers (ports, timers, etc.) to their reset values, and re-starts the program from location 0. Therefore, timer reloads, interrupt enables, baud rates, port status, etc. need to be re-established. Reset does not affect the content of the on-chip data RAM. If V_{CC} was held during Power Down, the RAM data is still good.

USING THE POWER DOWN MODE

The software-invoked Power Down feature offers a means of reducing the power consumption to a mere trickle in systems which are to remain dormant for some period of time, while retaining important data.

The user should give some thought to what state the port pins should be left in during the time the clock is stopped, and write those values to the port latches before invoking Power Down.

If V_{CC} is going to be held to the entire circuit, one would want to write values to the port latches that would deselect peripherals before invoking Power Down. For example, if external memory is being used, the P2 SFR should be loaded with a value which will not generate an active chip select to any memory device.

In some applications, V_{CC} to part of the system may be shut off during Power Down, so that even quiescent and standby currents are eliminated. Signal lines that connect to those chips must be brought to a logic low, whether the chip in question is CMOS, NMOS, or TTL, before V_{CC} is shut off to them. CMOS pins have parasitic pn junctions to V_{CC}, which will be forward biased if V_{CC} is reduced to zero while the pin is held at a logic high. NMOS pins often have FETs that look like diodes to V_{CC}. TTL circuits may actually be damaged by an input high if $V_{CC} = 0$. That's why the 80C51BH outputs lows at ALE and $\overline{PSEN}$ during Power Down.

Figure 9 shows a circuit that can be used to turn V_{CC} off to part of the system during Power Down. The circuit will ensure that the secondary circuit is not de-energized until after the 80C31BH is in Power Down, and that the 80C31BH does not receive a reset (terminating the Power Down mode) before the secondary circuit is re-energized. Therefore, the program memory itself can be part of the secondary circuit.

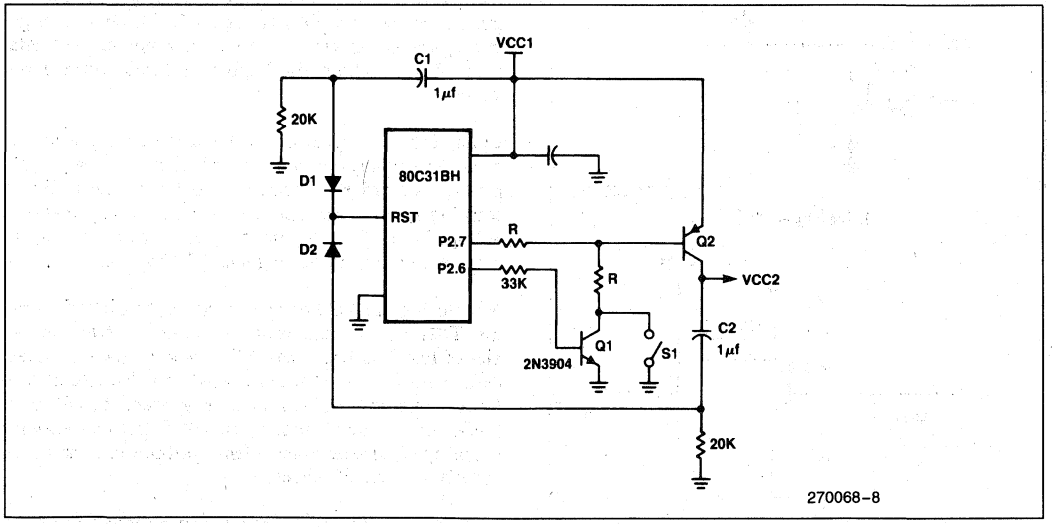


Figure 9. The 80C31BH de-energizes part of the circuit (VCC2) when it goes into Power Down. Selections of R and Q2 depend on VCC2 current draw.

In Figure 9, when V_{CC} is switched on to the 80C31BH, capacitor C1 provides a power-on reset. The reset function writes 1s to all the port pins. The 1 at P2.6 turns Q1 on, enabling V_{CC} to the secondary circuit through transistor Q2. As the 80C31BH comes out of reset, Port 2 commences emitting the high byte of the Program Counter, which results in the P2.7 and P2.6 pins outputting 0s. The 0 at P2.7 ensures continuation of V_{CC} to the secondary circuit.

The system software must now write a 1 to P2.7 and a 0 to P2.6 in the Port 2 SFR, P2. These values will not appear at the Port 2 pins as long as the device is fetching instructions from external program memory. However, whenever the 80C31BH goes into Power Down, these values will appear at the port pins, and will shut off both transistors, disabling V_{CC} to the secondary circuit.

Closing the switch S1 re-energizes the secondary circuit, and at the same time sends a reset through C2 to the 80C31BH to wake it up. The diode D1 is to prevent C1 from hogging current from C2 during this secondary reset. D2 prevents C2 from discharging through the RST pin when V_{CC} to the secondary circuit goes to zero.

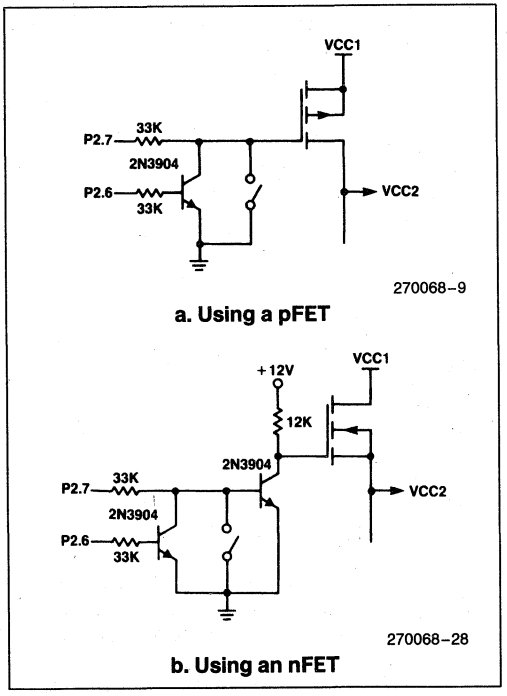


Figure 10. Using Power MOSFETs to Control VCC2

USING POWER MOSFETs to CONTROL V_{CC}

Power MOSFETs are gaining in popularity (and availability). The easiest way to control V_{CC} is with a Logic Level pFET, as shown in Figure 10a. This circuit allows the full V_{CC} to be used to turn the device on. Unfortunately, power pFETs are not economically competitive with bipolar transistors of comparable ratings.

Power nFETs are both economical and available, and can be used in this application if a DC supply of higher voltage is available to drive the gate. Figure 10b shows how to implement a V_{CC} switch using a power nFET and a (nominally) + 12V supply. The problem here is that if the device is on, its source voltage is +5V. To maintain the on state, the gate has to be another 5 or 10V above that. The "12V" supply is not particularly critical. A minimally filtered, unregulated rectifier will suffice.

BATTERY BACKUP SYSTEMS

Here we consider circuits that normally draw power from the AC line, but switch to battery operation in the event of a power failure. We assume that in battery operation high-current loads will be allowed to die along with the AC power. The system may continue then with reduced functionality, monitoring a control transducer, perhaps, or driving an LCD. Or it may go into a bare-bones survival mode, in which critical data is saved but nothing else happens till AC power is restored.

In any case it is necessary to have some early warning of an impending power failure so that the system can arrange an orderly transfer to battery power. Early warning systems can operate by monitoring either the AC line voltage or the unregulated rectifier output, or even by monitoring the regulated DC voltage.

Monitoring the AC line voltage gives the earliest warning. That way you can know within one or two half-cycles of line frequency that AC power is down. In most cases you then have at least another half-cycle of line frequency before the regulated V_{CC} starts to fall. In a half-cycle of line frequency an 80C51BH can execute about 5,000 instructions—plenty of time to arrange an orderly transfer of power.

The circuit in Figure 11 uses a Zener diode to test the line voltage each half-cycle, and a junction transistor to pass the information on to the 80C51BH. (Obviously a voltage comparator with a suitable reference source can

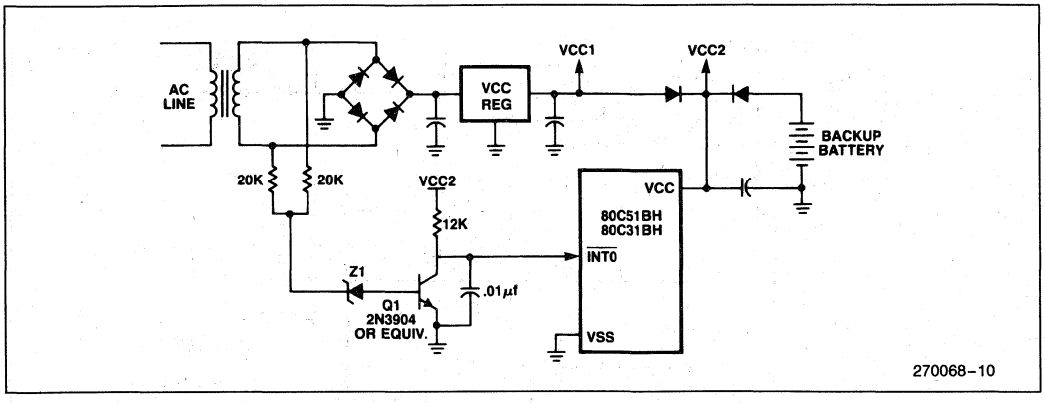


Figure 11. Power Failure Detector with Battery Backup. When AC power fails, VCC1 goes down and VCC2 is held.

perform the same function, if one prefers.) The way it works is if the line voltage reaches an acceptably high level, it breaks over Z1, drives Q1 to saturation, and interrupts the 80C51BH. The interrupt would be transition-activated, in this application. The interrupt service routine reloads one of the C51BH's timers to a value that will make it roll over in something between one and two half-cycles of line frequency. As long as the line voltage is healthy, the timer never rolls over, because it is reloaded every half-cycle. If there is a single half-cycle in which the line voltage doesn't reach a high enough level to generate the interrupt, the timer rolls over and generates a **timer** interrupt.

The timer interrupt then commences the transition to battery backup. Critical data needs to be copied into protected RAM. Signals to circuits that are going to lose power must be written to logic low. Protected circuits (those powered by $V_{CC}2$) that communicate with unprotected circuits must be deselected. The microcontroller itself may be put into Idle, so that it can continue some level of interrupt-driven functionality, or it may be put into Power Down.

Note that if the CPU is going to invoke Power Down, the Special Function Registers may also need to be copied into protected RAM, since the reset that terminates the Power Down mode will also intialize all the SFRs to their reset values.

The circuit in Figure 11 does not show a wake-up mechanism. A number of choices are available, however. A pushbutton could be used to generate an interrupt, if the CPU is in Idle, or to activate reset, if the CPU is in Power Down.

Automatic wake-up on power restoration is also possible. If the CPU is in Idle, it can continue to respond to any interrupts that might be generated by Q1. The interrupt service routine determines from the status of flag bits GF0 and GF1 in PCON that it is in Idle because there was a power outage. It can then sample $V_{CC}1$ through a voltage comparator similar to Z1, Q1 in Figure 11. A satisfactory level of $V_{CC}1$ would be indicated by the transistor being in saturation.

But perhaps you can't spare the timer that is the key to the operation of the circuit in Figure 11. In that case a retriggerable one-shot, triggered by the AC line voltage, can perform essentially the same function. Figure 12 shows an example of this type of power failure detector. A retriggerable one-shot (one half of a 74HC123) monitors the AC line voltage through transistor Q1. Q1 retriggers the one-shot every half-cycle of line frequency. If the output pulse width is between one and two half-cycles of line frequency, then a single missing or low half-cycle will generate an active low warning flag, which can be used to interrupt the microcontroller.

The interrupt routine takes care of the transition to battery backup. From this point $V_{CC}1$ may or may not actually drop out. The missing half-cycle of line voltage that caused the power down sequence may have been nothing more than a short glitch. If the AC line comes back strong enough to trigger the one-shot while $V_{CC}1$ is still up (as indicated by the state of transistor Q2), then the other half of the 74HC123 will generate a wake-up signal.

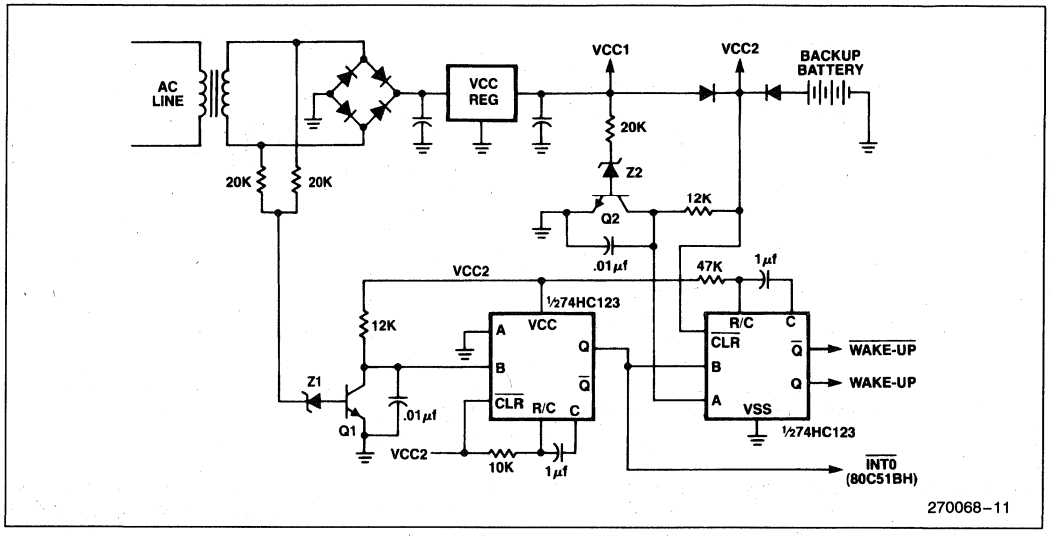


Figure 12. Power Failure Detector uses retriggerable one-shots to flag impending power outage and generate automatic wake-up when power returns.

Having been awakened, the 80C51BH will stay awake for at least another half-cycle of line frequency (another 5,000 or so instructions) before possibly being told to arrange another transfer of power. Consequently, if the line voltage is jittering erratically around the switchover point (determined by diode Z1), the system will limp along executing in half-cycle units of line frequency.

On the other hand, if the power outage is real and lengthy, $V_{CC}1$ will eventually fall below the level at which the backup battery takes over. The backup battery maintains power to the 80C51BH, and to the 74HC123, and to whatever other circuits are being protected during this outage. The battery voltage must be high enough to maintain V_{CC}MIN specs to the 80C51BH.

If the microcontroller is an 80C31BH, executing out of external ROM, and if the C31BH is put into Idle during the power outage, then the external ROM must also be supplied by the battery. On the other hand, if the C31BH is put into Power Down during the outage, then the ROM can be allowed to die with the AC power. The considerations here are the same as in Figure 9: V_{CC} to the ROM is still up at the time Power Down is invoked, and we must ensure (through selection of diode Z2 in Figure 12) that the 80C31BH is not awakened till ROM power is back in spec.

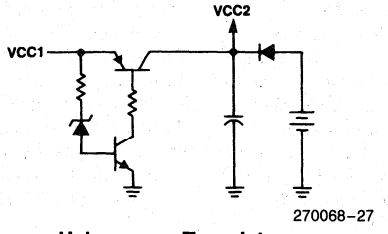
POWER SWITCHOVER CIRCUITS

Battery backup systems need to have a way for the protected circuits to draw power from the line-operated power supply when that source is available, and to switch over to battery power when required. The switchover circuit is simple if the entire system is to be battery powered in the event of a line power outage. In that case a pair of diodes suffice, as shown in Figure 12, provided V_{CC}MIN specs are still met after the diode drop has been subtracted from its respective power source.

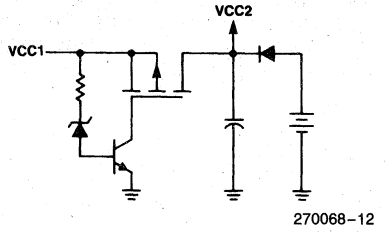
The situation becomes more complicated when part of the circuit is going to be allowed to die when the AC power goes out. In that case it is difficult to maintain equal V_{CC}s to protected and unprotected circuits (and possibly dangerous not to).

The problem can be alleviated by using a Schottky diode instead of a 1N4001, for its lower forward voltage drop. The 1N5820, for example, has a foward drop of about 0.35V at 1A.

Other solutions are to use a transistor or power MOSFET switch, as shown in Figure 13. With minor modifications this switch can be controlled by port pins.



a. Using a pnp Transistor



b. Using a Power MOSFET

Figure 13. Power Switchover Ckts.

80C31BH + CHMOS EPROM

The 27C64 and 87C64 are Intel's 8K byte CHMOS EPROMs. The 27C64 requires an external address latch, and can be used with the 80C31BH as shown in Figure 14a. In most 8031 + 2764 (HMOS) applications, the 2764's Chip Enable ($\overline{CE}$) pin is hardwired to ground (since it's normally the only program memory on the bus). This can be done with the CHMOS versions as well, but there is some advantage in connecting $\overline{CE}$ to ALE, as shown in Figure 14a. The advantage is that if the 80C31BH is put into Idle mode, since ALE goes to a 1 in that mode, the 27C64 will be deselected and go into a low current standby mode.

The timing waveforms for this configuration are shown in Figure 14b. In Figure 14b the signals and timing parameters in parenthesis are those of the 27C64, and the others are of the 80C31BH, except Tprop is a parameter of the address latch. The requirements for timing compatibility are

TAVIV − Tprop > tACC
TLLIV > tCE
TPLIV > tOE
TPXIZ > tDF

If the application is going to use the Power Down mode then we have another consideration: In Idle, ALE = $\overline{PSEN}$ = 1, and in Power Down, ALE = $\overline{PSEN}$ = 0. In a realistic application there are likely to be more chips in the circuit than are shown in Figure 14, and it is likely that the nonessential ones will have their V_{CC} removed while the CPU is in Power Down. In that case the EPROM and the address latch should be among the chips that have V_{CC} removed, and logic lows are exactly what are required at ALE and $\overline{PSEN}$.

But if V_{CC} is going to be maintained to the EPROM during Power Down, then it will be necessary to de-

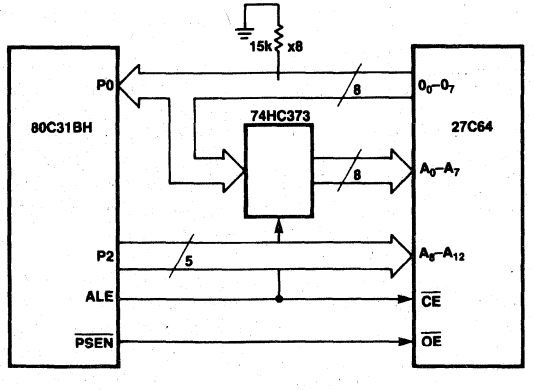


Figure 14a. 80C31BH + 27C64

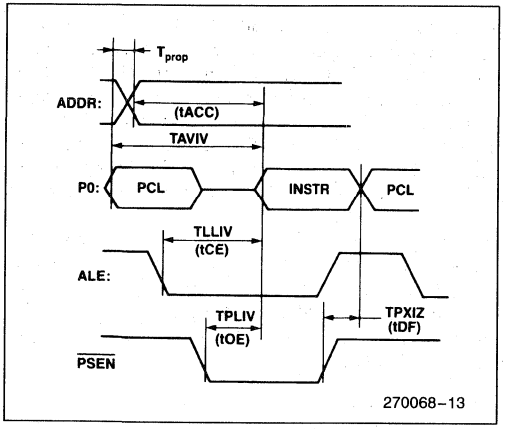


Figure 14b. Timing Waveforms for 80C31BH + 27C64

select the EPROM when the CPU is in Power Down. If Idle is never invoked, $\overline{CE}$ of the EPROM can be connected to P2.7 of the 80C31BH, as shown in Figure 15a. In normal operation, P2.7 will be emitting the MSB of the Program Counter, which is 0 if the program contains less than 32K of code. Then when the CPU goes into Power Down, the Port 2 pins emit P2 SFR data, which puts a 1 at P2.7, thus deselecting the EPROM.

If Idle and Power Down are both going to be used, $\overline{CE}$ of the EPROM can be driven by the logical OR of ALE and P2.7, as shown in Figure 15b. In Idle, ALE = 1 will deselect the EPROM, and in Power Down, P2.7 = 1 will deselect it.

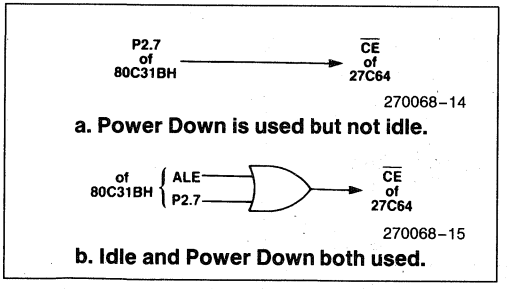


Figure 15. Modifications to 80C31BH/27C64 Interface

Pulldown resistors are shown in Figure 14a under the assumption that something on the bus is going to have its V_{CC} removed during Power Down. If this is not the case, pullups can be used as well as pulldowns.

The 87C64 is like the 27C64 except that it has an on-chip address latch. The Port 0 pins are tied to both address and data pins of the 87C64, as shown in Figure 16a. ALE drives the EPROM's ALE/$\overline{CS}$ input. During ALE high, the address information is allowed to flow into the EPROM and begin accessing the code byte. On the falling edge of ALE the address byte is internally latched. The A0–A7 inputs are then ignored and the same bus lines are used to transmit the fetched code byte from the O0–O7 pins back to the 80C31BH.

The timing waveforms for this configuration are shown in Figure 16b. In Figure 16b the signals and timing parameters in parentheses are those of the 87C64, and the others are of the 80C31BH. The requirements for timing compatibility are

TLHLL > tLL

TAVLL > tAL

TLLAX > tLA

TLLIV > tACL

TPLIV > tOE

TLLPL > tCOE

TPXIZ > tOHZ

The same considerations apply to the 87C64 as to the 27C64 with regards to the Idle and Power Down modes. Basically you want $\overline{CS}$ = 1 if V_{CC} is maintained to the EPROM, and $\overline{CS}$ = $\overline{OE}$ = 0 if V_{CC} is removed.

SCANNING A KEYBOARD

There are many different kinds of keyboards, but alphanumeric keyboards generally consist of a matrix of 8 scan lines and 8 receive lines as shown in Figure 17. Each set of lines connects to one port of the microcontroller. The software has written 0s to the scan lines, and 1s to the receive lines. Pressing a key connects a scan line to a receive line, thus pulling the receive line to a logic low.

The 8 receive lines are ANDed to one of the external interrupt pins, so that pulling any of the receive lines low generates an interrupt. The interrupt service routine has to identify the pressed key, if only one key is down, and convert that information to some useful output. If more than one key in the line matrix is found to be pressed, no action is taken. (This is a "two key lockout" scheme.)

On some keyboards, certain keys (Shift, Control, Escape, etc.) are not a part of the line matrix. These keys would connect directly to a port pin on the microcontroller, and would not cause lock-out if pressed simultaneously with a matrix key, nor generate an interrupt if pressed singly.

Normally the microcontroller would be in idle mode when a key has not been pressed, and another task is not in progress. Pressing a matrix key generates an interrupt, which terminates the Idle. The interrupt service routine would first call a 30 ms (or so) delay to debounce the key, and then set about the task of identifying which key is down.

First, the current state of the receive lines is latched into an internal register. If a single key is down, all but one of the lines would be read as 1s. Then 0s are written to the receive lines and 1s to the scan lines, and the scan lines are read. If a single key is down, all but one of

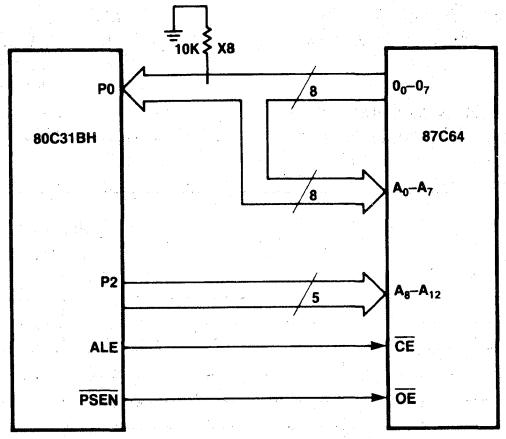


Figure 16a. 80C31BH + 87C64

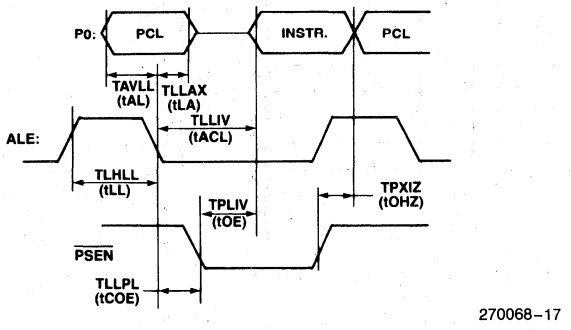


Figure 16b. Timing Waveforms for 80C31BH + 87C64

these lines would be read as 1s. By locating the single 0 in each set of lines, the pressed key can be identified. If more than one matrix key is down, one or both sets of lines will contain multiple 0s.

A subroutine is used to determine which of 8 bits in either set of lines is 0, and whether more than one bit is 0. Figure 18 shows a subroutine (SCAN) which does that using the 8051's bit-addressing capability. To use the subroutine, move the line data into a bit-addressable RAM location named LINE, and call the SCAN routine. The number of LINE bits which are zero is returned in ZERO__COUNTER. If only one bit is zero, its number (1 through 8) is returned in ZERO__BIT.

The interrupt service routine that is executed in response to a key closure might then be as follows:

```
RESPONSE_TO_KEY_CLOSURE:
        CALL   DEBOUNCE_DELAY
        MOV    LINE,P1; ;See Figure 17.
        CALL   SCAN
        DJNZ   ZERO_COUNTER,REJECT
        MOV    ADDRESS,ZERO_BIT
        MOV    P2,#0FFH; ;See Figure 17.
        MOV    P1,#0
        MOV    LINE,P2
        CALL   SCAN
        DJNZ   ZERO_COUNTER,REJECT
        XCH    A,ZERO_BIT
        SWAP   A
        ORL    ADDRESS,A
        XCH    A,ZERO_BIT
        MOV    P1,#0FFH
        MOV    P2,#0
REJECT: CLR    EX0
        RETI
```

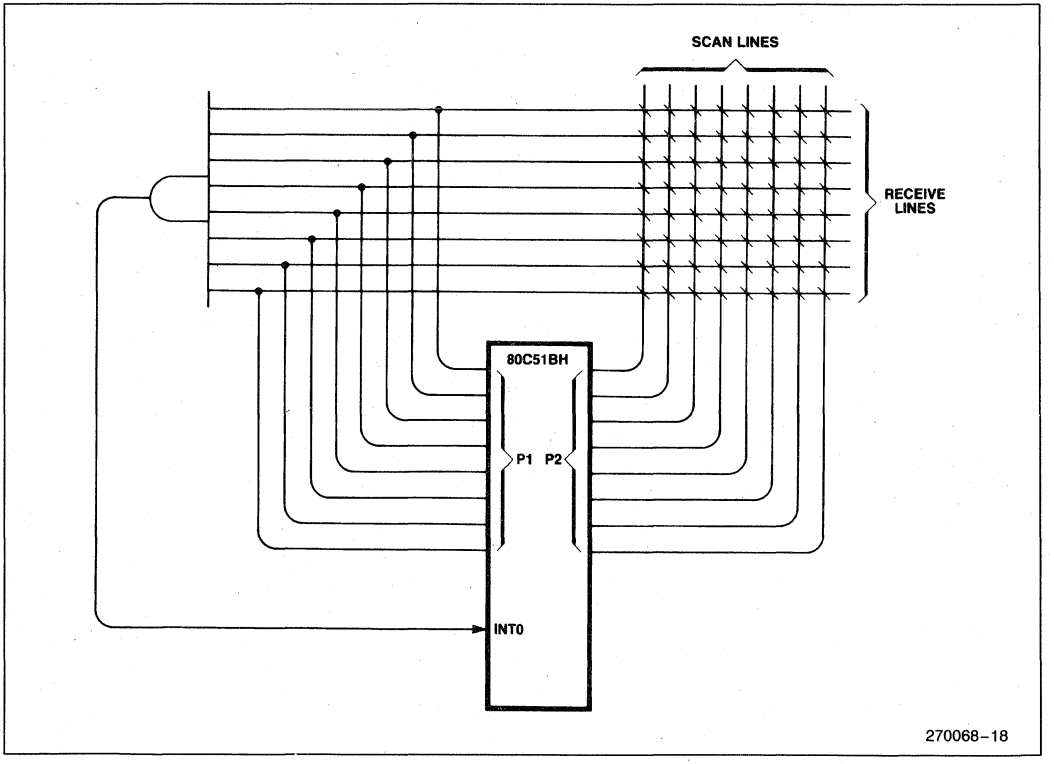


Figure 17. Scanning a Keyboard

```
SCAN:   MOV     ZERO_COUNTER,#0 ; ZERO_COUNTER counts the number of 0s in LINE.
        JB      LINE.0,ONE      ; Test LINE bit 0.
        INC     ZERO_COUNTER    ; If LINE.0 = 0, increment ZERO_COUNTER
        MOV     ZERO_BIT,#1     ;    and record that line number 1 is active.
ONE:    JB      LINE.1,TWO      ; Procedure continues for other LINE bits.
        INC     ZERO_COUNTER
        MOV     ZERO_BIT,#2     ; Line number 2 is active.
TWO:    JB      LINE.2,THREE
        INC     ZERO_COUNTER
        MOV     ZERO_BIT,#3     ; Line number 3 is active.
THREE:  JB      LINE.3,FOUR
        INC     ZERO_COUNTER
        MOV     ZERO_BIT,#4     ; Line number 4 is active.
FOUR:   JB      LINE.4,FIVE
        INC     ZERO_COUNTER
        MOV     ZERO_BIT,#5     ; Line number 5 is active.
FIVE:   JB      LINE.5,SIX
        INC     ZERO_COUNTER
        MOV     ZERO_BIT,#6     ; Line number 6 is active.
SIX:    JB      LINE.6,SEVEN
        INC     ZERO_COUNTER
        MOV     ZERO_BIT,#7     ; Line number 7 is active.
SEVEN:  JB      LINE.7,EIGHT
        INC     ZERO_COUNTER
        MOV     ZERO_BIT,#8     ; Line number 8 is active.
EIGHT:  RET
```

270068-19

Figure 18. Subroutine SCAN Determines Which of 8 Bits in LINE is Zero

Notice that RESPONSE_TO_KEY_CLOSURE does not change the Accumulator, the PSW, nor any of the registers R0 through R7. Neither do SCAN or DEBOUNCE_DELAY.

What we come out with then is a one-byte key address (ADDRESS) which identifies the pressed key. The key's scan line number is in the upper nibble of ADDRESS, and its receive line number is in the lower nibble. ADDRESS can be used in a look-up table to generate a key code to transmit to a host computer, and/or to a display device.

The keyboard interrupt itself must be edge-triggered, rather than level-activated, so that the interrupt routine is invoked when a key is pressed, and is not constantly being repeated as long as the key is held down. In edge-triggered mode, the on-chip hardware clears the interrupt flag (EX0, in this case) as the service routine is being vectored to. In this application, however, contact bounce will cause several more edges to occur after the service routine has been vectored to, during the DEBOUNCE_DELAY routine. Consequently it is necessary to clear EX0 again in software before executing RETI.

The debounce delay routine also takes advantage of the Idle mode. In this routine a timer must be preloaded with a value appropriate to the desired length of delay. This would be

$$\text{timer preload} = \frac{(\text{osc kHz}) \times (\text{delay time ms})}{12}$$

For example, with a 3.58 MHz oscillator frequency, a 30 ms delay could be obtained using a preload value of −8950, or DD0A, in hex digits.

In the debounce delay routine (Figure 19), the timer interrupt is enabled and set to a higher priority than the keyboard interrupt, because as we invoke Idle, the keyboard interrupt is still "in progress". An interrupt of the same priority will not be acknowledged, and will not terminate the Idle mode. With the timer interrupt set to priority 1, while the keyboard interrupt is a priority 0, the timer interrupt, when it occurs, will be acknowledged and will wake up the CPU. The timer interrupt service routine does not itself have to do anything. The service routine might be nothing more than a single RETI instruction. RETI from the timer interrupt service routine then returns execution to the debounce delay routine, which shuts down the timer and returns execution to the keyboard service routine.

DRIVING AN LCD

An LCD (Liquid Crystal Display) consists of a backplane and any number of segments or dots which will be used to form the image being displayed. Applying a voltage (nominally 4 or 5V) between any segment and the backplane causes the segment to darken. The only catch is that the polarity of the applied voltage has to be periodically reversed, or else a chemical reac-

```
DEBOUNCE_DELAY:
        MOV     TL1, #TL1_PRELOAD ; Preload low byte.
        MOV     TH1, #TH1_PRELOAD ; Preload high byte.
        SETB    ET1               ; Enable Timer 1 interrupt.
        SETB    PT1               ; Set Timer 1 interrupt to high priority.
        SETB    TR1               ; Start timer running.
        ORL     PCON, #1          ; Invoke Idle mode.
;
; The next instruction will not be executed until the delay times out.
;
        CLR     TR1               ; Stop the timer.
        CLR     PT1               ; Back to priority 0 (if desired).
        CLR     ET1               ; Disable Timer 1 interrupt (if desired).
        RET                       ; Continue keyboard scan.
```

270068-20

Figure 19. Subroutine DEBOUNCE_DELAY Puts the 80C51BH into Idle During the Delay Time

tion takes place in the LCD which causes deterioration and eventual failure of the liquid crystal.

To prevent this happening, the backplane and all the segments are driven with an AC signal, which is derived from a rectangular voltage waveform. If a segment is to be "off" it is driven by the same waveform as the backplane. Thus it is always at backplane potential. If the segment is to be "on" it is driven with a waveform that is the inverse of the backplane waveform. Thus it has about 5V of periodically changing polarity between it and the backplane.

With a little software overhead, the 80C51BH can perform this task without the need for additional LCD drivers. The only drawback is that each LCD segment uses up one port pin, and the backplane uses one more. If more than, say, two 7-segment digits are being driven, there aren't many port pins left for other tasks. Nevertheless, assuming a given application leaves enough port pins available to support this task, the considerations for driving the LCD are as follows.

Suppose, for example, it is a 2-digit display with a decimal point. One port (TENS_DIGIT) connects to the 7 segments of the tens digit plus the backplane. Another port (ONES_DIGIT) connects to a decimal point plus the 7 segments of the ones digit.

One of the 80C51BH's timers is used to mark off half-periods of the drive voltage waveform. The LCD drive waveform should have a rep rate between 30 and 100 Hz, but it's not very critical. A half-period of 12 ms will set the rep rate to about 42 Hz. The preload/reload value to get 12 ms to rollover is the 2's complement negative of the oscillator frequency in kHz: if the oscillator frequency is 3.58 MHz, the reload value is −3580, or F204 in hex digits.

Now, the 80C51BH would normally be in Idle, to conserve power, during the time that the LCD and other tasks are not requiring servicing. When the timer rolls over it generates an interrupt, which brings the 80C51BH out of Idle. The service routine reloads the timer (for the next rollover), and inverts the logic levels of all the pins that are connected to the LCD. It might look like this:

```
LCD_DRIVE_INTERRUPT:
  MOV   TL1,#LOW( - XTAL_FREQ)
  MOV   TH1,#HIGH( - XTAL_FREQ)
  XRL   TENS_DIGIT,#0FFH
  XRL   ONES_DIGIT,#0FFH
  RETI
```

To update the display, one would use a look-up table to generate the characters. In the table, "on" segments are represented as 1s, and "off" segments as 0s. The backplane bit is represented as a 0. The quantity to be displayed is stored in RAM as a BCD value. The look-up table operates on the low nibble of the BCD value, and produces the bit pattern that is to be written to either the ones digit or the tens digit. Before the new patterns can be written to the LCD, the LCD drive interrupt has to be disabled. That is to prevent a polarity reversal from taking place between the times the two digits are written. An update subroutine is shown in Figure 20.

USING AN LCD DRIVER

As was noted, driving an LCD directly with an 80C51BH uses a lot of port pins. LCD drivers are available in CMOS to interface an 80C51BH to a 4-digit display using only 7 of the C51BH's I/O pins. Basically, the C51BH tells the LCD driver what digit is to be displayed (4 bits) and what position it is to be displayed in (2 bits), and toggles a Chip Select pin to tell the driver to latch this information. The LCD driver generates the display characters (hex digits), and takes care of the polarity reversals using its own RC oscillator to generate the timing.

Figure 25 shows an 80C51BH working with an ICM7211M to drive a 4-digit LCD, and the software that updates the display.

One could equally well send information to the LCD driver over the bus. In that case, one would set up the Accumulator with the digit select and data input bits, and execute a MOVX@ R0,A instruction. The LCD driver's chip select would be driven by the CPU's $\overline{WR}$ signal. This is a little easier in software than the direct bit manipulation shown in Figure 21. However, it uses more I/O pins, unless there is already some external memory involved. In that case, no **extra** pins are used up by adding the LCD driver to the bus.

RESONANT TRANSDUCERS

Analog transducers are often used to convert the value of a physical property, such as temperature, pressure, etc., to an analog voltage. These kinds of transducers then require an analog-to-digital converter to put the measurement into a form that is compatible with a digital control system. Another kind of transducer is now becoming available that encodes the value of the physical property into a signal that can be directly read by a digital control system. These devices are called resonant transducers.

Resonant transducers are oscillators whose frequency depends in a known way on the physical property being measured. These devices output a train of rectangular pulses whose repetition rate encodes the value of the quantity being measured. The pulses can in most cases be fed directly into the 80C51BH, which then measures either the frequency or period of the incoming signal, basing the measurement on the accuracy of its own clock oscillator. The 80C51BH can even do this in its sleep; that is, in Idle.

When the frequency or period measurement is completed, the C51BH wakes itself up for a very short time to perform a sanity check on the measurement and convert it in software to any scaling of the measured quantity that may be desired. The software conversion can include corrections for nonlinearities in the transducer's transfer function.

Resolution is also controlled by software, and can even be dynamically varied to meet changing needs as a situation becomes more critical. For example, in a process controller you can increase your resolution ("fine tune" the control, as it were) as the process approaches its target.

The nominal reference frequency of the output signal from these devices is in the range of 20 Hz to 500 kHz, depending on the design. Transducers are available that have a full scale frequency shift 2 to 1. The transducer operates from a supply voltage range of 3V to 20V, which means it can operate from the same supply voltage as the 80C51BH. At 5V, the transducer draws less than 5 mA (Reference 7). It can normally be connected directly to one of the C51BH's port pins, as shown in Figure 22.

FREQUENCY MEASUREMENTS

Measuring a frequency means counting pulses for a known sample time. Two timer/counters can be used, one to mark off the sample time and one to count pulses. If the frequency being counted doesn't exceed 50 kHz or so, one may equally well connect the transducer signal to one of the external interrupt pins, and count pulses in software. That frees up one timer, with very little cost in CPU time.

The count that is directly obtained is TxF, where T is the sample time and F is the frequency. The full scale

```
UPDATE_LCD:
        CLR     ET1                     ; Disable LCD drive interrupt.
        MOV     DPTR, #TABLE_ADDRESS    ; Look-up table begins at TABLE_ADDRESS
        MOV     A, BCD_VALUE            ; Digits to be displayed.
        SWAP    A                       ; Move tens digit to low nibble.
        ANL     A, #0FH                 ; Mask off high nibble.
        MOVC    A, @A+DPTR              ; Tens digit pattern to accumulator.
        MOV     TENS_DIGIT, A           ; Update LCD tens digit.
        MOV     A, BCD_VALUE            ; Digits to be displayed.
        ANL     A, #0FH                 ; Mask off tens digit.
        MOVC    A, @A+DPTR              ; Ones digit pattern to accumulator.
        MOV     C, DECIMAL_POINT        ; Add decimal point to segment
        MOV     ACC. 7, C               ;  pattern.  Update LCD decimal point
        MOV     ONES_DIGIT, A           ;  and ones digit.
        SETB    ET1                     ; Re-enable LCD drive interrupt.
        RET
```

270068-21

Figure 20. UPDATE_LCD Routine Writes Two Digits to an LCD

range is Tx(Fmax-Fmin). For n-bit resolution

$$1\ LSB = \frac{Tx(Fmax\text{-}Fmin)}{2^n}$$

Therefore the sample time required for n-bit resolution is

$$T = \frac{2^n}{Fmax\text{-}Fmin}$$

For example, 8-bit resolution in the measurement of a frequency that varies between 7 kHz and 9 kHz would require, according to this formula, a sample time of 128 ms. The maximum acceptable frequency count would be 128 ms × 9 kHz = 1152 counts. The minimum would be 896 counts. Subtracting 896 from each frequency count (or presetting the frequency counter to −896 = 0FC80H) would allow the frequency to be reported on a scale of 0 to FF in hex digits.

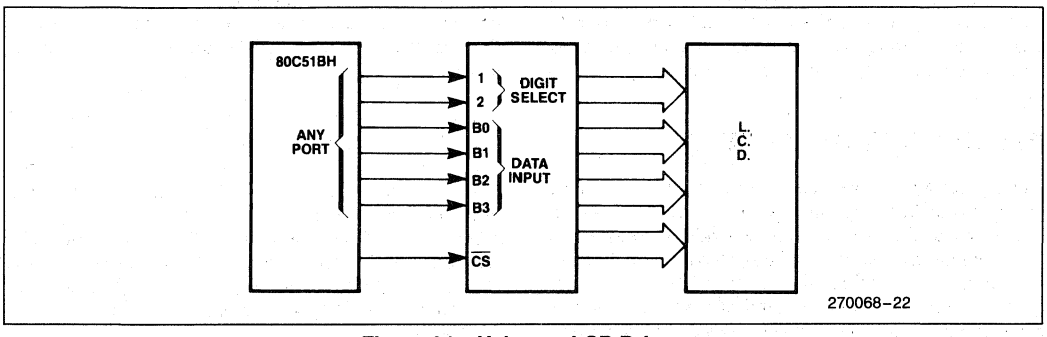


Figure 21a. Using an LCD Driver

```
UPDATE_LCD:
        MOV     A,DISPLAY_HI    ; High byte of 4-digit display.
        SETB    DIGIT_SELECT_2  ; Select leftmost digit of LCD.
        SETB    DIGIT_SELECT_1  ;  (Digit address = 11B.)
        CALL    SHIFT_AND_LOAD  ; High nibble of high byte to selected digit
        CLR     DIGIT_SELECT_1  ; Select second digit of LCD (address = 10B)
        CALL    SHIFT_AND_LOAD  ; Low nibble of high byte to selected digit.
        MOV     A,DISPLAY_LO    ; Low byte of 4-digit display.
        CLR     DIGIT_SELECT_2  ; Select third digit of LCD.
        SETB    DIGIT_SELECT_1  ;   (Digit address = 01B.)
        CALL    SHIFT_AND_LOAD  ; High nibble of low byte to selected digit.
        CLR     DIGIT_SELECT_1  ; Select fourth digit (address = 00B).
        CALL    SHIFT_AND_LOAD  ; Low nibble of low byte to selected digit.
        RET

SHIFT_AND_LOAD:
        RLC     A                       ; MSB to carry bit (CY).
        MOV     DATA_INPUT_B3,C         ; CY to Data Input pin B3.
        RLC     A                       ; Next bit to CY.
        MOV     DATA_INPUT_B2,C         ; CY to Data Input pin B2.
        RLC     A                       ; Next bit to CY.
        MOV     DATA_INPUT_B1,C         ; CY to Data Input pin B1.
        RLC     A                       ; Last bit to CY.
        MOV     DATA_INPUT_B0,C         ; CY to Data Input pin B0.
        CLR     CHIP_SELECT             ; Toggle Chip Select.
        SETB    CHIP_SELECT             ; 0-to-1 transition latches info.
        RET
```

270068-23

Figure 21b. UPDATE_LCD Routine Writes 4 Digits to an LCD Driver

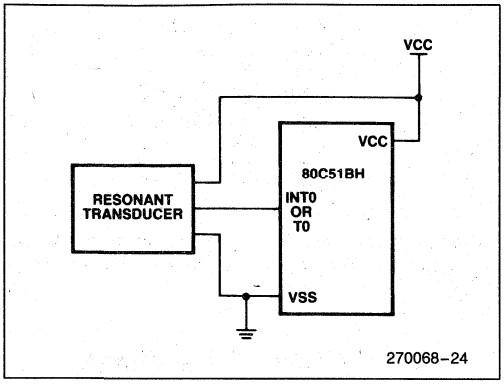


Figure 22. Resonant Transducer Does Not Require an A/D Converter

To implement the measurement, one timer is used to establish the sample time. The timer is preset to a value that causes it to roll over at the end of the sample time, generating an interrupt and waking the CPU from its Idle mode. The required preset value is the 2's complement negative of the sample time measured in machine cycles. The conversion from sample time to machine cycles is to multiply it by 1/12 the clock frequency. For example, if the clock frequency is 12 MHz, then a sample time of 128 ms is

(128 ms) × (12000 kHz)/12 = 128000 machine cycles.

Then the required preset value to cause the timer to roll over in 128 ms is

−128000 = FE0C00, in hex digits.

Note that the preset value is 3 bytes wide whereas the timer is only 2 bytes wide. This means the timer must be augmented in software in the timer interrupt routine to three bytes. The 80C51BH has a DJNZ instruction (decrement and jump if not zero) that makes it easier to code the third timer byte to count down instead of up. If the third timer byte counts down, its reload value is the 2's complement of what it would be for an up-counter. For example, if the 2's complement of the sample time is FE0C00, then the reload value for the third timer byte would be 02, instead of FE. The timer interrupt routine might then be:

```
TIMER_INTERRUPT_ROUTINE:
        DNJZ    THIRD_TIMER_BYTE,OUT
        MOV     TL0,#0
        MOV     TH0,#0CH
        MOV     THIRD_TIMERBYTE,#2
        MOV     FREQUENCY,COUNTER_L0
;Preset COUNTER to -896:
        MOV     COUNTER_L0,#80H
        MOV     COUNTER_HI,#0FCH
OUT:    RETI
```

At this point the value of the frequency of the transducer signal, measured to 8 bit resolution, is contained in FREQUENCY. Note that the timer can be reloaded on the fly. Note too that the timer can be reloaded on the fly. Note too that for 8-bit resolution only the low byte of the frequency counter needs to be read, since the high byte is necessarily 0. However, one may want to test the high byte to ensure that it is zero, as a sanity check on the data. Both bytes, of course must be reloaded.

PERIOD MEASUREMENTS

Measuring the period of the transducer signal means measuring the total elapsed time over a known number, N, of transducer pulses. The quantity that is directly measured is NT, where T is the period of the transducer signal in *machine cycles*. The relationship between T in machine cycles and the transducer frequency F in arbitrary frequency units is

$$T = \frac{Fxtal}{F} \times (1/12),$$

where Fxtal is the 80C51BH clock frequency, in the same units as F.

The full scale range then is Nx (Tmax − Tmin). For n-bit resolution.

$$1\ LSB = \frac{Ns(Tmax\text{-}Tmin)}{2^n}.$$

Therefore the number of periods over which the elapsed time should be measured is

$$N = \frac{2^n}{Tmax\text{-}Tmin}$$

However, N must also be an integer. It is logical to evaluate the above formula (don't forget Tmax and Tmin have to be in machine cycles) and select for N the next higher integer. This selection gives a period measurement that has somewhat more than n-bit resolution, but it can be scaled back if desired.

For example, suppose we want 8-bit resolution in the measurement of the period of a signal whose frequency varies from 7.1 kHz to 9 kHz. If the clock frequency is 12 MHz, then Tmax is (12000 kHz/7.1 kHz) x (1/12) = 141 machine cycles. Tmin is 111 machine cycles. The required value for N, then, is 256/(141-111) = 8.53 periods, according to the formula. Using N = 9 periods will give a maximum NT value of 141 x 9 = 1269 machine cycles. The minimum NT will be 111 × 9 = 999 machine cycles. A lookup table can be used to

scale these values back to a range of 0 to 255, giving precisely the 8-bit resolution desired.

To implement the measurement, one timer is used to measure the elapsed time, NT. The transducer is connected to one of the external interrupt pins, and this interrupt is configured to the transition-activated mode. In the transition-activated mode every 1-to-0 transition in the transducer output will generate an interrupt. The interrupt routine counts transducer pulses, and when it gets to the predetermined N, it reads and clears the timer. For the specific example cited above, the interrupt routine might be:

```
INTERRUPT_RESPONSE:
        DJNZ    N,OUT
        MOV     N,#9
        CLR     EA
        CLR     TR1
        MOV     NT_LO,TL1
        MOV     NT_HI,TH1
        MOV     TL1,#9
        MOV     TH1,#0
        SETB    TR1
        SETB    EA
        CALL    LOOKUP_TABLE
OUT:    RETI
```

In this routine a pulse counter N is decremented from its preset value, 9, to zero. When the counter gets to zero it is reloaded to 9. Then all interrupts are blocked for a short time while the timer is read and cleared. The timer is stopped during the read and clear operations, so "clearing" it actually means presetting it to 9, to make up for the 9 machine cycles that are missed while the timer is stopped.

The subroutine LOOKUP_TABLE is used to scale the measurement back to the desired 8-bit resolution. It can also include built-in corrections for errors or nonlinearities in the transducer's transfer function.

The subroutine uses the MOVC A, @ A + DPTR instruction to access the table, which contains 270 entries commencing at the 16-bit address referred to as TABLE. The subroutine must compute the address of the table entry that corresponds to the measured value of NT. This address is

DPTR = TABL + NT − NTMIN,

where NTMIN = 999, in this specific example.

```
LOOKUP_TABLE:
        PUSH  ACC
        PUSH  PSW
        MOV   A,#LOW(TABLE-NTMIN)
        ADD   A,NT_LO
        MOV   DPL,A
        MOV   A,#HIGH(TABLE-NMTIN)
        ADDC  A,NT_HI
        MOV   DPH,A
        CLR   A
        MOVC  A,@A+DTPR
        MOV   PERIOD,A
        POP   PSW
        POP   ACC
        RET
```

At this point the value of the period of the transducer signal, measured to 8 bit resolution, is contained in PERIOD.

PULSE WIDTH MEASUREMENTS

The 80C51BH timers have an operating mode which is particularly suited to pulse width measurements, and will be useful in these applications if the transducer signal has a fixed duty cycle.

In this mode the timer is turned on by the on-chip circuitry in response to an input high at the external interrupt pin, and off by an input low, and it can do this while the 80C51BH is in Idle. (The "GATE" mode of timer operation is described in the Intel Microcontroller Handbook.) The external interrupt itself can be enabled, so the same 1-to-0 transition from the transducer that turns off the timer also generates an interrupt. The interrupt routine then reads and resets the timer.

The advantage of this method is that the transducer signal has direct access to the timer gate, with the result that variations in interrupt response time have no effect on the measurement.

Resonant transducers that are designed to fully exploit the GATE mode have an internal divide-by-N circuit that fixes the duty cycle at 50% and lowers the output frequency to the range of 250 to 500 Hz (to control RFI). The transfer function between transducer period and measurand is approximately linear, with known and repeatable error functions.

HMOS/CHMOS Interchangeability

The CHMOS version of the 8051 is architecturally identical with the HMOS version, but there are nevertheless some important differences between them which the designer should be aware of. In addition, some applications require interchangeability between HMOS and CHMOS parts. The differences that need to be considered are as follows:

External Clock Drive: To drive the HMOS 8051 with an external clock signal, one normally grounds the XTAL1 pin and drives the XTAL2 pin. To drive the CHMOS 8051 with an external clock signal, one must drive the XTAL1 pin and leave the XTAL2 pin unconnected. The reason for the difference is that in the

HMOS 8051, it is the XTAL2 pin that drives the internal clocking circuits, whereas in the CHMOS version it is the XTAL1 pin that drives the internal clocking circuits.

There are several ways to design an external clock drive to work with both types. For low clock frequencies (below 6 MHz), the HMOS 8051 can be driven in the same way as the CHMOS version, namely, through XTAL1 with XTAL2 unconnected. Another way is to drive both XTAL1 **and** XTAL2; that is, drive XTAL1 and use and external inverter to derive from XTAL1 a signal with which to drive XTAL2.

In either case, a 74HC or 74HCT circuit makes an excellent driver for XTAL1 and/or XTAL2, because neither the HMOS nor the CHMOS XTAL pins have TTL-like input logic levels.

Unused Pins: Unused pins of Ports 1, 2 and 3 can be ignored in both HMOS and CHMOS designs. The internal pullups will put them into a defined state. Unused Port 0 pins in 8051 applications can be ignored, even if they're floating. But in 80C51BH applications, these pins should not be left afloat. They can be externally pulled up or down, or they can be internally pulled down by writing 0s to them.

8031/80C31BH designs may or may not need pullups on Port 0. Pullups aren't needed for program fetches, because in bus operations the pins are actively pulled high or low by either the 8031 or the external program memory. But they are needed for the CHMOS part if the Idle or Power Down mode is invoked, because in these modes Port 0 floats.

Logic Levels: If V_{CC} is between 4.5V and 5.5V, an input signal that meets the HMOS 8051's input logic levels will also meet the CHMOS 80C51BH's input logic levels (except for XTAL1/XTAL2 and RST). For the same V_{CC} condition, the CHMOS device will reach or surpass the output logic levels of the HMOS device. The HMOS device will not necessarily reach the output logic levels of the CHMOS device. This is an important consideration if HMOS/CHMOS interchangeability must be maintained in an otherwise CMOS system.

HMOS 8051 outputs that have internal pullups (Ports 1, 2, and 3) "typically" reach 4V or more if I_{OH} is zero, but not fast enough to meet timing specs. Adding an external pullup resistor will ensure the logic level, but still not the timing, as shown in Figure 23. If timing is an issue, the best way to interface HMOS to CMOS is through a 74HCT circuit.

Idle and Power Down: The Idle and Power Down modes exist only on the CHMOS devices, but if one

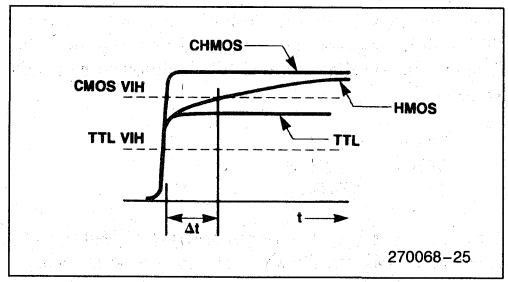


Figure 23. 0-to-1 Transition Shows Unspec'd Delay (Δt) in HMOS to 74HC Logic

wishes to preserve the capability of interchanging HMOS and CHMOS 8051s the software has to be designed so that the HMOS parts will respond in an acceptable manner when a CHMOS reduced power mode is invoked.

For example, an instruction that invokes Power Down can be followed by a "JMP $":

```
CLR   EA
ORL   PCON,#2
JMP   $
```

The CHMOS and HMOS parts will respond to this sequence of code differently. The CHMOS part, going into a normal CHMOS Power Down Mode, will stop fetching instructions until it gets a hardware reset. The HMOS part will go through the motions of executing the ORL instruction, and then fetch the JMP instruction. It will continue fetching and executing JMP $ until hardware reset.

Maintaining HMOS/CHMOS 8051 interchangeability in response to Idle requires more planning. The HMOS part will not respond to the instruction that puts the CHMOS part into Idle, so that instruction needs to be followed by a software idle. This would be an idling loop which would be terminated by the same conditions that would terminate the CHMOS's hardware Idle. Then when the CHMOS device goes into Idle, the HMOS version executes the idling loop, until either a hardware reset or an enabled interrupt is received. Now if Idle is terminated by an interrupt, execution for the CHMOS device will proceed after RETI from the instruction following the one that invoked Idle. The instruction following the one that invoked Idle is the idling loop that was inserted for the HMOS device. At this point, both the HMOS and CHMOS devices must be able to fall through the loop to continue execution.

One way to achieve the desired effect is to define a "fake" Idle flag, and set it just before going into Idle. The instruction that invoked Idle is followed by a software idle:

```
SETB    IDLE
ORL     PCON,#1
JB      IDLE,$
```

Now the interrupt that terminates the CHMOS's Idle must also break the software idle. It does so by clearing the "Idle" bit:

```
...
CLR    IDLE
RETI
```

Note too that the PCON register in the HMOS 8051 contains only one bit, SMOD, whereas the PCON register in CHMOS contains SMOD plus four other bits. Two of those other bits are general purpose flags. Maintaining HMOS/CHMOS interchangeability requires that these flags not be used.

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APPLICATION NOTE

AP-410

November 1987

2

Enhanced Serial Port on the 83C51FA

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Order Number: 270490-001

The serial port on the 8051 has been enhanced on the 83C51FA with the addition of two new features: Automatic Address Recognition and Framing Error Detection. **Automatic Address Recognition** facilitates multiprocessor communications by reducing CPU overhead. **Framing Error Detection** increases communication reliability by checking each reception for a valid stop bit.

This Application Note explains how to use these new features with samples of code for typical applications. A section is also included which reviews how to set up the serial port for multiprocessor applications.

MULTIPROCESSOR COMMUNICATIONS

In applications where multiple controllers jointly perform a task, the master controller must be able to communicate selectively with individual slaves. To do this, the master first identifies the target slave (or slaves) with an address byte and then transmits a block of data. The target slaves must be able to identify their own address before receiving any data bytes.

The serial port on the 8051 provides a 9-bit mode to facilitate multiprocessor communication. The 9th bit allows the controller to distinguish between address and data bytes. In this mode, a total of 11 bits are received or transmitted: a start bit (0), 8 data bits (LSB first), a programmable 9th bit, and a stop bit (1). See Figure below.

The 9th bit is set to 1 to identify address bytes and set to 0 for data bytes. A typical data stream is seen below:

ADDRESS BYTE	/ DATA BYTE	/ DATA BYTE	/ ...
D8 = 1	D8 = 0	D8 = 0	

Initially the slave is set up to only receive address bytes. Once it receives its own address, the slave reconfigures itself to receive data. On the 8051 serial port, an address byte interrupts **all** slaves for an address comparison. On the 83C51FA, however, Automatic Address Recognition allows the addressed slave to be the **only** one interrupted; that is, the address comparison occurs in hardware, not software. With this feature, the master controller can establish communication with one or more slaves without all the slaves having to respond to the transmission.

AUTOMATIC ADDRESS RECOGNITION

Automatic Address Recognition reduces the CPU time required to service the serial port. Since the CPU is only interrupted when it receives its own address, the software overhead to compare addresses is eliminated. This would also effectively reduce the sophistication of the serial protocol when numerous controllers are sharing the same serial link.

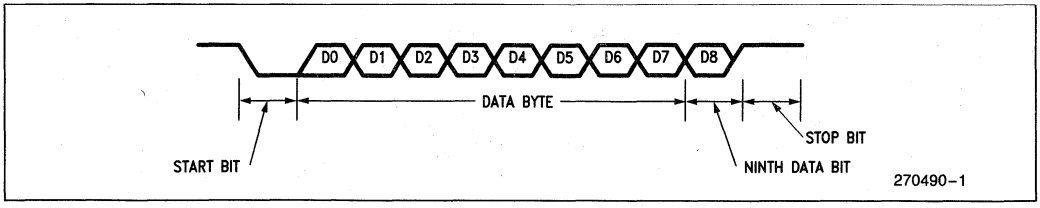
This same feature can also be used in conjunction with the Idle Mode to reduce the system's overall power consumption. For instance, a master may need to communicate with only one slave at a time. With all slaves in Idle Mode, only that one slave would be interrupted to respond to the master's transmission. Without Automatic Addressing, each slave would have to "wake up" to check for its address. Limiting the interruptions reduces the amount of current drawn by the system and thus reduces the power consumption.

In multiprocessor applications the serial port is configured in either of the 9-bit modes (Mode 2 or 3). Mode 2 has a fixed baud rate whereas Mode 3 is variable. For more information on the different serial port modes refer to the "Serial Port Set Up" section.

Automatic Address Recognition is enabled by setting the SM2 bit in SCON. Each slave has its SM2 bit set waiting for an address byte (9th bit = 1). The Receive Interrupt (RI) flag will get set when the received byte corresponds to either a Given or Broadcast Address. The slave then clears its SM2 bit to enable reception of data bytes (9th bit = 0) from the master.

The master can selectively communicate with groups of slaves by using the Given Address. Addressing all slaves at once is possible with the Broadcast Address. These addresses are defined for each slave by two new Special Function Registers: SADDR and SADEN.

A slave's individual address is specified in SADDR. SADEN is a mask byte that defines don't-cares to form the Given Address. These don't-cares allow flexibility in the user-defined protocol to address one or more slaves. The following is an example of how to define Given Addresses and selectively address different slaves.



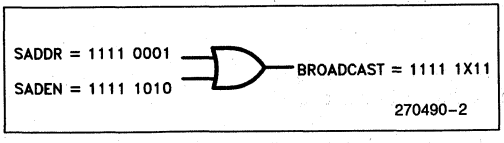
Slave 1			
SADDR	=	1111	0001
SADEN	=	1111	1010
GIVEN	=	1111	0X0X
Slave 2			
SADDR	=	1111	0011
SADEN	=	1111	1001
GIVEN	=	1111	0XX1

The SADEN bytes have been selected such that bit 1 (LSB) is a don't-care for Slave 1's Given Address, but bit 1 = 1 for Slave 2. Thus, to selectively communicate with just Slave 1 an address with bit 1 = 0 would be used (e.g. 1111 0000).

Similarly, bit 2 = 0 for Slave 1, but is a don't-care for Slave 2. Now to communicate with just Slave 2 an address with bit 2 = 1 would be used (e.g. 1111 0111).

Finally, to communicate with both slaves at once the address must have bit 1 = 1 and bit 2 = 0. Notice, however, that bit 3 is a "don't-care" for both slaves. This allows two different addresses to select both slaves (1111 0001 or 1111 0101). If a third slave was added that required its bit 3 = 0, then the latter address could be used to communicate with Slave 1 and 2 but not Slave 3.

The master can also communicate with all slaves at once with the Broadcast Address. It is formed from the logical OR of SADDR and SADEN with zeros defined as don't-cares. For example, the Broadcast address for Slave 1 would be formed as follows:



The don't-cares also allow flexibility in defining the Broadcast Address, but in most applications a Broadcast Address will be 0FFH.

SADDR and SADEN are located at address A9H and B9H, respectively. On Reset, SADDR and SADEN are initialized to 00H which defines the Given and Broadcast Addresses as XXXX XXXX (all don't-cares). This assures the 83C51FA serial port to be backwards compatible with the other MCS®-51 products which do not implement Automatic Addressing.

FRAMING ERROR DETECTION

Framing Error Detection is another new feature on 83C51FA serial port which allows the receiving controller to check for valid stop bits in Modes 1, 2, or 3. A missing stop bit can be caused, for example, by noise on the serial lines or transmission by two CPUs simultaneously.

If a stop bit is missing a Framing Error bit FE will be set. This bit can then be checked in software after each reception to detect communication errors. Once set, the FE bit must be cleared in software. A valid stop bit will not clear FE.

The FE bit is located in SCON and shares the same bit address as SM0. To determine which is accessed, a new control bit called SMOD0 has been added in the PCON register (see figures below). If SMOD0 = 0, then accesses to SCON.7 are to SM0. If SMOD0 = 1, then accesses to SCON.7 are to FE.

PCON: Power Control Register (Not Bit Addressable)

SMOD1	**SMOD0**	—	POF	GF1	GF0	PD	IDL

Address = 87H

SCON: Serial Port Control Register (Bit Addressable)

SM0/FE	SM1	SM2	REN	TB8	RB8	TI	RI

Address = 98H

SERIAL PORT SOFTWARE

The following sections of code show examples of how to invoke Automatic Addressing and Framing Error Detection. Routines for both the slave and master are given. Code is also included to initialize both serial ports; however, for more information on setting up the serial port refer to the next section.

For this example, the master and slave are transmitting/receiving at 9600 baud with a 12 MHz crystal frequency. To obtain this baud rate, the serial port is configured in Mode 3 and Timer 2 is used as the baud-rate generator.

Listing 1 shows the initialization for the slave. Notice that Automatic Addressing and Framing Error Detection are enabled. The Given and Broadcast addresses for this slave are taken from Slave 1 in the previous example. A temporary byte has also been defined to store the incoming data byte.

The slave will remain in Idle Mode until it is interrupted by its own address. At that point, it clears the SM2

Listing 1. Initialization Routine for the Slave

```
ORG   00H
LJMP  INIT

ORG   0023H
LJMP  SERIAL_PORT_INTERRUPT

TEMP  DATA  30H                      ; Temporary storage byte

INIT: MOV SCON, #0F0H                ; Mode 3, enable Auto Addressing
                                     ; and reception
      ORL PCON, #40H                 ; FE bit accessed (SM0D0 = 1)
      MOV RCAP2H, #0FFH              ; Reload values for 9600 Baud
      MOV RCAP2L, #0D9H
      MOV T2CON, #34H                ; Timer 2 set up, TR2 = 1 turns
                                     ; timer on

INTERRUPTS:  SETB EA                 ; Enable global interrupt
             SETB ES                 ; Enable serial port interrupt

ADDRESSES:   MOV SADDR, # 11110001   ; Define Given & Broadcast
             MOV SADEN, # 11111010   ; Addresses
                                     ; GIVEN     = 11110X0X
                                     ; BROADCAST = 11111X11

IDLE_MODE:   ORL PCON, #01H          ; Invoke Idle Mode
```

Listing 2. Receive Routine for the Slave

```
SERIAL_PORT INTERRUPT:
        PUSH PSW
        CLR RI                       ; RI set when address is
                                     ; recognized & must be cleared
                                     ; in software
        CLR SM2                      ; Reconfigure slave to receive
                                     ; data bytes

RECEIVE_DATA:
        JNB RI, $                    ; Wait for RI to be set
        MOV C, SCON.7                ; Check for framing error
        JC FRAMING_ERROR
        MOV TEMP, SBUF               ; Receive data byte & store
                                     ; in temporary location
        CLR RI                       ; Clear flag for next
                                     ; reception
        SETB SM2                     ; Re-enable Automatic
                                     ; Addressing
        POP PSW
        RETI

FRAMING_ERROR:
        CLR SCON.7                   ; Clear FE bit
        CLR C
            •
            •                        ; Error routine left up to
            •                        ; the user
        POP PSW
        RETI
```

Listing 3. Initialization and Transmit Routines for the Master

```
GIVEN_1       equ    11110001B
MESSAGE_1     data   30H

INIT:    MOV SCON, #0D0H          ; Mode 3, REN = 1
         MOV RCAP2H, #0FFH        ; 9600 Baud
         MOV RCAP2L, #0D9H
         MOV T2CON, #34H          ; Timer 2 set up, TR2 = 1

TRANSMIT_ADDRESS:
         CLR TI
         SETB TB8                 ; Mark 1st byte as an address
                                  ; byte (9th bit = 1)
         MOV SBUF, #GIVEN_1       ; Send address
         JNB   TI, $              ; Wait for transmission
                                  ; complete
         CLR TI                   ; Clear flag for next
                                  ; transmission

TRANSMIT_DATA:
         CLR TB8                  ; Mark 2nd byte as a data
                                  ; byte (9th bit = 0)
         MOV SBUF, MESSAGE_1      ; Send data byte
         JNB TI, $
         CLR TI
```

bit to enable reception of data bytes. Depending on the user's protocol, more than one data byte may actually be received. This example, however, assumes only one byte of data follows each address byte.

Listing 2 shows the receive routine. Notice that when the data byte is received, the software checks for a framing error. The error routine could, for example, send an error message to the master and ask the master to re-transmit the last message. Before exiting the routine the SM2 is set to 1 to reenable Automatic Addressing. Once the slave has responded to the master's command, it could also put itself back into Idle Mode to wait for the next message.

The initialization routine for the master in Listing 3 is very similar to the slave. In this example, however, the master does not need Automatic Addressing; it is simply transmitting address and data bytes. GIVEN_1 is a byte to address the slave in the above example. MESSAGE_1 is a register that contains the data byte sent to this slave. Its value is arbitrary for the sample code.

SERIAL PORT SET UP

This section describes how to initialize the 83C51FA serial port for multiprocessor applications. Two different modes are available which provide 9-bit operation: Mode 2 which has a fixed baud rate and Mode 3 which has a variable baud rate. Baud rates can be generated by either Timer 1 or Timer 2 (available on the 83C51FA but not the 8051). Deciding which mode and timer to use is determined by the desired baud rate and clock frequency of the particular application.

Another consideration is the tolerance needed between serial ports. Since the serial port re-synchs its receiver at every start bit, only 8 or 9 bit-times are available to accumulate timing errors. As a result, the receiver and transmitter only have to be within about 5% of each other's baud rate. Allowing equal error to both transmitter and receiver, only about 2% accuracy is actually needed.

Following is a discussion of both Modes 2 and 3 and examples of how to program each. The mode selection bits (SM0 and SM1) are located in SCON. The REN bit must also be set to enable reception.

SCON: Serial Port Control Register (Bit Addressable)

SM0	SM1	SM2	REN	TB8	RB8	TI	RI

Address = 98H

Mode	SM0	SM1	Baud Rate
2	1	0	Fosc/64 or Fosc/32
3	1	1	Variable

Example 1. Serial Port Mode 2

```
; Frequency           = 12 MHz
; Desired Baud Rate   = 375 kBaud
;                     = 1/32 (Osc Freq)

MOV SCON, #0B0H     ; Serial port Mode 2
                    ; Automatic Addressing (SM2 = 1),
                    ; reception enabled (REN = 1)
ORL PCON, #80H      ; SMOD1 = 1 to double baud rate
```

Mode 2

Mode 2 uses a fixed baud rate of 1/32 or 1/64 of the oscillator frequency depending on the value of the SMOD1 bit in PCON. This mode basically offers a choice of two high-speed baud rates. With a 12 MHz clock frequency, baud rates of 187.5 kbaud or 375 kbaud can be obtained.

None of the timer/counters need to be set up for Mode 2. Only the SFRs SCON and PCON need to be defined.

PCON: Power Control Register (Not Bit Addressable)

SMOD1	SMOD0	—	POF	GF1	GF0	PD	IDL

Address = 87H

The baud rate in this mode is calculated by:

$$\text{Mode 2 Baud Rate} = \frac{2^{\text{SMOD1}} \times \text{Osc Freq}}{64}$$

SMOD1 = 0, Baud Rate = 1/64 Osc Freq

SMOD1 = 1, Baud Rate = 1/32 Osc Freq

Mode 3

Mode 3 of the serial port has a variable baud rate generated by either Timer 1 or Timer 2. The baud rate is generated by the rollover rate of the selected timer. The timer is operated in an auto-reload mode so it will roll over to the reload value selected in software.

Baud rates based off Timer 2 have less granularity so that almost any baud rate can be obtained at a given clock frequency. However, Timer 1 is sufficient if the desired baud rate can be obtained at the specified clock frequency. Remember baud rates only need about 2% accuracy.

Timer 1 Set Up

To generate baud rates Timer 1 is usually configured in 8-bit auto-reload mode (Mode 2). The mode select bits are M1 and M0 located in TMOD. To turn on Timer 1 the TR1 bit in TCON must be set. Also, the Timer 1 interrupt should be disabled in this application so that when the timer overflows it does not generate an interrupt.

TMOD: Timer/Counter Mode Control Register
(Not bit addressable)

GATE	C/$\overline{T}$	**M1**	**M0**	GATE	C/$\overline{T}$	M1	M0
Timer 1				Timer 0			

Address = 89H

TCON: Timer/Counter Control Register
(Bit addressable)

TF1	**TR1**	TF0	TR0	IE1	IT1	IE0	IT0

Address = 88H

The formula for calculating the baud rate is given below. TH1 is the reload value for Timer 1 when it overflows.

$$\text{Baud Rate} = \frac{K \times \text{Osc Freq}}{32 \times 12 \times [256 - (\text{TH1})]}$$

K = 1 if SMOD1 = 0.

K = 2 if SMOD1 = 1. (SMOD1 is at PCON.7)

If the baud rate is known, the reload value TH1 can be calculated by:

$$\text{TH1} = 256 - \frac{K \times \text{Osc Freq}}{384 \times \text{Baud Rate}}$$

TH1 must be an integer value. Rounding off TH1 to the nearest integer may not produce the desired baud rate with the 2% accuracy required. In this case, another crystal frequency may have to be chosen.

Refer to Table 1 for timer reload values for commonly used baud rates.

Table 1. Commonly Used Baud Rates Generated by Timer 1

Baud Rate	Osc Freq	SMOD1	Timer 1	
			TMOD	Reload Value
62.5K	12 MHz	1	20	FFH
19.2K	11.06 MHz	1	20	FDH
9.6K	11.06 MHz	0	20	FDH
4.8K	11.06 MHz	0	20	FAH
2.4K	11.06 MHz	0	20	F4H
1.2K	11.06 MHz	0	20	E8H
300	6 MHz	0	20	CCH
110	6 MHz	0	20	72H

Example 2. Serial Port Mode 3, with Timer 1 as Baud-Rate Generator

```
; Frequency           = 11.0 MHz
; Desired Baud Rate   = 19.2 kBaud
;
;
;   TH1 = 256 - (2) x (11.0 x 10^6)
;               (32) x (12) x (19200)
;

;       = 253 = FDH

MOV SCON, #0FOH     ; Serial port Mode 3, SM2 = 1,
                    ; REN = 1
ORL PCON, #80H      ; SMOD1 = 1
MOV TMOD, #20H      ; Timer 1 Mode 2
MOV TH1, #0FDH      ; Reload value for desired baud
                    ; rate
SETB TR1            ; Turn on Timer 1
```

It can be seen that the exact frequency to generate the standard baud rates (19.2K, 9600, 4800, etc.) is 11.06 MHz. However, it is **not** necessary to use this exact frequency. With a 2% tolerance any crystal value from 10.8 MHz to 11.3 MHz is sufficient.

Timer 2 Set Up

Timer 2 has a special baud-rate generator mode which transmits and receives at the same baud rate. This mode is invoked by setting both the RCLK and TCLK bits in T2CON. To turn Timer 2 on the TR2 bit should also be set.

Unlike Timer 1, this mode does not require that the timer overflow interrupt be disabled. That is, when Timer 2 is in the baud-rate generator mode, its interrupt is disconnected from the Timer 2 overflow. This interrupt then becomes available as a third external interrupt. (For more information on external interrupts, refer to the chapter "Hardware Description of the 8051" in the Embedded Controller Handbook.)

T2CON: Timer/Counter 2 Control Register
(Bit Addressable)

TF2	EXF2	**RCLK**	**TCLK**	EXEN2	**TR2**	C/$\overline{T2}$	CP/$\overline{RL2}$

Address = C8H

This formula for calculating the baud rate is given below. (RCAP2H, RCAP2L) is the 16-bit reload value when Timer 2 overflows.

$$\text{Baud Rate} = \frac{\text{Osc Freq}}{32 \times [65536 - (\text{RCAP2H, RCAP2L})]}$$

where (RCAP2H, RCAP2L) is a 16-bit unsigned integer.

To obtain the reload value for RCAP2H and RCAP2L the above equation can be rewritten as:

$$(RCAP2H, RCAP2L) = 65536 - \frac{\text{Osc Freq}}{32 \times \text{Baud Rate}}$$

Refer to Table 2 for reload values for commonly used baud rates.

Notice that when using Timer 2, most standard baud rates can be obtained at 12 MHz.

Table 2. Commonly Used Baud Rates Generated by Timer 2

Baud Rate	Osc Freq	Timer 2	
		RCAP2H	RCAP2L
375K	12 MHz	FF	FF
9.6K	12 MHz	FF	D9
4.8K	12 MHz	FF	B2
2.4K	12 MHz	FF	64
1.2K	12 MHz	FE	C8
300	12 MHz	FB	1E
110	12 MHz	F2	AF
300	6 MHz	FD	8F
110	6 MHz	F9	57

Example 3. Serial Port Timer with Timer 2 as Baud-Rate Generator

```
; Frequency           = 12 MHz
; Desired Baud Rate   = 9600 Baud
;
;
;    (RCAP2H, RCAP2L) = 65536 - (12 x 10^6) / (32) x (9600)
;
;                     = 65497 = FFD9H

MOV SCON, #0F0H       ; Serial port Mode 3, SM2 = 1,
                      ; REN = 1
MOV RCAP2H, #0FFH     ; Reload values for desired
MOV RCAP2L, #0D9H     ; baud rate
MOV T2CON, #34H       ; Timer 2 as baud rate
                      ; generator, turn on Timer 2
```

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APPLICATION BRIEF

AB-41

April 1989

2

Software Serial Port Implemented with the PCA

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Order Number: 270531-002

SOFTWARE SERIAL PORT IMPLEMENTED WITH THE PCA

CONTENTS

For microcontroller applications which require more than one serial port, the 83C51FA Programmable Counter Array (PCA) can implement additional half-duplex serial ports. If the on-chip UART is being used as an inter-processor link, the PCA can be used to interface the 83C51FA to additional asynchronous lines.

This application uses several different Compare/Capture modes available on the PCA to receive or transmit bytes of data. It is assumed the reader is familiar the PCA and ASM51. For more information on the PCA refer to the "Hardware Description of the 83C51FA" chapter in the Embedded Controller Handbook (Order No. 210918).

Introduction

The figure below shows the format of a standard 10-bit asynchronous frame: 1 start bit (0), 8 data bits, and 1 stop bit (1). The start bit is used to synchronize the receiver to the transmitter; at the leading edge of the start bit the receiver must set up its timing logic to sample the incoming line in the center of each bit. Following the start bit are eight data bits which are transmitted least significant bit first. The stop bit is set to the opposite state of the start bit to guarantee that the leading edge of the start bit will cause a transition on the line. It also provides a dead time on the line so that the receiver can maintain its synchronization.

Two of the Compare/Capture modes on the PCA are used in receiving and transmitting data bits. When receiving, the Negative-Edge Capture mode allows the PCA to detect the start bit. Then using the Software Timer mode, interrupts are generated to sample the incoming data bits. This same mode is used to clock out bits when transmitting.

This Application Note contains four sections of code:

(1) List of variables
(2) Initialization routine
(3) Receive routine
(4) Transmit routine.

A complete listing of the routines and the test loop which was used to verify their operation is found in the Appendix. A total of three half-duplex channels were run at 2400 Baud in the test program. The listings shown here are simplified to one channel (Channel 0).

Variables

Listing 1 shows the variables used in both the receive and transmit routines. Flags are defined to signify the status of the reception or transmission of a byte (e.g. RCV_START_BIT, TXM_START_BIT). RCV_BUF and TXM_BUF simulate the on-chip serial port SBUF as two separate buffer registers. The temporary registers, RCV_REG and TXM_REG, are used to save bits as they are received or transmitted. Finally, two counter registers keep track of how many bits have been received or transmitted.

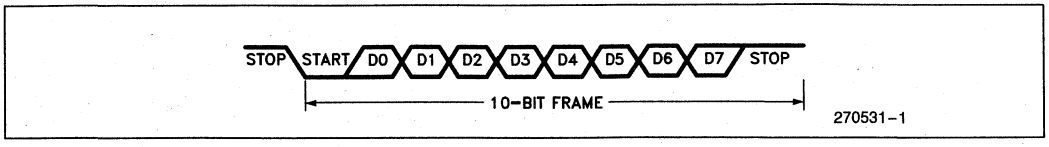
Variables are also needed to define one-half and one-full bit times in units of PCA timer ticks. (One bit time = 1 / baud rate.) With the PCA timer incremented every machine cycle, the equation to calculate one bit time can be written as:

$$\frac{\text{Osc. Freq.}}{(12) \times (\text{baud rate})} = 1 \text{ bit time (in PCA timer ticks)}$$

In this example, the baud rate is 2400 at 16 MHz.

$$\frac{16 \text{ MHz}}{(12) \times (2400)} = 556 \text{ counts} = 22\text{C Hex}$$

The high and low byte of this value is placed in the variables FULL_BIT_HIGH and FULL_BIT_LOW, respectively. 115H is the value loaded into HALF_BIT_HIGH and HALF_BIT_LOW.



Listing 1. Variables used by the software serial port. Channel 0

```
;
;  Receive Routine
;
RCV_START_BIT_0    BIT       20H.0     ; Indicates  start bit
                                       ; has been received
RCV_DONE_0         BIT       20H.1     ; Indicates  data byte
                                       ; has been received
RCV_BUF_0          DATA      30H       ; Software Receive
                                       ; "SBUF"
RCV_REG_0          DATA      31H       ; Temporary register
                                       ; for receive bits
RCV_COUNT_0        DATA      32H       ; Counter for receiving
                                       ; bits
;  Transmit Routine:
;
TXM_START_BIT_0    BIT       20H.3     ; Indicates start bit
                                       ; has been transmitted
TXM_IN_PROGRESS_0  BIT       20H.4     ; Indicates transmit is
                                       ; in progress
TXM_BUF_0          DATA      34H       ; Software transmit
                                       ; "SBUF"
TXM_REG_0          DATA      35H       ; Temporary register
                                       ; for transmitting bits
TXM_COUNT_0        DATA      36H       ; Counter for transmit-
                                       ; ting bits
DATA_0             DATA      37H       ; Register used for the
                                       ; test program
;
NEG_EDGE           EQU       11H       ; Two modes of operation
S_W_TIMER          EQU       49H       ; for compare/capture
                                       ; modules
;
HALF_BIT_HIGH      EQU       01H       ; Half bit time = 115H
HALF_BIT_LOW       EQU       15H
FULL_BIT_HIGH      EQU       02H       ; Full bit time = 22CH
FULL_BIT_LOW       EQU       2CH       ; 2400 Baud at 16 MHz
```

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Initialization

Listing 2 contains the intialization code for the receive and transmit process. Module 0 of the PCA is used as a receiver and is first set up to detect a negative edge from the start bit. Modules 2 and 3 are used for the additional 2 channels (see the Appendix). Module 3 is used as a separate software timer to transmit bits.

Listing 2. Initialization Routine

```
ORG 0000H
LJMP INITIALIZE
ORG 001BH
LJMP RECEIVE_DONE                ; Timer 1 overflow -
                                 ; simulates "RI" interrupt
ORG 0033H
LJMP RECEIVE                     ; PCA interrupt
;
INITIALIZE: MOV SP, #5FH         ; Initialize stack pointer
                                 ; (specific to test program)
INIT_PCA: MOV CMOD, #00H         ; Increment PCA timer
                                 ; @ 1/12 Osc Frequency
          MOV CCON, #00H         ; Clear all status flags
          MOV CCAPM0, #NEG_EDGE  ; Module 0 in negative-edge
                                 ; trigger mode (P1.3)
          MOV CCAPM3, #S_W_TIMER ; Module 3 as software timer
                                 ; mode
          MOV CL, #00H
          MOV CH, #00H
          MOV IE, #0D8H          ; Init all needed interrupts
                                 ; EA, EC, ES, ET1
          SETB CR                ; Turn on PCA Counter
```

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All flags and registers from Listing 1 should be cleared in the initialization process.

Receive Routine

Two operating modes of the PCA are needed to receive bits. The module must first be able to detect the leading edge of a start bit so it is initially set up to capture a 1-to-0 transition (i.e. Negative-Edge Capture mode). The module is then reconfigured as a software timer to cause an interrupt at the center of each bit to deserialize the incoming data. The flowchart for the receive routine is given in Figure 1.

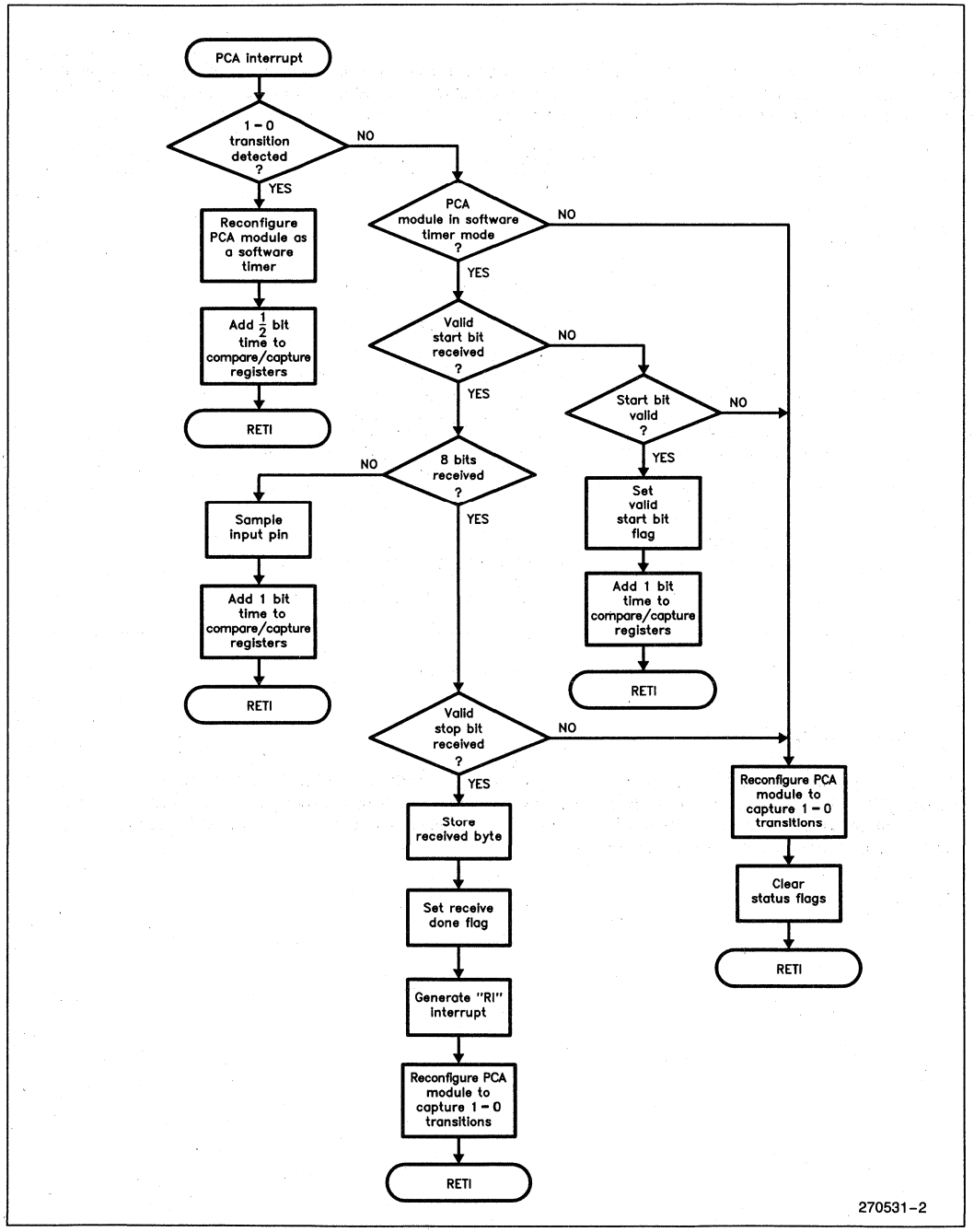

Figure 1. Flowchart for the Receive Routine

Listing 3.1 shows the code needed to detect a start bit. Notice that the first software timer interrupt will occur one-half bit time after the leading edge of the start bit to check its validity. If it is valid, the RCV_START_BIT is set. The rest of the samples will occur a full bit time later. The RCV_COUNT register is loaded with a value of 9 which indicates the number of bits to be sampled: 8 data bits and 1 stop bit.

Listing 3.1. Receive Interrupt Routine

```
RECEIVE:  PUSH ACC
          PUSH PSW
;
MODULE_0: CLR CCF0                  ; Assume reception on
                                    ; Module 0
          MOV A, CCAPM0             ; Check mode of module.  If
          ANL A, #01111111B         ; set up to receive negative
          CJNE A,#NEG_EDGE, RCV_START_0 ; edges, then module
                                    ; is waiting for a start  bit
;
          CLR C                     ; Update compare/capture
          MOV A, #HALF_BIT_LOW      ; registers for half bit time
          ADD A, CCAP0L             ; to sample start bit
          MOV CCAP0L, A             ; Half bit time = 115H
          MOV A, #HALF_BIT_HIGH
          ADDC A, CCAP0H
          MOV CCAP0H, A
          MOV CCAPM0, #S_W_TIMER ; Reconfigure module 0 as
          POP PSW                   ; a software timer to sample
          POP ACC                   ; bits
          RETI
;
RCV_START_0: CJNE A, #S_W_TIMER, ERROR_0 ; Check module is
                                    ; configured as a software
                                    ; timer, otherwise error.
          JB RCV_START_BIT_0, RCV_BYTE_0 ; Check if start bit
                                    ; is received yet.
          JB P1.3, ERROR_0          ; Check that start bit = 0,
                                    ; otherwise error.
          SETB RCV_START_BIT_0      ; Signify valid start bit
                                    ; was received
          MOV RCV_COUNT_0, #09H     ; Start counting bits sampled
;
          CLR C                     ; Update compare/capture
          MOV A, #FULL_BIT_LOW      ; registers to sample
          ADD A, CCAP0L             ; incoming bits
          MOV CCAP0L, A             ; Full bit time = 22CH
          MOV A, #FULL_BIT_HIGH
          ADDC A, CCAP0H
          MOV CCAP0H, A
          POP PSW
          POP ACC
          RETI
```

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The next 8 timer interrupts will receive the incoming data bits; the RCV__COUNT register keeps track of how many bits have been sampled. As each bit is sampled, it is shifted through the Carry Flag and saved in RCV__REG. The ninth sample checks the validity of the stop bit. If it is valid, the data byte is moved into RCV__BUF.

The main routine must have a way to know that a byte has been received. With the on-chip UART, the RI (Receive Interrupt) bit is set whenever a byte has been received. For the software serial port, any unimplemented interrupt vector can be used to generate an interrupt when a byte has been received. This routine uses the Timer 1 Overflow interrupt (its selection is arbitrary). A routine to test this interrupt is included in the listing in the Appendix.

Listing 3.2. Receive Interrupt Routine (Continued)

```
RCV_BYTE_0: DJNZ RCV_COUNT_0, RCV_DATA_0  ; On 9th sample,
                                          ; check for valid stop bit
RCV_STOP_0: JNB P1.3, ERROR_0
            MOV RCV_BUF_0, RCV_REG_0 ; Save received byte in
                                     ; receive "SBUF"
            SETB RCV_DONE_0          ; Flag which module received
                                     ; a byte
            SETB TF1                 ; Generate an interrupt so
                                     ; main program knows a byte
                                     ; has been received
                                     ; (Note: selection of TF1 is
                                     ; arbitrary)
            MOV CCAPM0, #NEG_EDGE    ; Reconfigure module 0 for
                                     ; Reception of a start bit
            POP PSW
            POP ACC
            RETI
;
RCV_DATA_0: MOV C, P1.3              ; Sampling data bits
            MOV A, RCV_REG_0         ; Shifts bits thru CY into
            RRC A                    ; ACC
            MOV RCV_REG_0, A         ; Save each reception in
                                     ; temporary register
            CLR C                    ; Update c/c register for
            MOV A, #FULL_BIT_LOW     ; next sample time
            ADD A, CCAP0L
            MOV CCAP0L, A
            MOV A, #FULL_BIT_HIGH
            ADDC A, CCAP0H
            MOV CCAP0H, A
            POP PSW
            POP ACC
            RETI
```

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In addition, an error routine (Listing 3.3) is included for invalid start or stop bits to offer some protection against noise. If an error occurs, the module is re-initialized to look for another start bit.

Listing 3.3 Error Routine for Receive Routine

```
ERROR_0:  MOV CCAPM0, #NEG_EDGE  ; Reset module to look for
                                 ; start bit
          CLR RCV_START_BIT_0    ; Clear flags which might
                                 ; have been set
          POP PSW
          POP ACC
          RETI
```

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Transmit Routine

Another PCA module is configured as a software timer to interrupt the CPU every bit time. With each timer interrupt one or more bits can be transmitted through port pins. In the test program three channels were operated simultaneously, but in the listings below, one channel is shown for simplicity. The selection of port pins is user programmable. The flowchart for the transmit routine is given in Figure 2.

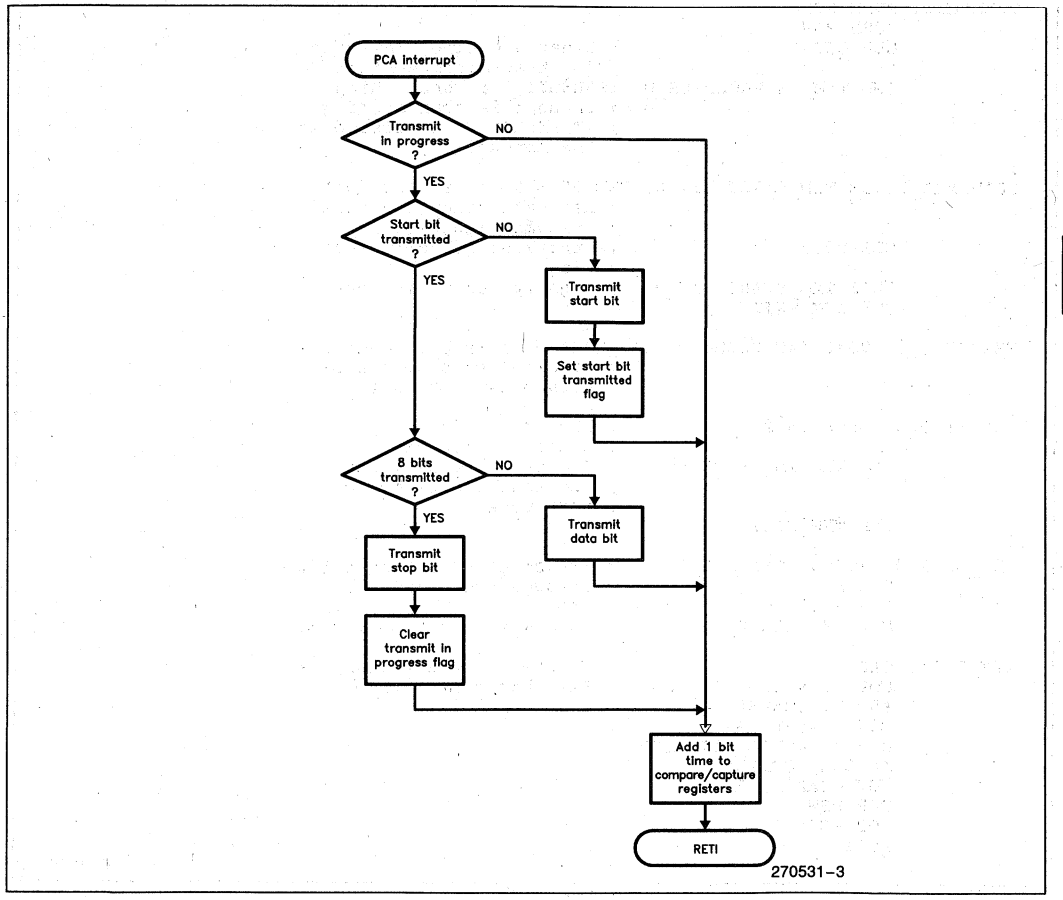

Figure 2. Flowchart for the Transmit Routine

When a byte is ready to be transmitted, the main program moves the data byte into the TXM_BUF register and sets the corresponding TXM_IN_PROGRESS bit. This bit informs the interrupt routine which channel is transmitting. The data byte is then moved in the storage register TXM_REG, and the TXM_COUNT is loaded. This main routine is shown in Listing 4.1.

Listing 4.1 Transmit Set Up Routine. Channel 0.

```
TXM_ON_0: CLR TXM_START_BIT_0     ; Clear status flag from
                                  ; previous transmission
          MOV TXM_BUF_0, DATA_0   ; Load "SBUF" with data byte
          MOV TXM_REG_0, TXM_BUF_0
          MOV TXM_COUNT_0, #09    ; 8 data bits + 1 stop bit
          SETB TXM_IN_PROGRESS_0
```

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Listing 4.2 shows the transmit interrupt routine. The first time through, the start bit is transmitted. As each successive interrupt outputs a bit, the contents of TXM_REG is shifted right one place into the Carry flag, and the TXM_COUNT is decremented. When TXM_COUNT equals zero, the stop bit is transmitted.

Listing 4.2. Transmit Interrupt Routine

```
TRANSMIT: PUSH ACC
          PUSH PSW
          CLR CCF3                  ; Clear s/w timer interrupt
                                    ; for transmitting bits
          JNB TXM_IN_PROGRESS_0, TRANSMIT_1 ; Check which
                                    ; channel is transmitting.
                                    ; "TRANSMIT_1" is listed in
                                    ; the Appendix
;
TRANSMIT_0: JB TXM_START_BIT_0, TXM_BYTE_0  ; If start bit
                                    ; has been sent, continue
                                    ; transmitting bits.
          CLR P3.2                  ; Otherwise transmit start
                                    ; bit
          SETB TXM_START_BIT_0      ; Signify start bit sent
          JMP TXM_EXIT
;
TXM_BYTE_0: DJNZ TXM_COUNT_0, TXM_DATA_0  ; If bit count
                                    ; equals 1 thru 9, transmit
                                    ; data bits (8 total)
;
TXM_STOP_0: SETB P3.2               ; When bit count = 0,
                                    ; transmit stop bit
          CLR TXM_IN_PROGRESS_0     ; Indicate transmission is
                                    ; finished and ready for
                                    ; next byte
          JMP TXM_EXIT
;
TXM_DATA_0: MOV A, TXM_REG_0        ; Transmit one bit at a time
          RRC A                     ; through the carry bit
          MOV P3.2, C
          MOV TXM_REG_0, A          ; Save what's not been sent
;
TXM_EXIT: CLR C                     ; Update compare value with
          MOV A, #FULL_BIT_LOW      ; Full bit time = 22CH
          ADD A, CCAP3L
          MOV CCAP3L, A
          MOV A, #FULL_BIT_HIGH
          ADDC A, CCAP3H
          MOV CCAP3H, A
          POP PSW
          POP ACC
          RETI
```

270531-10

Conclusion

The software routines in the Appendix can be altered to vary the baud rate and number of channels to fit a particular application. The number of channels which can be implemented is limited by the CPU time required to service the PCA interrupt. At higher baud rates, fewer channels can be run.

The test program verifies the simultaneous operation of three half-duplex channels at 2400 Baud and the on-chip full-duplex channel at 9600 Baud. Thirty-three percent of the CPU time is required to operate all four channels. The test was run for several hours with no apparent malfunctions.

```
MCS-51 MACRO ASSEMBLER    SWPORT                                    01/01/80   PAGE    1

DOS 3.20 (038-N) MCS-51 MACRO ASSEMBLER, V2.2
OBJECT MODULE PLACED IN SWPORT.OBJ
ASSEMBLER INVOKED BY:  C:\AEDIT\ASM51.EXE SWPORT.RCV

LOC  OBJ            LINE     SOURCE

                       1     $NOMOD51
                       2     $NOSYMBOLS
                       3     $NOLIST
                     152     ;
                     153     ;
                     154     ;
                     155     ; This program tests the receive routines of a software serial port.
                     156     ; Three half-duplex channels are implemented in software to run at
                     157     ; 2400 Baud (16MHz).  The on-chip serial port is also running full-duplex
                     158     ; at 9600 Baud.  Thirty-three percent of the CPU time is required to run
                     159     ; all four ports simultaneously.
                     160     ;
                     161     ; To test the receive routines, "dummy" terminals transmit 00 - FF hex
                     162     ; continually to the PCA.  When the first byte is received, it is
                     163     ; compared with 00.  If the comparison is valid, the compare value is
                     164     ; incremented and the routine waits to receive the next byte.  Error
                     165     ; routines toggle various Port 3 pins if an invalid comparison occurs
                     166     ; or if an invalid start bit or stop bit is received.
                     167     ;
0000                 168     ORG 00H
0000 020036          169     LJMP INITIALIZE
                     170     ;
001B                 171     ORG 001BH
001B 02025C          172     LJMP RECEIVE_DONE              ; Timer 1 Overflow - simulates "RI" interrupt
                     173     ;
0023                 174     ORG 0023H
0023 020282          175     LJMP SERIAL_PORT               ; Serial port interrupt
                     176     ;
0033                 177     ORG 0033H                      ; PCA interrupt
0033 0200DC          178     LJMP RECEIVE
                     179     ;
                     180     ;
                     181     ;               VARIABLES USED BY THE SOFTWARE SERIAL PORT
                     182     ;               =========================================
                     183     ;
                     184     ;  RECEIVE ROUTINE:
                     185     ;  ----------------
                     186     ;
0000                 187     RCV_START_BIT_0        BIT          20H.0   ; Indicates start bit has been
0008                 188     RCV_START_BIT_1        BIT          21H.0   ; received
0010                 189     RCV_START_BIT_2        BIT          22H.0
                     190     ;
0001                 191     RCV_DONE_0             BIT          20H.1   ; Indicates data byte has been
0009                 192     RCV_DONE_1             BIT          21H.1   ; received
0011                 193     RCV_DONE_2             BIT          22H.1
                     194     ;
0002                 195     RCV_ON_0               BIT          20H.2   ; Used in main test program to check
000A                 196     RCV_ON_1               BIT          21H.2   ; for a received byte
0012                 197     RCV_ON_2               BIT          22H.2
                     198     ;
```

270531-11

```
LOC  OBJ            LINE     SOURCE

  0030                199     RCV_BUF_0             DATA        30H     ; Software receive "SBUF"
  0040                200     RCV_BUF_1             DATA        40H
  0050                201     RCV_BUF_2             DATA        50H
                      202     ;
  0031                203     RCV_REG_0             DATA        31H     ; Temporary register for
  0041                204     RCV_REG_1             DATA        41H     ; receiving bits
  0051                205     RCV_REG_2             DATA        51H
                      206     ;
  0032                207     RCV_COUNT_0           DATA        32H     ; Counter for receiving bits
  0042                208     RCV_COUNT_1           DATA        42H
  0052                209     RCV_COUNT_2           DATA        52H
                      210     ;
  0033                211     COUNT_0               DATA        33H     ; Used in test program to check
  0043                212     COUNT_1               DATA        43H     ; bytes being received
  0053                213     COUNT_2               DATA        53H
                      214     ;
  0011                215     NEG_EDGE              EQU         11H     ; Two modes of operation for the
  0049                216     S_W_TIMER             EQU         49H     ; Compare/Capture modules
                      217     ;
  0015                218     HALF_BIT_LOW          EQU         15H     ; Half bit time = 115H
  0001                219     HALF_BIT_HIGH         EQU         01H
  002C                220     FULL_BIT_LOW          EQU         2CH     ; Full bit time = 22CH
  0002                221     FULL_BIT_HIGH         EQU         02H
                      222                                               ; 2400 Baud @ 16MHz
                      223     ;
                      224     ;
                      225
                      226     ;
                      227     ;                                 INITIALIZATION ROUNTINE
                      228     ;                                 =======================
                      229     ;
0036 75815F           230     INITIALIZE:     MOV SP, #5FH                ; Initialize stack pointer
                      231                                                 ; (specific to the test program)
0039 75D900           232     INIT_PCA:       MOV CMOD, #00H              ; Increment PCA clock @ 1/12 Osc Freq
003C 75D800           233                     MOV CCON, #00H              ; Clear all status flags
003F 75DA11           234                     MOV CCAPM0, #NEG_EDGE       ; Module 0 in Neg-edge capture mode (P1.3)
0042 75DB11           235                     MOV CCAPM1, #NEG_EDGE       ; Module 1        "                 (P1.4)
0045 75DC11           236                     MOV CCAPM2, #NEG_EDGE       ; Module 2        "                 (P1.5)
                      237     ;
0048 75E900           238                     MOV CL, #00H
004B 75F900           239                     MOV CH, #00H
004E 75A8D8           240                     MOV IE, #0D8H               ; Initialize needed interrupt: EA,EC,ES,ET1
0051 D2DE             241                     SETB CR                     ; Turn on PCA counter
                      242     ;
0053 759850           243     INIT_SP:        MOV SCON, #50H              ; Serial port in mode 1 (8-Bit UART)
0056 75CBFF           244                     MOV RCAP2H, #0FFH           ; Reload values for 9600 Baud @ 16 MHz
0059 75CACC           245                     MOV RCAP2L, #0CCH
005C 75C834           246                     MOV T2CON, #34H             ; Timer 2 as a baud-rate generator,
                      247                                                 ; turn on timer 2
                      248     ;
005F C200             249     INIT_FLAGS:     CLR RCV_START_BIT_0
0061 C208             250                     CLR RCV_START_BIT_1
0063 C210             251                     CLR RCV_START_BIT_2
                      252     ;
0065 C201             253                     CLR RCV_DONE_0
```

```
LOC  OBJ            LINE     SOURCE

0067 C209            254                 CLR RCV_DONE_1
0069 C211            255                 CLR RCV_DONE_2
                     256     ;
006B C202            257                 CLR RCV_ON_0
006D C20A            258                 CLR RCV_ON_1
006F C212            259                 CLR RCV_ON_2
                     260     ;
                     261     ; Port 3 pins used in test program for error routines
                     262     ;
                     263     ; Main program:
0071 D2B2            264                 SETB P3.2                   ; Error in comparison on module 0
0073 D2B3            265                 SETB P3.3                   ; Error in comparison on module 1
0075 D2B4            266                 SETB P3.4                   ; Error in comparison on module 2
                     267     ;
                     268     ; Interrupt routines:
0077 D2B5            269                 SETB P3.5                   ; Error in reception on module 0
0079 D2B6            270                 SETB P3.6                   ; Error in reception on module 1
007B D2B7            271                 SETB P3.7                   ; Error in reception on module 2
                     272     ;
007D 753000          273                 MOV RCV_BUF_0, #00H
0080 754000          274                 MOV RCV_BUF_1, #00H
0083 755000          275                 MOV RCV_BUF_2, #00H
                     276     ;
0086 753200          277                 MOV RCV_COUNT_0, #00H
0089 754200          278                 MOV RCV_COUNT_1, #00H
008C 755200          279                 MOV RCV_COUNT_2, #00H
                     280     ;
008F 753100          281                 MOV RCV_REG_0, #00H
0092 754100          282                 MOV RCV_REG_1, #00H
0095 755100          283                 MOV RCV_REG_2, #00H
                     284     ;
0098 753300          285                 MOV COUNT_0, #00H
009B 754300          286                 MOV COUNT_1, #00H
009E 755300          287                 MOV COUNT_2, #00H
                     288     ;
                     289     ;
                     290     ;                       MAIN TEST ROUTINE - RECEIVE BITS
                     291     ;                       ================================
                     292     ;
                     293     ;
00A1 300209          294     CHECK_0:    JNB RCV_ON_0, CHECK_1       ; Main program continually checks
00A4 E530            295                 MOV A, RCV_BUF_0            ; each channel for a received byte.
00A6 B5331E          296                 CJNE A, COUNT_0, ERROR0     ; Once a byte is received, it is compared
00A9 C202            297                 CLR RCV_ON_0                ; with the current value in the "COUNT"
00AB 0533            298                 INC COUNT_0                 ; register
                     299     ;
00AD 300A09          300     CHECK_1:    JNB RCV_ON_1, CHECK_2
00B0 E540            301                 MOV A, RCV_BUF_1
00B2 B54319          302                 CJNE A, COUNT_1, ERROR1
00B5 C20A            303                 CLR RCV_ON_1
00B7 0543            304                 INC COUNT_1
                     305     ;
00B9 3012E5          306     CHECK_2:    JNB RCV_ON_2, CHECK_0
00BC E550            307                 MOV A, RCV_BUF_2
00BE B55314          308                 CJNE A, COUNT_2, ERROR2
```

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```
LOC  OBJ            LINE     SOURCE

00C1 C212            309              CLR RCV_ON_2
00C3 0553            310              INC COUNT_2
00C5 80DA            311              JMP CHECK_0
                     312      ;
00C7 C2B2            313      ERROR0: CLR P3.2                 ; Error in comparison on module 0
00C9 75DA00          314              MOV CCAPM0, #00H        ; Discontinue receiving bytes
00CC 80DF            315              JMP CHECK_1
                     316      ;
00CE C2B3            317      ERROR1: CLR P3.3                 ; Error in comparison on module 1
00D0 75DB00          318              MOV CCAPM1, #00H
00D3 80E4            319              JMP CHECK_2
                     320      ;
00D5 C2B4            321      ERROR2: CLR P3.4                 ; Error in comparison on module 2
00D7 75DC00          322              MOV CCAPM2, #00H
00DA 80C5            323              JMP CHECK_0
                     324      ;
                     325      ;
                     326      ;
                     327      ;                       PCA INTERRUPT ROUNTINE - RECEIVE BITS
                     328      ;                       =====================================
                     329      ;
00DC C0E0            330      RECEIVE: PUSH ACC
00DE C0D0            331              PUSH PSW
                     332      ;
00E0 20D811          333              JB CCF0, MODULE_0       ; Check which module caused
00E3 20D908          334              JB CCF1, JUMP_1         ; PCA interrupt and jump to
00E6 20DA08          335              JB CCF2, JUMP_2         ; appropriate routine
00E9 D0D0            336              POP PSW
00EB D0E0            337              POP ACC
00ED 32              338              RETI
                     339      ;
00EE 02016C          340      JUMP_1: LJMP MODULE_1
00F1 0201E4          341      JUMP_2: LJMP MODULE_2
                     342      ;
                     343      ;
                     344      ;
                     345      ;                       CHANNEL 0
                     346      ;                       ---------
                     347      ;
00F4 C2D8            348      MODULE_0: CLR CCF0               ; Reception on module 0
00F6 E5DA            349              MOV A, CCAPM0           ; Check mode of module. If set up to
00F8 547F            350              ANL A, #01111111B       ; receive negative edges, then module
00FA B41115          351              CJNE A, #NEG_EDGE, RCV_START_0 ; is waiting for a start bit
                     352      ;
00FD C3              353              CLR C                   ; Update Compare/Capture registers for
00FE 7415            354              MOV A, #HALF_BIT_LOW    ; half a bit time
0100 25EA            355              ADD A, CCAP0L           ; to sample start bit
0102 F5EA            356              MOV CCAP0L, A           ; Half bit time = 115H
0104 7401            357              MOV A, #HALF_BIT_HIGH
0106 35FA            358              ADDC A, CCAP0H
0108 F5FA            359              MOV CCAP0H, A
010A 75DA49          360              MOV CCAPM0, #S_W_TIMER  ; Reconfigure module 0 as
                     361                                      ; a software timer to sample bits
010D D0D0            362              POP PSW
010F D0E0            363              POP ACC
```

270531-14

```
LOC  OBJ             LINE     SOURCE

0111 32               364                 RETI
                      365      ;
0112 B4494B           366      RCV_START_0:  CJNE A, #S_W_TIMER, ERROR_0     ; Check module is configured
                      367                                                    ; as a software timer, otherwise error.
0115 20001A           368                 JB RCV_START_BIT_0, RCV_BYTE_0    ; Check if start bit
                      369                                                    ; has been received yet
0118 209345           370                 JB P1.3, ERROR_0                  ; Check that start bit = 0,
                      371                                                    ; otherwise error.
011B D200             372                 SETB RCV_START_BIT_0              ; Signify valid start bit
                      373                                                    ; was received
011D 753209           374                 MOV RCV_COUNT_0, #09H             ; Start counting bits sampled
                      375      ;
0120 C3               376                 CLR C                             ; Update C/C registers to sample
0121 742C             377                 MOV A, #FULL_BIT_LOW              ; incoming bits
0123 25EA             378                 ADD A, CCAP0L                     ; Full bit time = 22CH
0125 F5EA             379                 MOV CCAP0L, A
0127 7402             380                 MOV A, #FULL_BIT_HIGH
0129 35FA             381                 ADDC A, CCAP0H
012B F5FA             382                 MOV CCAP0H, A
012D D0D0             383                 POP PSW
012F D0E0             384                 POP ACC
0131 32               385                 RETI
                      386      ;
0132 D53212           387      RCV_BYTE_0:   DJNZ RCV_COUNT_0, RCV_DATA_0    ; On 9th sample, check for
                      388                                                    ; valid stop bit
0135 309328           389      RCV_STOP_0:   JNB P1.3, ERROR_0
0138 853130           390                 MOV RCV_BUF_0, RCV_REG_0          ; Save received byte in receive "SBUF"
013B D201             391                 SETB RCV_DONE_0                   ; Flag which module received a byte
013D D28F             392                 SETB TF1                          ; Generate an interrupt so main program
                      393                                                    ; knows a byte has been received
                      394                                                    ; (NOTE: selection of TF1 is arbitrary)
013F 75DA11           395                 MOV CCAPM0, #NEG_EDGE             ; Reconfigure module 0 for next
0142 D0D0             396                 POP PSW                           ; reception of a start bit
0144 D0E0             397                 POP ACC
0146 32               398                 RETI
                      399      ;
0147 A293             400      RCV_DATA_0:   MOV C, P1.3                     ; Sampling data bits
0149 E531             401                 MOV A, RCV_REG_0                  ; Shift bits through CY into ACC
014B 13               402                 RRC A
014C F531             403                 MOV RCV_REG_0, A                  ; Save each reception in temporary
                      404                                                    ; register
014E C3               405                 CLR C
014F 742C             406                 MOV A, #FULL_BIT_LOW              ; Update C/C register for next
0151 25EA             407                 ADD A, CCAP0L                     ; sample time
0153 F5EA             408                 MOV CCAP0L, A
0155 7402             409                 MOV A, #FULL_BIT_HIGH
0157 35FA             410                 ADDC A, CCAP0H
0159 F5FA             411                 MOV CCAP0H, A
015B D0D0             412                 POP PSW
015D D0E0             413                 POP ACC
015F 32               414                 RETI
                      415      ;
0160 C2B5             416      ERROR_0:      CLR P3.5                        ; Error routine for invalid start or
                      417                                                    ; stop bit or invalid mode comparison
```

270531-15

```
LOC  OBJ            LINE     SOURCE

                     418                                        ; Port pin used for debug only
0162 75DA11          419                 MOV CCAPM0, #NEG_EDGE  ; Reset module to look for start bit
0165 C200            420                 CLR RCV_START_BIT_0    ; Clear flags which might have been set
0167 D0D0            421                 POP PSW
0169 D0E0            422                 POP ACC
016B 32              423                 RETI
                     424     ;
                     425     ;
                     426     ;                     CHANNEL 1
                     427     ;                     ---------
                     428     ;
016C C2D9            429     MODULE_1:   CLR CCF1               ; Similar to module 0
016E E5DB            430                 MOV A, CCAPM1
0170 547F            431                 ANL A, #01111111B
0172 B41115          432                 CJNE A, #NEG_EDGE, RCV_START_1
                     433     ;
0175 C3              434                 CLR C
0176 7415            435                 MOV A, #HALF_BIT_LOW
0178 25EB            436                 ADD A, CCAP1L
017A F5EB            437                 MOV CCAP1L, A
017C 7401            438                 MOV A, #HALF_BIT_HIGH
017E 35FB            439                 ADDC A, CCAP1H
0180 F5FB            440                 MOV CCAP1H, A
0182 75DB49          441                 MOV CCAPM1, #S_W_TIMER
0185 D0D0            442                 POP PSW
0187 D0E0            443                 POP ACC
0189 32              444                 RETI
                     445     ;
018A B4494B          446     RCV_START_1: CJNE A, #S_W_TIMER, ERROR_1
018D 20081A          447                 JB RCV_START_BIT_1, RCV_BYTE_1
0190 209445          448                 JB P1.4, ERROR_1
                     449     ;
0193 D208            450                 SETB RCV_START_BIT_1
0195 754209          451                 MOV RCV_COUNT_1, #09H
                     452     ;
0198 C3              453                 CLR C
0199 742C            454                 MOV A, #FULL_BIT_LOW
019B 25EB            455                 ADD A, CCAP1L
019D F5EB            456                 MOV CCAP1L, A
019F 7402            457                 MOV A, #FULL_BIT_HIGH
01A1 35FB            458                 ADDC A, CCAP1H
01A3 F5FB            459                 MOV CCAP1H, A
01A5 D0D0            460                 POP PSW
01A7 D0E0            461                 POP ACC
01A9 32              462                 RETI
                     463     ;
01AA D54212          464     RCV_BYTE_1: DJNZ RCV_COUNT_1, RCV_DATA_1
                     465     ;
01AD 309428          466     RCV_STOP_1: JNB P1.4, ERROR_1
01B0 854140          467                 MOV RCV_BUF_1, RCV_REG_1
01B3 D209            468                 SETB RCV_DONE_1
01B5 D28F            469                 SETB TF1
01B7 75DB11          470                 MOV CCAPM1, #NEG_EDGE
01BA D0D0            471                 POP PSW
01BC D0E0            472                 POP ACC
```

270531-16

```
LOC  OBJ            LINE     SOURCE

01BE 32              473                    RETI
                     474     ;
01BF A294            475     RCV_DATA_1:    MOV C, P1.4
01C1 E541            476                    MOV A, RCV_REG_1
01C3 13              477                    RRC A
01C4 F541            478                    MOV RCV_REG_1, A
                     479     ;
01C6 C3              480                    CLR C
01C7 742C            481                    MOV A, #FULL BIT_LOW
01C9 25EB            482                    ADD A, CCAP1L
01CB F5EB            483                    MOV CCAP1L, A
01CD 7402            484                    MOV A, #FULL BIT_HIGH
01CF 35FB            485                    ADDC A, CCAP1H
01D1 F5FB            486                    MOV CCAP1H, A
01D3 D0D0            487                    POP PSW
01D5 D0E0            488                    POP ACC
01D7 32              489                    RETI
                     490     ;
01D8 C2B6            491     ERROR_1:       CLR P3.6
01DA 75DB11          492                    MOV CCAPM1, #NEG EDGE
01DD C208            493                    CLR RCV_START_BIT_1
01DF D0D0            494                    POP PSW
01E1 D0E0            495                    POP ACC
01E3 32              496                    RETI
                     497     ;
                     498     ;
                     499     ;                              CHANNEL 2
                     500     ;                              ---------
                     501     ;
                     502     ;
                     503     ;
01E4 C2DA            504     MODULE_2:      CLR CCF2                    ; Similar to module 0
01E6 E5DC            505                    MOV A, CCAPM2
01E8 547F            506                    ANL A, #01111111B
01EA B41115          507                    CJNE A, #NEG_EDGE, RCV_START_2
                     508     ;
01ED C3              509                    CLR C
01EE 7415            510                    MOV A, #HALF BIT_LOW
01F0 25EC            511                    ADD A, CCAP2L
01F2 F5EC            512                    MOV CCAP2L, A
01F4 7401            513                    MOV A, #HALF BIT_HIGH
01F6 35FC            514                    ADDC A, CCAP2H
01F8 F5FC            515                    MOV CCAP2H, A
01FA 75DC49          516                    MOV CCAPM2, #S_W_TIMER
01FD D0D0            517                    POP PSW
01FF D0E0            518                    POP ACC
0201 32              519                    RETI
                     520     ;
0202 B4494B          521     RCV_START_2:   CJNE A, #S W TIMER, ERROR 2
0205 20101A          522                    JB RCV START BIT 2, RCV_BYTE_2
0208 209545          523                    JB P1.5, ERROR_2
                     524     ;
020B D210            525                    SETB RCV START BIT 2
020D 755209          526                    MOV RCV_COUNT_Z, #09H
                     527     ;
```

270531-17

```
LOC  OBJ             LINE     SOURCE

0210 C3               528                      CLR C
0211 742C             529                      MOV A, #FULL_BIT_LOW
0213 25EC             530                      ADD A, CCAP2L
0215 F5EC             531                      MOV CCAP2L, A
0217 7402             532                      MOV A, #FULL_BIT_HIGH
0219 35FC             533                      ADDC A, CCAPZH
021B F5FC             534                      MOV CCAP2H, A
021D D0D0             535                      POP PSW
021F D0E0             536                      POP ACC
0221 32               537                      RETI
                      538      ;
0222 D55212           539      RCV_BYTE_2:     DJNZ RCV_COUNT_2, RCV_DATA_2
                      540      ;
0225 309528           541      RCV_STOP_2:     JNB P1.5, ERROR_2
0228 855150           542                      MOV RCV_BUF_2, RCV_REG_2
022B D211             543                      SETB RCV_DONE_2
022D D28F             544                      SETB TF1
022F 75DC11           545                      MOV CCAPM2, #NEG_EDGE
0232 D0D0             546                      POP PSW
0234 D0E0             547                      POP ACC
0236 32               548                      RETI
                      549      ;
0237 A295             550      RCV_DATA_2:     MOV C, P1.5
0239 E551             551                      MOV A, RCV_REG_2
023B 13               552                      RRC A
023C F551             553                      MOV RCV_REG_2, A
023E C3               554                      CLR C
023F 742C             555                      MOV A, #FULL_BIT_LOW
0241 25EC             556                      ADD A, CCAP2L
0243 F5EC             557                      MOV CCAP2L, A
0245 7402             558                      MOV A, #FULL_BIT_HIGH
0247 35FC             559                      ADDC A, CCAPZH
0249 F5FC             560                      MOV CCAP2H, A
024B D0D0             561                      POP PSW
024D D0E0             562                      POP ACC
024F 32               563                      RETI
                      564      ;
0250 C2B7             565      ERROR_2:        CLR P3.7
0252 75DC11           566                      MOV CCAPM2, #NEG_EDGE
0255 C210             567                      CLR RCV_START_BIT_2
0257 D0D0             568                      POP PSW
0259 D0E0             569                      POP ACC
025B 32               570                      RETI
                      571      ;
                      572      ;
                      573      ;
                      574      ;
                      575      ; This routine simulates the "RI" interrupt.  When a byte is received on one
                      576      ; of the channels, this interrupt is generated.  Bits are set so the main
                      577      ; routine knows which channel received a byte.
                      578      ;
                      579      ;
025C C0E0             580      RECEIVE_DONE:   PUSH ACC
025E C0D0             581                      PUSH PSW
0260 C28F             582                      CLR TF1
```

```
LOC  OBJ            LINE     SOURCE

0262 300106          583                 JNB RCV_DONE_0, RCV_1   ; Check which module received a byte
0265 C201            584                 CLR RCV_DONE_0          ; Clear flags needed for next reception
0267 C200            585                 CLR RCV_START_BIT_0
0269 D202            586                 SETB RCV_ON_0           ; Tell main routine which channel received
                     587                                         ; a byte
026B 300906          588     RCV_1:      JNB RCV_DONE_1, RCV_2
026E C209            589                 CLR RCV_DONE_1
0270 C208            590                 CLR RCV_START_BIT_1
0272 D20A            591                 SETB RCV_ON_1
                     592     ;
0274 301106          593     RCV_2:      JNB RCV_DONE_2, RETURN
0277 C211            594                 CLR RCV_DONE_2
0279 C210            595                 CLR RCV_START_BIT_2
027B D212            596                 SETB RCV_ON_2
                     597     ;
027D D0D0            598     RETURN:     POP PSW
027F D0E0            599                 POP ACC
0281 32              600                 RETI
                     601     ;
                     602     ;
                     603     ;
                     604     ;
                     605     ;           SERIAL PORT INTERRUPT
                     606     ;           =====================
                     607     ;
                     608     ; When a byte is received on the full-duplex serial port, it is then
                     609     ; transmitted back to a "dummy" terminal.  This terminal checks that the
                     610     ; byte it transmitted to the PCA is the same value it receives back.
                     611     ;
                     612     ;
0282 C0E0            613     SERIAL_PORT:PUSH ACC
0284 C0D0            614                 PUSH PSW
0286 30980B          615                 JNB RI, TXM             ; Check whether RI or TI
0289 E599            616                 MOV A, SBUF             ; caused the interrupt
028B C298            617                 CLR RI
028D F599            618                 MOV SBUF, A
028F D0D0            619                 POP PSW
0291 D0E0            620                 POP ACC
0293 32              621                 RETI
                     622     ;
0294 C299            623     TXM:        CLR TI
0296 D0D0            624                 POP PSW
0298 D0E0            625                 POP ACC
029A 32              626                 RETI
                     627     ;
                     628     END

REGISTER BANK(S) USED: 0

ASSEMBLY COMPLETE, NO ERRORS FOUND
```

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```
MCS-51 MACRO ASSEMBLER    SWPORT                                    01/01/80   PAGE    1


DOS 3.20 (038-N) MCS-51 MACRO ASSEMBLER, V2.2
OBJECT MODULE PLACED IN SWPORT.OBJ
ASSEMBLER INVOKED BY:  C:\AEDIT\ASM51.EXE SWPORT.TR


LOC  OBJ            LINE     SOURCE

                       1     $NOMOD51
                       2     $NOSYMBOLS
                       3     $NOLIST
                     152     ;
                     153     ;
                     154     ; This program tests the transmit routines for the software serial port.
                     155     ; To initialize the first transmission, the compare values are loaded before
                     156     ; the PCA timer is started.  Successive interrupts are generated every bit
                     157     ; time by the software timer.
                     158     ;
                     159     ; For test purposes, the data transmitted increments from 00 to FF hex.
                     160     ; "Dummy" terminals receive these bytes and display the bytes as they
                     161     ; are incremented.
                     162     ;
                     163     ;
0000                 164     ORG 00H
0000 020036          165     LJMP INIT_TXM
                     166     ;
0023                 167     ORG 0023H
0023 02014B          168     LJMP SERIAL_PORT                    ; Serial port interrupt
                     169     ;
0033                 170     ORG 0033H
0033 0200D0          171     LJMP TRANSMIT                       ; PCA software timer interrupt
                     172     ;
                     173     ;
                     174     ;                          VARIABLES USED BY THE SOFTWARE SERIAL PORT
                     175     ;                          ==========================================
                     176     ;
  0003               177     TXM_START_BIT_0       BIT          20H.3   ; Indicates start bit has been
  000B               178     TXM_START_BIT_1       BIT          21H.3   ; transmitted
  0013               179     TXM_START_BIT_2       BIT          22H.3
                     180     ;
  0004               181     TXM_IN_PROGRESS_0     BIT          20H.4   ; Indicates transmit is in progress
  000C               182     TXM_IN_PROGRESS_1     BIT          21H.4
  0014               183     TXM_IN_PROGRESS_2     BIT          22H.4
                     184     ;
  0034               185     TXM_BUF_0             DATA         34H     ; Software transmit "SBUF"
  0044               186     TXM_BUF_1             DATA         44H
  0054               187     TXM_BUF_2             DATA         54H
                     188     ;
  0035               189     TXM_REG_0             DATA         35H     ; Temporary register for
  0045               190     TXM_REG_1             DATA         45H     ; transmitting bits
  0055               191     TXM_REG_2             DATA         55H
                     192     ;
  0036               193     TXM_COUNT_0           DATA         36H     ; Counter for transmitting bits
  0046               194     TXM_COUNT_1           DATA         46H
  0056               195     TXM_COUNT_2           DATA         56H
                     196     ;
  0037               197     DATA_0                DATA         37H     ; Register used for the test
  0047               198     DATA_1                DATA         47H     ; program
```

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```
LOC  OBJ            LINE     SOURCE

  0057              199      DATA_2                DATA            57H
                    200      ;
  0049              201      S_W_TIMER             EQU             49H     ; Software timer mode for the
                    202                                                    ; compare/capture module
  002C              203      FULL_BIT_LOW          EQU             2CH     ; Full bit time = 22CH
  0002              204      FULL_BIT_HIGH         EQU             02H     ; 2400 Baud at 16 MHz
                    205      ;
                    206      ;
                    207      ;                     INITIALIZATION
                    208      ;                     ==============
                    209      ;
0036 75815F         210      INIT_TXM:     MOV SP, #5FH                    ; (Compatible with receive routines)
                    211      ;
0039 75D900         212                    MOV CMOD, #00H                  ; Increment PCA timer @ 1/12 osc. freq.
003C 75D800         213                    MOV CCON, #00H                  ; Clear all status flags
003F 75F900         214                    MOV CH, #00H
0042 75E900         215                    MOV CL, #00H
0045 75DD49         216                    MOV CCAPM3, #S_W_TIMER          ; Module 3 configured as software timer
                    217      ;
0048 75A8D8         218                    MOV IE, #0D8H                   ; Initialize all needed interrupts
                    219
004B 759850         220      INIT_SP:      MOV SCON, #50H                  ; Serial port in mode 1 (8-bit UART)
004E 75CBFF         221                    MOV RCAP2H, #0FFH               ; Reload values for 9600 Baud @ 16 MHz
0051 75CACC         222                    MOV RCAP2L, #0CCH
0054 75C834         223                    MOV T2CON, #34H                 ; Timer 2 as a baud-rate generator,
                    224                                                    ; turn Timer 2 on
                    225      ;
0057 C203           226      INIT_FLAGS:   CLR TXM_START_BIT_0
0059 C20B           227                    CLR TXM_START_BIT_1
005B C213           228                    CLR TXM_START_BIT_2
                    229      ;
005D C204           230                    CLR TXM_IN_PROGRESS_0
005F C20C           231                    CLR TXM_IN_PROGRESS_1
0061 C214           232                    CLR TXM_IN_PROGRESS_2
                    233      ;
0063 753400         234                    MOV TXM_BUF_0, #00H
0066 754400         235                    MOV TXM_BUF_1, #00H
0069 755400         236                    MOV TXM_BUF_2, #00H
                    237      ;
006C 753500         238                    MOV TXM_REG_0, #00H
006F 754500         239                    MOV TXM_REG_1, #00H
0072 755500         240                    MOV TXM_REG_2, #00H
                    241      ;
0075 753600         242                    MOV TXM_COUNT_0, #00H
0078 754600         243                    MOV TXM_COUNT_1, #00H
007B 755600         244                    MOV TXM_COUNT_2, #00H
                    245      ;
007E 7537FF         246                    MOV DATA_0, #0FFH
0081 7547FF         247                    MOV DATA_1, #0FFH
0084 7557FF         248                    MOV DATA_2, #0FFH
                    249      ;
0087 75ED2C         250                    MOV CCAP3L, #2CH                ; Cause the first software timer to
008A 75FD02         251                    MOV CCAP3H, #02H                ; interrupt one bit time after
008D D2DE           252                    SETB CR                         ; PCA timer is started
                    253      ;
```

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```
LOC  OBJ             LINE     SOURCE

                      254     ;
                      255     ;                       MAIN TEST ROUTINE - TRANSMIT BITS
                      256     ;                       =================================
                      257     ;
008F 02009D           258     FIRST_TXM:      JMP TXM_ON_0
                      259     ;
0092 300408           260     MAIN_TXM:       JNB TXM_IN_PROGRESS_0, TXM_ON_0 ; Determine if ready to send
0095 300C16           261                     JNB TXM_IN_PROGRESS_1, TXM_ON_1 ; next byte. (i.e. transmit
0098 301424           262                     JNB TXM_IN_PROGRESS_2, TXM_ON_2 ; "not" in progress)
009B 80F5             263                     JMP MAIN_TXM                    ; Waiting for "TI" flag
                      264     ;
                      265     ;
009D C203             266     TXM_ON_0:       CLR TXM_START_BIT_0             ; Clear flag from previous
009F 0537             267                     INC DATA_0                      ; transmission
00A1 853734           268                     MOV TXM_BUF_0, DATA_0           ; Load "SBUF" with data byte
00A4 853435           269                     MOV TXM_REG_0, TXM_BUF_0
00A7 753609           270                     MOV TXM_COUNT_0, #09H           ; 8 data bits + 1 stop bit
00AA D204             271                     SETB TXM_IN_PROGRESS_0
00AC 80E4             272                     JMP MAIN_TXM
                      273     ;
00AE C20B             274     TXM_ON_1:       CLR TXM_START_BIT_1
00B0 0547             275                     INC DATA_1
00B2 854744           276                     MOV TXM_BUF_1, DATA_1
00B5 854445           277                     MOV TXM_REG_1, TXM_BUF_1
00B8 754609           278                     MOV TXM_COUNT_1, #09H
00BB D20C             279                     SETB TXM_IN_PROGRESS_1
00BD 80D3             280                     JMP MAIN_TXM
                      281     ;
00BF C213             282     TXM_ON_2:       CLR TXM_START_BIT_2
00C1 0557             283                     INC DATA_2
00C3 855754           284                     MOV TXM_BUF_2, DATA_2
00C6 855455           285                     MOV TXM_REG_2, TXM_BUF_2
00C9 755609           286                     MOV TXM_COUNT_2, #09H
00CC D214             287                     SETB TXM_IN_PROGRESS_2
00CE 80C2             288                     JMP MAIN_TXM
                      289     ;
                      290     ;
                      291     ;                       PCA INTERRUPT ROUTINE - TRANSMIT BITS
                      292     ;                       =====================================
                      293     ;
00D0 C0E0             294     TRANSMIT:       PUSH ACC
00D2 C0D0             295                     PUSH PSW
00D4 C2DB             296                     CLR CCF3                        ; Clear s/w timer interrupt
00D6 30041E           297                     JNB TXM_IN_PROGRESS_0,TRANSMIT_1  ; Check which channel is
                      298                                                     ; transmitting
                      299     ;
                      300     ;                               CHANNEL 0
                      301     ;                               ---------
                      302
00D9 200307           303     TRANSMIT_0:     JB TXM_START_BIT_0, TXM_BYTE_0  ; If start bit has been sent,
                      304                                                     ; continue transmitting data bits,
00DC C2B2             305                     CLR P3.2                        ; otherwise transmit start bit
00DE D203             306                     SETB TXM_START_BIT_0            ; Signify start bit sent
00E0 0200F7           307                     JMP TRANSMIT_1                  ; Check next transmit pin
                      308     ;
```

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```
LOC  OBJ            LINE     SOURCE

00E3 D53607          309     TXM_BYTE_0:     DJNZ TXM_COUNT_0, TXM_DATA_0    ; If bit count equals 1 thru 9,
                     310                                                     ; Transmit data bits (8 total)
00E6 D2B2            311     TXM_STOP_0:     SETB P3.2                       ; When bit count = 0, transmit stop bit
00E8 C204            312                     CLR TXM_IN_PROGRESS_0           ; Indicate transmission is finished and
                     313                                                     ; ready for next byte
00EA 0200F7          314                     JMP TRANSMIT_1                  ; Check next transmit pin
                     315     ;
00ED E535            316     TXM_DATA_0:     MOV A, TXM_REG_0                ; Transmit one bit at a time
00EF 13              317                     RRC A                           ; through the carry bit
00F0 92B2            318                     MOV P3.2, C
00F2 F535            319                     MOV TXM_REG_0, A                ; Save what's not been sent
00F4 0200F7          320                     JMP TRANSMIT_1                  ; Check next transmit pin
                     321     ;
                     322     ;                               CHANNEL 1
                     323     ;                               ---------
                     324     ;
00F7 300C1E          325     TRANSMIT_1:     JNB TXM_IN_PROGRESS_1, TRANSMIT_2 ; Similar to TRANSMIT_0
00FA 200B07          326                     JB TXM_START_BIT_1, TXM_BYTE_1
00FD C2B3            327                     CLR P3.3
00FF D20B            328                     SETB TXM_START_BIT_1
0101 020118          329                     JMP TRANSMIT_2
                     330     ;
0104 D54607          331     TXM_BYTE_1:     DJNZ TXM_COUNT_1, TXM_DATA_1
                     332     ;
0107 D2B3            333     TXM_STOP_1:     SETB P3.3
0109 C20C            334                     CLR TXM_IN_PROGRESS_1
010B 020118          335                     JMP TRANSMIT_2
                     336     ;
010E E545            337     TXM_DATA_1:     MOV A, TXM_REG_1
0110 13              338                     RRC A
0111 92B3            339                     MOV P3.3, C
0113 F545            340                     MOV TXM_REG_1, A
0115 020118          341                     JMP TRANSMIT_2
                     342     ;
                     343     ;                               CHANNEL 2
                     344     ;                               ---------
                     345     ;
0118 30141E          346     TRANSMIT_2:     JNB TXM_IN_PROGRESS_2, TXM_EXIT ; Similar to TRANSMIT_0
011B 201307          347                     JB TXM_START_BIT_2, TXM_BYTE_2
011E C2B4            348                     CLR P3.4
0120 D213            349                     SETB TXM_START_BIT_2
0122 020139          350                     JMP TXM_EXIT
                     351     ;
0125 D55607          352     TXM_BYTE_2:     DJNZ TXM_COUNT_2, TXM_DATA_2
                     353     ;
0128 D2B4            354     TXM_STOP_2:     SETB P3.4
012A C214            355                     CLR TXM_IN_PROGRESS_2
012C 020139          356                     JMP TXM_EXIT
                     357     ;
012F E555            358     TXM_DATA_2:     MOV A, TXM_REG_2
0131 13              359                     RRC A
0132 92B4            360                     MOV P3.4, C
0134 F555            361                     MOV TXM_REG_2, A
0136 020139          362                     JMP TXM_EXIT
                     363     ;
```

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```
LOC  OBJ             LINE     SOURCE

0139 C3               364     TXM_EXIT:       CLR C                           ; Update compare value with
013A 742C             365                     MOV A, #FULL_BIT_LOW            ; full bit time = 22CH
013C 25ED             366                     ADD A, CCAP3L
013E F5ED             367                     MOV CCAP3L, A
0140 7402             368                     MOV A, #FULL_BIT_HIGH
0142 35FD             369                     ADDC A, CCAP3H
0144 F5FD             370                     MOV CCAP3H, A
0146 D0D0             371                     POP PSW
0148 D0E0             372                     POP ACC
014A 32               373                     RETI
                      374     ;
                      375     ;
                      376     ;               SERIAL PORT INTERRUPT
                      377     ;               ====================
                      378     ;
                      379     ; When a byte is received on the full-duplex serial port, it is then
                      380     ; transmitted back to a "dummy" terminal.  This terminal checks that
                      381     ; the byte it transmitted to the PCA is the same value it receives back.
                      382     ;
                      383     ;
014B C0E0             384     SERIAL_PORT:    PUSH ACC
014D C0D0             385                     PUSH PSW
014F 30980B           386                     JNB RI, TXM                     ; Check whether RI or TI
0152 E599             387                     MOV A, SBUF                     ; caused the interrupt
0154 C298             388                     CLR RI
0156 F599             389                     MOV SBUF, A
0158 D0D0             390                     POP PSW
015A D0E0             391                     POP ACC
015C 32               392                     RETI
                      393     ;
015D C299             394     TXM:            CLR TI
015F D0D0             395                     POP PSW
0161 D0E0             396                     POP ACC
0163 32               397                     RETI
                      398     ;
                      399     ;
                      400     END

REGISTER BANK(S) USED: 0

ASSEMBLY COMPLETE, NO ERRORS FOUND
```

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intel®

APPLICATION NOTE

AP-415

July 1988

2

83C51FA/FB PCA Cookbook

BETSY JONES
ECO APPLICATIONS ENGINEER

Order Number: 270609-001

83C51FA/FB PCA COOKBOOK

CONTENTS

FIGURES

LISTINGS

TABLES

This application note illustrates the different functions of the Programmable Counter Array (PCA) which are available on the 83C51FA and 83C51FB. Included are cookbook samples of code in typical applications to simplify the use of the PCA. Since all the examples are written in assembly language, it is assumed the reader is familiar with ASM51. For further information on these products or ASM51 refer to the Embedded Controller Handbook (Vol. I).

PCA OVERVIEW

The major new feature on the 83C51FA and 83C51FB is the Programmable Counter Array. The PCA provides more timing capabilities with less CPU intervention than the standard timer/counters. Its advantages include reduced software overhead and improved accuracy.

The PCA consists of a dedicated timer/counter which serves as the time base for an array of five compare/capture modules. Figure 1 shows a block diagram of the PCA. Notice that the PCA timer and modules are all 16-bits. If an external event is associated with a module, that function is shared with the corresponding Port 1 pin. If the module is not using the port pin, the pin can still be used for standard I/O.

Each of the five modules can be programmed in any one of the following modes:

- Rising and/or Falling Edge Capture
- Software Timer
- High Speed Output
- Watchdog Timer (Module 4 only)
- Pulse Width Modulator.

All of these modes will be discussed later in detail. However, let's first look at how to set up the PCA timer and modules.

PCA TIMER/COUNTER

The timer/counter for the PCA is a free-running 16-bit timer consisting of registers CH and CL (the high and low bytes of the count values). It is the only timer which can service the PCA. The clock input can be selected from the following four modes:

- oscillator frequency ÷ 12 (Mode 0)
- oscillator frequency ÷ 4 (Mode 1)
- Timer 0 overflows (Mode 2)
- external input on P1.2 (Mode 3)

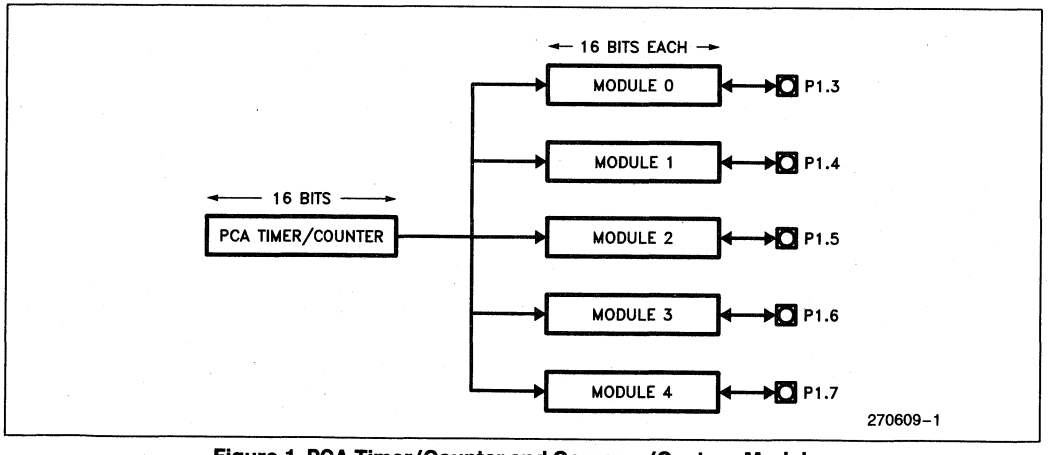


Figure 1. PCA Timer/Counter and Compare/Capture Modules

The table below summarizes the various clock inputs for each mode at two common frequencies. In Mode 0, the clock input is simply a machine cycle count, whereas in Mode 1 the input is clocked three times faster. In Mode 2, Timer 0 overflows are counted allowing for a range of slower inputs to the timer. And finally, if the input is external the PCA timer counts 1-to-0 transitions with the maximum clock frequency equal to $\frac{1}{8}$ x oscillator frequency.

Table 1. PCA Timer/Counter Inputs

PCA Timer/Counter Mode	Clock Increments	
	12 MHz	16 MHz
Mode 0: fosc / 12	1 μsec	0.75 μsec
Mode 1: fosc / 4	330 nsec	250 nsec
Mode 2*: Timer 0 Overflows Timer 0 programmed in: 8-bit mode 16-bit mdoe 8-bit auto-reload	 256 μsec 65 msec 1 to 255 μsec	 192 μsec 49 msec 0.75 to 191 μsec
Mode 3: External Input MAX	0.66 μsec	0.50 μsec

*In Mode 2, the overflow interrupt for Timer 0 does not need to be enabled.

Special Function Register CMOD contains the Count Pulse Select bits (CPS1 and CPS0) to specify the PCA timer input. This register also contains the ECF bit which enables an interrupt when the counter overflows. In addition, the user has the option of turning off the PCA timer during Idle Mode by setting the Counter Idle bit (CIDL). This can further reduce power consumption by an additional 30%.

CMOD: Counter Mode Register

CIDL	WDTE	—	—	—	CPS1	CPS0	ECF

Address = 0D9H
Not Bit Addressable

Reset Value = 00XX X000B

NOTE:
The user should write 0s to unimplemented bits. These bits may be used in future MCS-51 products to invoke new features, and in that case the inactive value of the new bit will be 0. When read, these bits must be treated as don't-cares.

Table 2 lists the values for CMOD in the four possible timer modes with and without the overflow interrupt enabled. This list assumes that the PCA will be left running during Idle Mode.

Table 2. CMOD Values

PCA Count Pulse Selected	CMOD value	
	without interrupt enabled	with interrupt enabled
Internal clock, Fosc/12	00 H	01 H
Internal clock, Fosc/ 4	02 H	03 H
Timer 0 overflow	04H	05 H
External clock at P1.2	06 H	07 H

The CCON register shown below contains the Counter Run bit (CR) which turns the timer on or off. When the PCA timer overflows, the Counter Overflow bit (CF) gets set. CCON also contains the five event flags for the PCA modules. The purpose of these flags will be discussed in the next section.

CCON: Counter Control Register

CF	CR	—	CCF4	CCF3	CCF2	CCF1	CCF0

Address = 0D8H
Bit Addressable

Reset Value = 00X0 0000B

The PCA timer registers (CH and CL) can be read and written to at any time. However, to read the full 16-bit timer value simultaneously requires using one of the PCA modules in the capture mode and toggling a port pin in software. More information on reading the PCA timer is provided in the section on the Capture Mode.

COMPARE/CAPTURE MODULES

Each of the five compare/capture modules has a mode register called CCAPMn (n = 0,1,2,3,or 4) to select which function it will perform. Note the ECCFn bit which enables an interrupt to occur when a module's event flag is set.

CCAPMn: Compare/Capture Mode Register

—	ECOMn	CAPPn	CAPNn	MATn	TOGn	PWMn	ECCFn

Address = 0DAH (n=0)
0DBH (n=1)
0DCH (n=2)
0DDH (n=3)
0DEH (n=4)

Reset Value = X000 0000B

Table 3 lists the CCAPMn values for each different mode with and without the PCA interrupt enabled; that is, the interrupt is optional for all modes. However, some of the PCA modes require software servicing. For example, the Capture modes need an interrupt so that back-to-back events can be recognized. Also, in most applications the purpose of the Software Timer mode is to generate interrupts in software so it would be useless not to have the interrupt enabled. The PWM mode, on the other hand, does not require CPU intervention so the interrupt is normally not enabled.

Table 3. Compare/Capture Mode Values

Module Function	CCAPMn Value	
	without interrupt enabled	with interrupt enabled
Capture Positive only	20H	21 H
Capture Negative only	10H	11 H
Capture Pos. or Neg.	30H	31 H
Software Timer	48H	49 H
High Speed Output	4C H	4D H
Watchdog Timer	48 or 4C H	—
Pulse Width Modulator	42 H	43H

It should be mentioned that a particular module can change modes within the program. For example, a module might be used to sample incoming data. Initially it could be set up to capture a falling edge transition. Then the same module can be reconfigured as a software timer to interrupt the CPU at regular intervals and sample the pin.

Each module also has a pair of 8-bit compare/capture registers (CCAPnH, CCAPnL) associated with it. These registers are used to store the time when a capture event occurred or when a compare event should occur. Remember, event times are based on the free-running PCA timer (CH and CL). For the PWM mode, the high byte register CCAPnH controls the duty cycle of the waveform.

When an event occurs, a flag in CCON is set for the appropriate module. This register is bit addressable so that event flags can be checked individually.

CCON: Counter Control Register

CF	CR	—	CCF4	CCF3	CCF2	CCF1	CCF0

Address = 0D8H
Bit Addressable

Reset Value = 00X0 0000B

These five event flags plus the PCA timer overflow flag share an interrupt vector as shown below. These flags are not cleared when the hardware vectors to the PCA interrupt address (0033H) so that the user can determine which event caused the interrupt. This also allows the user to define the priority of servicing each module.

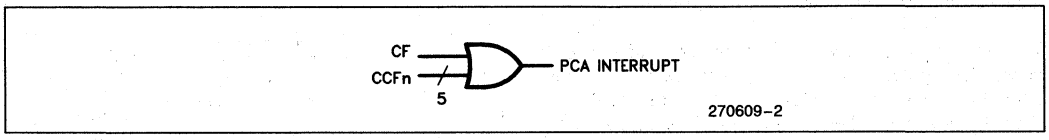


Figure 2. PCA Interrupt

An additional bit was added to the Interrupt Enable (IE) register for the PCA interrupt. Similarly, a high priority bit was added to the Interrupt Priority (IP) register.

IE: Interrupt Enable Register

EA	EC	ET2	ES	ET1	EX1	ET0	EX0

Address = 0A8H
Bit Addressable

Reset Value = 0000 0000B

IP: Interrupt Priority Register

—	PPC	PT2	PS	PT1	PX1	PT0	PX0

Address = 0B8H
Bit Addressable

Reset Value = X000 0000B

Remember, each of the six possible sources for the PCA interrupt must be individually enabled as well—in the CCAPMn register for the modules and in the CCON register for the timer.

CAPTURE MODE

Both positive and negative transitions can trigger a capture with the PCA. This allows the PCA flexibility to measure periods, pulse widths, duty cycles, and phase differences on up to five separate inputs. This section gives examples of all these different applications.

Figure 3 shows how the PCA handles a capture event. Using Module 0 for this example, the signal is input to P1.3. When a transition is detected on that pin, the 16-bit value of the PCA timer (CH,CL) is loaded into the capture registers (CCAP0H,CCAP0L). Module 0's event flag is set and an interrupt is flagged. The interrupt will then be generated if it has been properly enabled.

In the interrupt service routine, the 16-bit capture value must be saved in RAM before the next event capture occurs; a subsequent capture will write over the first capture value. Also, since the hardware does not clear the event flag, it must be cleared in software.

The time it takes to service this interrupt routine determines the resolution of back-to-back events with the same PCA module. To store two 8-bit registers and clear the event flag takes at least 9 machine cycles. That includes the call to the interrupt routine. At 12 MHz, this routine would take less than 10 microseconds. However, depending on the frequency and interrupt latency, the resolution will vary with each application.

Measuring Pulse Widths

To measure the pulse width of a signal, the PCA module must capture both rising and falling edges (see Figure 4). The module can be programmed to capture either edge if it is known which edge will occur first. However, if this is not known, the user can select which edge will trigger the first capture by choosing the proper mode for the module.

Listing 1 shows an example of measuring pulse widths. (It's assumed the incoming signal matches the one in Figure 4.) In the interrupt routine the first set of capture values are stored in RAM. After the second capture, a subtraction routine calculates the pulse width in units of PCA timer ticks. Note that the subtraction does not have to be completed in the interrupt service routine. Also, this example assumes that the two capture events will occur within 2^{16} counts of the PCA timer, i.e. rollovers of the PCA timer are not counted.

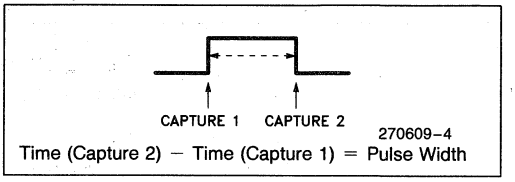


Figure 4. Measuring Pulse Width

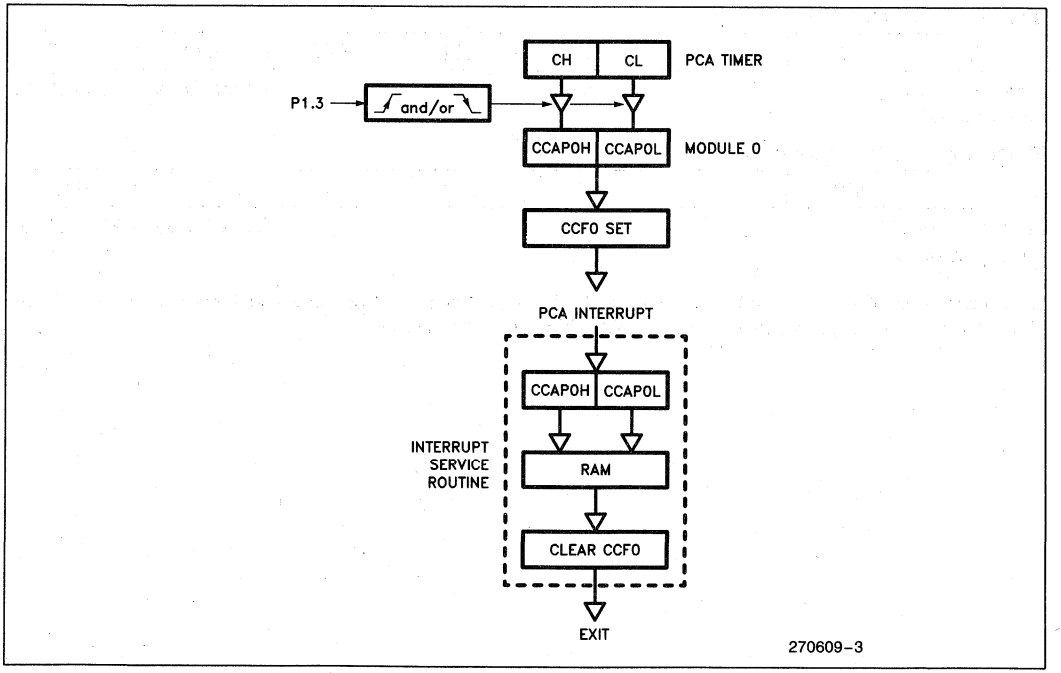


Figure 3. PCA Capture Mode (Module 0)

Listing 1. Measuring Pulse Widths

```
; RAM locations to store capture values
    CAPTURE              DATA      30H
    PULSE_WIDTH          DATA      32H
    FLAG                 BIT       20H.0
;
ORG 0000H
JMP PCA_INIT
ORG 0033H
JMP PCA_INTERRUPT
;
PCA_INIT:                        ; Initialize PCA timer
    MOV CMOD, #00H               ; Input to timer = 1/12 X Fosc
    MOV CH, #00H
    MOV CL, #00H
;
;   Initialize Module 0 in capture mode
    MOV CCAPM0, #21H             ; Capture positive edge first
                                 ; for measuring pulse width
;
    SETB EC                      ; Enable PCA interrupt
    SETB EA
    SETB CR                      ; Turn PCA timer on
    CLR FLAG                     ; clear test flag
;
;   ********************************************************************************
;                  Main program goes here
;   ********************************************************************************
;
;   This example assumes Module 0 is the only PCA module
;   being used. If other modules are used, software must
;   check which module's event caused the interrupt.
;
PCA_INTERRUPT:
    CLR CCF0                     ; Clear Module 0's event flag
    JB FLAG, SECOND_CAPTURE      ; Check if this is the first
                                 ; capture or second
FIRST_CAPTURE:
    MOV CAPTURE, CCAP0L          ; Save 16-bit capture value
    MOV CAPTURE+1, CCAP0H        ; in RAM
    MOV CCAPM0, #11H             ; Change module to now capture
                                 ; falling edges
    SETB FLAG                    ; Signify 1st capture complete
    RETI
;
SECOND_CAPTURE:
    PUSH ACC
    PUSH PSW
    CLR C
    MOV A, CCAP0L                ; 16-bit subtract
    SUBB A, CAPTURE
    MOV PULSE_WIDTH, A           ; 16-bit result stored in
    MOV A, CCAP0H                ; two 8-bit RAM locations
    SUBB A, CAPTURE+1
    MOV PULSE_WIDTH+1, A
    ;
    MOV CCAPM0, #21H             ; Optional--needed if user wants to
    CLR FLAG                     ; measure next pulse width
    POP PSW
    POP ACC
    RETI
```

Measuring Periods

Measuring the period of a signal with the PCA is similar to measuring the pulse width. The only difference will be the trigger source for the capture mode. In Figure 5, rising edges are captured to calculate the period. The code is identical to Listing 1 except that the capture mode should not be changed in the interrupt routine. The result of the subtraction will be the period.

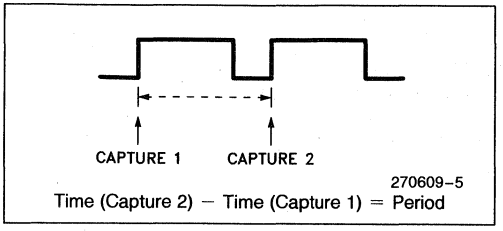


Figure 5. Measuring Period

Measuring Frequencies

Measuring a frequency with the PCA capture mode involves calculating a sample time for a known number of samples. In Figure 6, the time between the first capture and the "Nth" capture equals the sample time T. Listing 2 shows the code for N = 10 samples. It's assumed that the sample time is less than 2^{16} counts of the PCA timer.

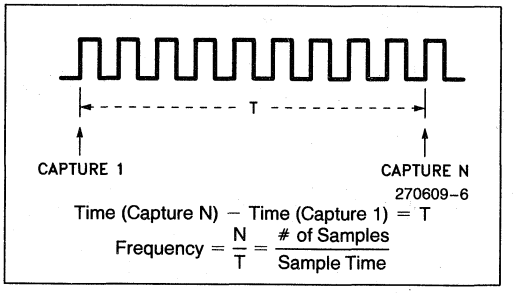


Figure 6. Measuring Frequency

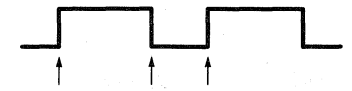
Listing 2. Measuring Frequencies

```
; RAM locations to store capture values
   CAPTURE         DATA      30H
   PERIOD          DATA      32H
   SAMPLE_COUNT    DATA      34H
   FLAG            BIT       20H.0
;
ORG 0000H
JMP PCA_INIT
ORG 0033H
JMP PCA_INTERRUPT
;
PCA_INIT:
; Initialization of PCA timer, Module 0, and interrupt is the
; same as in Listing 1. Also need to initialize the sample
; count.
;
   MOV SAMPLE_COUNT, #10D    ; N = 10 for this example
;
;*****************************************************************************
;                  Main program goes here
;*****************************************************************************
;
;  This code assumes only Module 0 is being used.
PCA_INTERRUPT:
   CLR CCF0                  ; Clear module 0's event flag
   JB FLAG, NEXT_CAPTURE
;
FIRST_CAPTURE:
   MOV CAPTURE, CCAP0L
   MOV CAPTURE+1, CCAP0H
   SETB FLAG                 ; Signify first capture complete
   RETI
;
NEXT_CAPTURE:
   DJNZ SAMPLE_COUNT, EXIT
   PUSH ACC
   PUSH PSW
   CLR C
   MOV A, CCAP0L             ; 16-bit subtraction
   SUBB A, CAPTURE
   MOV PERIOD, A
   MOV A, CCAP0H
   SUBB A, CAPTURE+1
   MOV PERIOD+1, A
   ;
   MOV SAMPLE_COUNT, #10D    ; Reload for next period
   CLR FLAG
   POP PSW
   POP ACC
EXIT:
   RETI
```

The user may instead want to measure frequency by counting pulses for a known sample time. In this case, one module is programmed in the capture mode to count edges (either rising or falling), and a second module is programmed as a software timer to mark the sample time. An example of a software timer is given later. For information on resolution in measuring frequencies, refer to Article Reprint AR-517, "Using the 8051 Microcontroller with Resonant Transducers," in the Embedded Controller Handbook.

Measuring Duty Cycles

To measure the duty cycle of an incoming signal, both rising and falling edges need to be captured. Then the duty cycle must be calculated based on three capture values as seen in Figure 7. The same initialization routine is used from the previous example. Only the PCA interrupt service routine is given in Listing 3.



$$\frac{\text{Time (Capture 2)} - \text{Time (Capture 1)}}{\text{Time (Capture 3)} - \text{Time (Capture 1)}} = \frac{\text{pulse width}}{\text{period}} = \text{duty cycle}$$

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Figure 7. Measuring Duty Cycle

Listing 3. Measuring Duty Cycle

```
; RAM locations to store capture values
   CAPTURE              DATA      30H
   PULSE_WIDTH          DATA      32H
   PERIOD               DATA      34H
   FLAG_1               BIT       20H.0
   FLAG_2               BIT       20H.1
;
ORG 0000H
JMP PCA_INIT
ORG 0033H
JMP PCA_INTERRUPT
;
PCA_INIT:
; Initialization for PCA timer, module, and interrupt the same
; as in Listing 1. Capture positive edge first, then either
; edge.
;
;*********************************************************************
;                  Main program goes here
;*********************************************************************
;
; This code assumes only Module 0 is being used.
PCA_INTERRUPT:
   CLR CCF0                  ; Clear Module 0's event flag
   JB FLAG_1, SECOND_CAPTURE
;
FIRST_CAPTURE:
   MOV CAPTURE, CCAP0L
   MOV CAPTURE+1, CCAP0H
   SETB FLAG_1               ; Signify first capture complete
   MOV CCAPM0, #31H          ; Capture either edge now
   RETI
```

Listing 3. Measuring Duty Cycle (Continued)

```
;
SECOND_CAPTURE:
   PUSH ACC
   PUSH PSW
   JB FLAG_2, THIRD_CAPTURE
   CLR C                    ; Calculate pulse width
   MOV A, CCAPOL            ; 16-bit subtract
   SUBB A, CAPTURE
   MOV PULSE_WIDTH, A
   MOV A, CCAPOH
   SUBB A, CAPTURE+1
   MOV PULSE_WIDTH+1, A
   SETB FLAG_2              ; Signify second capture complete
   POP PSW
   POP ACC
   RETI
;
THIRD_CAPTURE:
   CLR C                    ; Calculate period
   MOV A, CCAPOL            ; 16-bit subtract
   SUBB A, CAPTURE
   MOV PERIOD, A
   MOV A, CCAPOH
   SUBB A, CAPTURE+1
   MOV PERIOD+1, A
   MOV CCAPMO, #21H         ; Optional - reconfigure module to
   CLR FLAG_1               ; capture positive edges for next
   CLR FLAG_2               ; cycle
   POP PSW
   POP ACC
   RETI
```

After the third capture, a 16-bit by 16-bit divide routine needs to be executed. This routine is located in Appendix B. Due to its length, it's up to the user whether the divide routine should be completed in the interrupt routine or be called as a subroutine from the main program.

Measuring Phase Differences

Because the PCA modules share the same time base, the PCA is useful for measuring the phase difference between two or more signals. For this example, two signals are input to Modules 0 and 1 as seen in Figure 8. Both modules are programmed to capture rising edges only. Listing 4 shows the code needed to measure the difference between these two signals. This code does not assume one signal is leading or lagging the other.

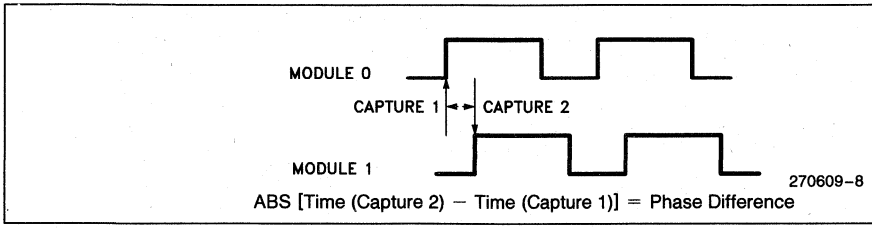


Figure 8. Measuring Phase Differences

Listing 4. Measuring Phase Differences

```
; RAM locations to store capture values
   CAPTURE_0           DATA      30H
   CAPTURE_1           DATA      32H
   PHASE               DATA      34H
   FLAG_0              BIT       20H.0
   FLAG_1              BIT       20H.1
;
ORG 0000H
JMP PCA_INIT
ORG 0033H
JMP PCA_INTERRUPT
;
PCA_INIT:
; Same initialization for PCA timer, and interrupt as
; in Listing 1. Initialize two PCA modules as follows:
;
   MOV CCAPM0, #21H        ; Module 0 capture rising edges
   MOV CCAPM1, #21H        ; Module 1 same
;
;*******************************************************************************
;                  Main program goes here
;*******************************************************************************
; This code assumes only Modules 0 and 1 are being used.
PCA_INTERRUPT:
   JB CCF0, MODULE_0             ; Determine which module's
   JB CCF1, MODULE_1             ; event caused the interrupt
;
MODULE_0:
   CLR CCF0                      ; Clear Module 0's event flag
   MOV CAPTURE_0, CCAP0L         ; Save 16-bit capture value
   MOV CAPTURE_0+1, CCAP0H
   JB FLAG_1, CALCULATE_PHASE    ; If capture complete on
                                 ; Module 1, go to calculation
   SETB FLAG_0                   ; Signify capture on Module 0
   RETI
```

Listing 4. Measuring Phase Differences (Continued)

```
MODULE_1:
   CLR CCF_1                        ; Clear Module 1's event flag
   MOV CAPTURE_1, CCAP1L
   MOV CAPTURE_1+1, CCAP1H
   JB FLAG_0, CALCULATE_PHASE       ; If capture complete on
                                    ; Module 0, go to calculation
   SETB FLAG_1                      ; Signify capture on Module 1
   RETI
;
CALCULATE_PHASE:
   PUSH ACC                         ; This calculation does not
   PUSH PSW                         ; have to be completed in the
   CLR C                            ; interrupt service routine
;
   JB FLAG_0, MOD0_LEADING
   JB FLAG_1, MOD1_LEADING
;
MOD0_LEADING:
   MOV A, CAPTURE_1
   SUBB A, CAPTURE_0
   MOV PHASE, A
   MOV A, CAPTURE_1+1
   SUBB A, CAPTURE_0+1
   MOV PHASE+1, A
   CLR FLAG_0
   JMP EXIT
;
MOD1_LEADING:
   MOV A, CAPTURE_0
   SUBB A, CAPTURE_1
   MOV PHASE, A
   MOV A, CAPTURE_0+1
   SUBB A, CAPTURE_1+1
   MOV PHASE+1, A
   CLR FLAG_1
EXIT:
   POP PSW
   POP ACC
   RETI
```

Reading the PCA Timer

Some applications may require that the PCA timer be read instantaneously as a real-time event. Since the timer consists of two 8-bit registers (CH,CL), it would normally take two MOV instructions to read the whole timer. An invalid read could occur if the registers rolled over in the middle of the two MOVs.

However, with the capture mode a 16-bit timer value can be loaded into the capture registers by toggling a port pin. For example, configure Module 0 to capture falling edges and initialize P1.3 to be high. Then when the user wants to read the PCA timer, clear P1.3 and the full 16-bit timer value will be saved in the capture registers. It's still optional whether the user wants to generate an interrupt with the capture.

COMPARE MODE

In this mode, the 16-bit value of the PCA timer is compared with a 16-bit value pre-loaded in the module's compare registers. The comparison occurs three times per machine cycle in order to recognize the fastest possible clock input, i.e. $\frac{1}{4}$ x oscillator frequency. When there is a match, one of three events can happen:

(1) an interrupt — Software Timer mode

(2) toggle of a port pin — High Speed Output mode

(3) a reset — Watchdog Timer mode.

Examples of each compare mode will follow.

SOFTWARE TIMER

In most applications a software timer is used to trigger interrupt routines which must occur at periodic intervals. Figure 9 shows the sequence of events for the Software Timer mode. The user preloads a 16-bit value in a module's compare registers. When a match occurs between this compare value and the PCA timer, an event flag is set and an interrupt is flagged. An interrupt is then generated if it has been enabled.

If necessary, a new 16-bit compare value can be loaded into (CCAP0H, CCAP0L) during the interrupt routine. *The user should be aware that the hardware temporarily disables the comparator function while these registers are being updated so that an invalid match will not occur.* That is, a write to the low byte (CCAPn0) disables the comparator while a write to the high byte (CCAP0H) re-enables the comparator. For this reason, user software must write to CCAP0L first, then CCAP0H. The user may also want to hold off any interrupts from occurring while these registers are being updated. This can easily be done by clearing the EA bit. See the code example in Listing 5.

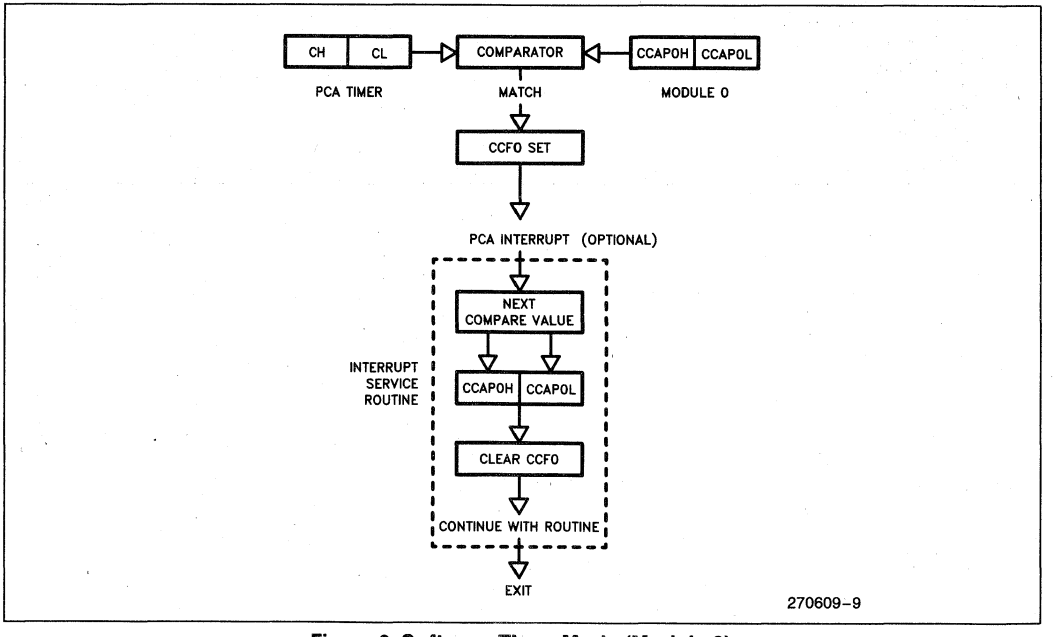


Figure 9. Software Timer Mode (Module 0)

Listing 5. Software Timer

```
; Generate an interrupt in software every 20 msec
;
;
; Frequency       = 12 MHz
; PCA clock input = 1/12 x Fosc  ->  1 µsec
;
; Calculate reload value for compare registers:
;              20 msec
;           ------------- = 20,000 counts
;           1 µsec/count
;
ORG 0000H
JMP PCA_INIT
ORG 0033H
JMP PCA_INTERRUPT
;
PCA_INIT:
; Initialize PCA timer same as in Listing 1
;  MOV CCAPM0, #49H          ; Module 0 in Software Timer mode
   MOV CCAP0L, #LOW(20000)   ; Write to low byte first
   MOV CCAP0H, #HIGH(20000)
;
   SETB EC                   ; Enable PCA interrupt
   SETB EA
   SETB CR                   ; Turn on PCA timer
;
;  ************************************************************************
;                  Main program goes here
;  ************************************************************************
;
PCA_INTERRUPT:
   CLR CCF0                  ; Clear Module 0's event flag
   PUSH ACC
   PUSH PSW
   CLR EA                    ; Hold off interrupts
   MOV A, #LOW(20000)        ; 16-Bit Add
   ADD A, CCAP0L             ; Next match will occur
   MOV CCAP0L, A             ; 20,000 counts later
   MOV A, #HIGH(20000)
   ADDC A, CCAP0H
   MOV CCAP0H, A
   SETB EA
;       .
;       .
; Continue with routine
;       .
;       .
   POP PSW
   POP ACC
   RETI
```

HIGH SPEED OUTPUT

The High Speed Output (HSO) mode toggles a port pin when a match occurs between the PCA timer and the pre-loaded value in the compare registers (see Figure 10). The HSO mode is more accurate than toggling pins in software because the toggle occurs *before* branching to an interrupt, i.e. interrupt latency will not effect the accuracy of the output. In fact, the interrupt is optional. Only if the user wants to change the time for the next toggle is it necessary to update the compare registers. Otherwise, the next toggle will occur when the PCA timer rolls over and matches the last compare value. Examples of both are shown.

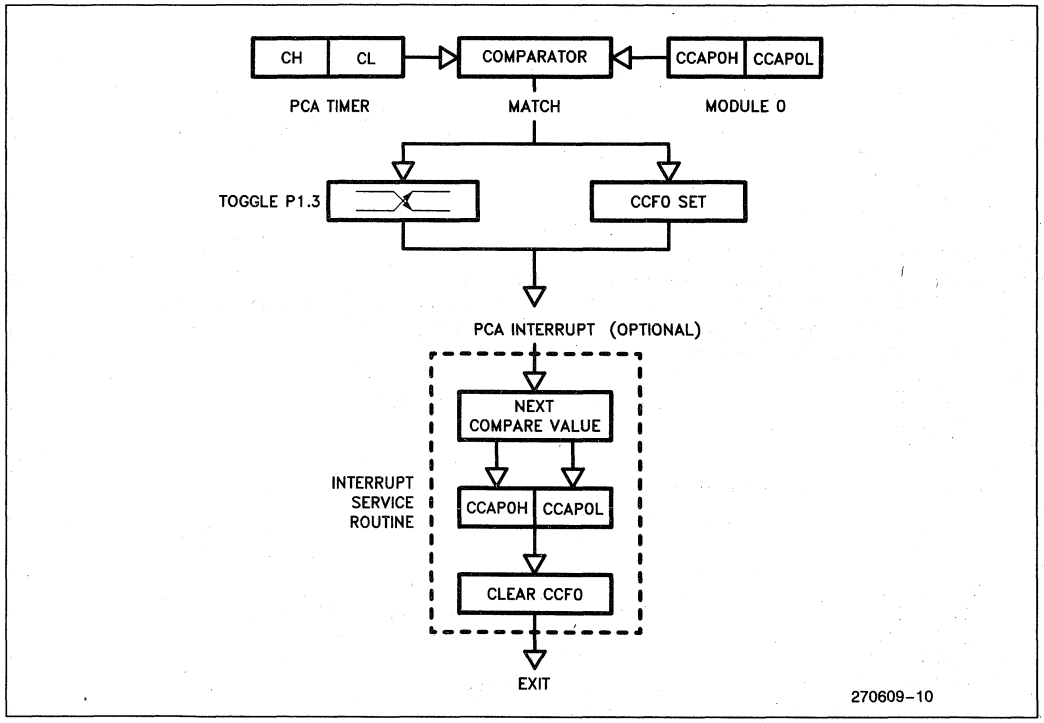


Figure 10. High Speed Output Mode (Module 0)

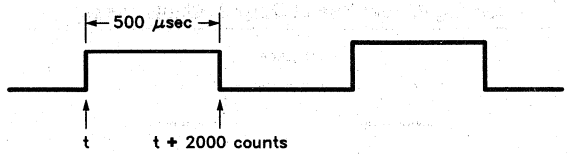
Without any CPU intervention, the fastest waveform the PCA can generate with the HSO mode is a 30.5 Hz signal at 16 MHz. Refer to Listing 6. By changing the PCA clock input, slower waveforms can also be generated.

Listing 6. High Speed Output (Without Interrupt)

```
; Maximum output with HSO mode without interrupts = 30.5 Hz signal
; Frequency       = 16 MHz
; PCA clock input = 1/4 x Fosc → 250 nsec
;
   MOV CMOD, #02H
   MOV CL, #00H
   MOV CH, #00H
   MOV CCAPM0, #4CH      ; HSO mode without interrupt enabled
   MOV CCAP0L, #0FFH     ; Write to low byte first
   MOV CCAP0H, #0FFH     ; P1.3 will toggle every 2^16 counts
                         ; or 16.4 msec
                         ; Period = 30.5 Hz
   SETB CR               ; Turn on PCA timer
```

In this next example, the PCA interrupt is used to change the compare value for each toggle. This way a variable frequency output can be generated. Listing 7 shows an output of 1 KHz at 16 Mhz.

Listing 7. High Speed Output (With Interrupt)



$$\frac{500\ \mu\text{sec}}{250\ \text{nsec/count}} = 2000\ \text{counts}$$

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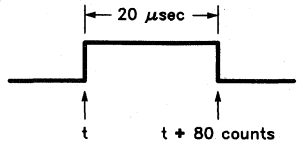
```
   ORG 0000H
   JMP PCA_INIT
   ORG 0033H
   JMP PCA_INTERRUPT
;
PCA_INIT:
   MOV CMOD, #02H                ; Clock input = 250 nsec
   MOV CL, #00H                  ; at 16 MHz
   MOV CH, #00H
   MOV CCAPM0, #4DH              ; Module 0 in HSO mode with
   MOV CCAP0L, #LOW(1000)        ; PCA interrupt enabled
   MOV CCAP0H, #HIGH(1000)       ; t = 1000 (arbitrary)
   CLR P1.3
;
   SETB EC                       ; Enable PCA interrupt
   SETB EA
   SETB CR                       ; Turn on PCA timer
;
;  ************************************************************************
;                  Main program goes here
;  ************************************************************************
;
; This code assumes only Module 0 is being used.
PCA_INTERRUPT:
   CLR CCF0                      ; Clear Module 0's event flag
   PUSH ACC
   PUSH PSW
   CLR EA                        ; Hold off interrupts
   MOV A, #LOW(2000)             ; 16-bit add
   ADD A, CCAP0L                 ; 2000 counts later, P1.3
   MOV CCAP0L, A                 ; will toggle
   MOV A, #HIGH(2000)
   ADDC A, CCAP0H
   MOV CCAP0H, A
   SETB EA
   POP PSW
   POP ACC
   RETI
```

Another option with the HSO mode is to generate a single pulse. Listing 8 shows the code for an output with a pulse width of 20 μsec. As in the previous example, the PCA interrupt will be used to change the time for the toggle. The first toggle will occur at time "t". After 80 counts of the PCA timer, 20 μsec will have expired, and the next toggle will occur. Then the HSO mode will be disabled.

Listing 8. High Speed Output (Single Pulse)



$$\frac{20\ \mu\text{sec}}{250\ \text{nsec/count}} = 80\ \text{counts}$$

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```
   ORG 0000H
   JMP PCA_INIT
   ORG 0033H
   JMP PCA_INTERRUPT
;
PCA_INIT:
   MOV CMOD, #02H                ; Clock input = 250 nsec
   MOV CL, #00H                  ; at 16 MHz
   MOV CH, #00H
   MOV CCAPM0, #4DH              ; Module 0 in HSO mode with
   MOV CCAP0L, #LOW(1000)        ; PCA interrupt enabled
   MOV CCAP0H, #HIGH(1000)       ; t = 1000 (arbitrary)
   CLR P1.3
   ;
   SETB EC                       ; Enable PCA interrupt
   SETB EA
   SETB CR                       ; Turn on PCA timer
;
;  ***************************************************************************
;                Main program goes here
;  ***************************************************************************
;
; This code assumes only Module 0 is being used.
PCA_INTERRUPT:
   CLR CCF0                      ; Clear Module 0's event flag
   JNB P1.3, DONE
;
   PUSH ACC
   PUSH PSW
   CLR EA                        ; Hold off interrupts
   MOV A, #LOW(80)               ; 16-bit add
   ADD A, CCAP0L                 ; 80 counts later, P1.3
   MOV CCAP0L, A                 ; will toggle
   MOV A, #HIGH(80)
   ADDC A, CCAP0H
   MOV CCAP0H, A
   SETB EA
   POP PSW
   POP ACC
   RETI
;
DONE:
   MOV CCAPM0, #00H              ; Disable HSO mode
   RETI
```

WATCHDOG TIMER

An on-board watchdog timer is available with the PCA to improve the reliability of the system without increasing chip count. Watchdog timers are useful for systems which are susceptible to noise, power glitches, or electrostatic discharge. Module 4 is the only PCA module which can be programmed as a watchdog. However, this module can still be used for other modes if the watchdog is not needed.

Figure 11 shows a diagram of how the watchdog works. The user pre-loads a 16-bit value in the compare registers. Just like the other compare modes, this 16-bit value is compared to the PCA timer value. If a match is allowed to occur, an internal reset will be generated. This will not cause the RST pin to be driven high.

In order to hold off the reset, the user has three options:

(1) periodically change the compare value so it will never match the PCA timer,

(2) periodically change the PCA timer value so it will never match the compare value, or

(3) disable the watchdog by clearing the WDTE bit before a match occurs and then re-enable it.

The first two options are more reliable because the watchdog timer is never disabled as in option #3. If the program counter ever goes astray, a match will eventually occur and cause an internal reset. The second option is also not recommended if other PCA modules are being used. Remember, the PCA timer is the time base for *all* modules; changing the time base for other modules would not be a good idea. Thus, in most applications the first solution is the best option.

Listing 9 shows the code for initializing the watchdog timer. Module 4 can be configured in either compare mode, and the WDTE bit in CMOD must also be set. The user's software then must periodically change (CCAP4H,CCAP4L) to keep a match from occurring with the PCA timer (CH,CL). This code is given in the WATCHDOG routine.

This routine should not be part of an interrupt service routine. Why? Because if the program counter goes astray and gets stuck in an infinite loop, interrupts will still be serviced and the watchdog will keep getting reset. Thus, the purpose of the watchdog would be defeated. Instead call this subroutine from the main program within 2^{16} count of the PCA timer.

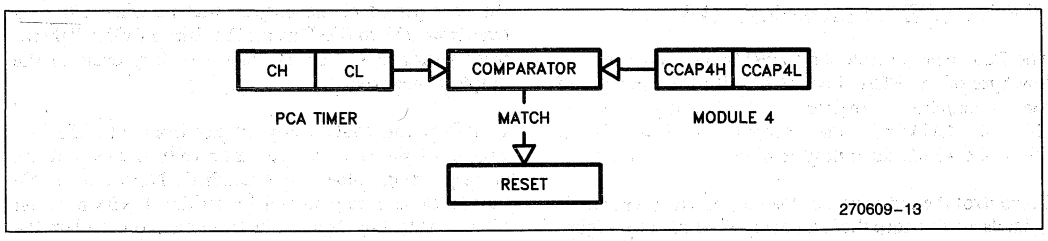

Figure 11. Watchdog Timer Mode (Module 4)

Listing 9. Watchdog Timer

```
INIT_WATCHDOG:
   MOV CCAPM4, #4CH          ; Module 4 in compare mode
   MOV CCAP4L, #0FFH         ; Write to low byte first
   MOV CCAP4H, #0FFH         ; Before PCA timer counts up to
                             ; FFFF Hex, these compare values
                             ; must be changed
   ORL CMOD, #40H            ; Set the WDTE bit to enable the
                             ; watchdog timer without changing
                             ; the other bits in CMOD
;
;*******************************************************************************
;
; Main program goes here, but CALL WATCHDOG periodically.
;
;*******************************************************************************
;
WATCHDOG:
   CLR EA                    ; Hold off interrupts
   MOV CCAP4L, #00           ; Next compare value is within
   MOV CCAP4H, CH            ; 255 counts of the current PCA
   SETB EA                   ; timer value
   RET
```

PULSE WIDTH MODULATOR

The PCA can generate 8-bit PWMs by comparing the low byte of the PCA timer (CL) with the low byte of the compare registers (CCAPnL). When CL < CCAPnL the output is low. When CL ≥ CCAPnL the output is high.

To control the duty cycle of the output, the user actually loads a value into the high byte CCAPnH (see Figure 12). Since a write to this register is asynchronous, a new value is not shifted into CCAPnL for comparison until the next period of the output: that is, when CL rolls over from 255 to 00. This mechanism provides "glitch-free" writes to CCAPnH when the duty cycle of the output is changed.

CCAPnH can contain any integer from 0 to 255, but Figure 13 shows a few common duty cycles and the corresponding values for CCAPnH. Note that a 0% duty cycle can be obtained by writing to the port pin directly with the CLR bit instruction. To calculate the CCAPnH value for a given duty cycle, use the following equation:

$$CCAPnH = 256\ (1 - \text{Duty Cycle})$$

where CCAPnH is an 8-bit integer and Duty Cycle is expressed as a fraction.

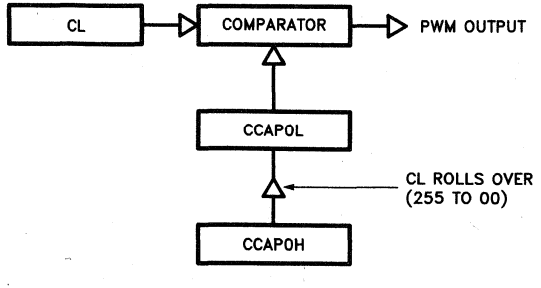

Figure 12. PWM Mode (Module 0)

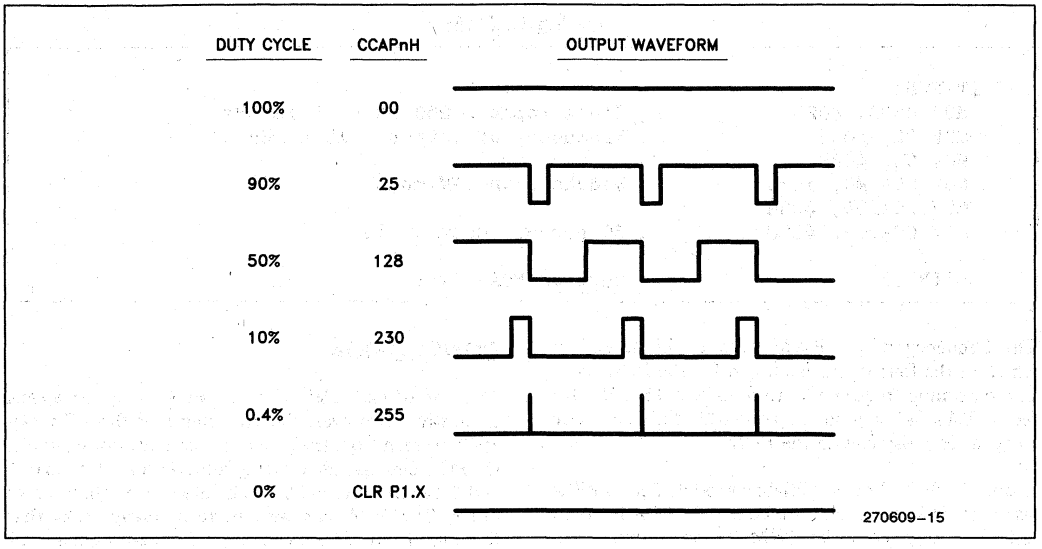

Figure 13. CCAPnH Varies Duty Cycle

Table 4. PWM Frequencies.

PCA Timer Mode	PWM Frequency	
	12 MHz	16 MHz
1/12 Osc. Frequency	3.9 KHz	5.2 KHz
¼ Osc. Frequency	11.8 KHz	15.6 KHz
Timer 0 Overflow: 8-bit 16-bit 8-bit Auto-Reload	 15.5 Hz 0.06 Hz 3.9 KHz to 15.3 Hz	 20.3 Hz 0.08 Hz 5.2 KHz to 20.3 Hz
External Input (Max)	5.9 KHz	7.8 KHz

Listing 10. PWM

```
INIT-PWM:
   MOV CMOD, #02H              ; Clock input = 250 nsec at 16 MHz
   MOV CL, #00H                ; Frequency of output = 15.6 KHz
   MOV CH, #00H
   MOV CCAPM0, #42H            ; Module 0 in PWM mode
   MOV CCAP0L, #00H
   MOV CCAP0H, #128D           ; 50 percent duty cycle
;
   SETB CR                     ; Turn on PCA timer
```

The frequency of the PWM output will depend on which of the four inputs is chosen for the PCA timer. The maximum frequency is 15.6 KHz at 16 MHz. Refer to Table 4 for a summary of the different PWM frequencies possible with the PCA.

Listing 10 shows how to initialize Module 0 for a PWM signal at 50% duty cycle. Notice that no PCA interrupt is needed to generate the PWM (i.e no software overhead!). To create a PWM output on the 8051 requires a hardware timer plus software overhead to toggle the port pin. The advantage of the PCA is obvious, not to mention it can support up to 5 PWM outputs with just one chip.

CONCLUSION

This list of examples with the PCA is by no means exhaustive. However, the advantages of the PCA can easily be seen from the given applications. For example, the PCA can provide better resolution than Timers 0, 1 and 2 because the PCA clock rate can be three times faster. The PCA can also perform many tasks that these hardware timers can not, i.e. measure phase differences between signals or generate PWMs. In a sense, the PCA provides the user with five more timer/counters in addition to Timers 0, 1 and 2 on the 8XC51FA/FB.

Appendix A includes test routines for all the software examples in this application note. The divide routine for calculating duty cycles is in Appendix B. And finally, Appendix C is a table of the Special Function Registers for the 8XC51FA/FB with the new or modified registers **boldfaced**.

APPENDIX A
TEST ROUTINES

```
;                Listing 1a - Measuring Pulse Widths

$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;       Variables
;
CAPTURE                 DATA        30H
PULSE_WIDTH             DATA        32H
FLAG                    BIT         20H.0
;
ORG 0000H
JMP PCA_INIT
;
ORG 0033H
JMP PCA_INTERRUPT
;
;       Initialize PCA timer
PCA_INIT:   MOV CMOD, #00H              ; Input to PCA timer = 1/12 x Fosc
            MOV CH, #00
            MOV CL, #00
;
;       Initialize Module 0 in capture mode
            MOV CCAPM0, #21H            ; Capture positive edge first on P1.3

            MOV CCAP0H, #00
            MOV CCAP0L, #00
;
            SETB EC                     ; Enable PCA interrupt
            SETB EA
            SETB CR                     ; Turn PCA timer on
            CLR FLAG                    ; Clear test flag
;
;*****************************************************************************************
;                           Test program only
;
WAIT:       JMP $                       ; Wait for PCA interrupt
            JMP WAIT
;*****************************************************************************************
;
;       This code assumes Module 0 is the only module being used. If
;       other PCA module's are being used, software must check which
;       module's event flag caused the interrupt.
;
PCA_INTERRUPT:
            CLR CCF0                    ; Clear module 0's event flag
            JB FLAG, SECOND_CAPTURE
;
FIRST_CAPTURE:
            MOV CAPTURE, CCAP0L
            MOV CAPTURE+1, CCAP0H
```

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```
                MOV CCAPM0, #11H        ; Change module to now capture
                                        ; falling edges
                SETB FLAG               ; Signify first capture complete
                RETI
;
SECOND_CAPTURE:
                PUSH ACC
                PUSH PSW
                CLR C
                MOV A, CCAP0L           ; 16-bit subtract
                SUBB A, CAPTURE
                MOV PULSE_WIDTH, A
                MOV A, CCAP0H
                SUBB A, CAPTURE+1
                MOV PULSE_WIDTH+1, A
;
                MOV CCAPM0, #21H        ; Optional if user wants to measure
                CLR FLAG                ; next pulse width
                POP PSW
                POP ACC
                RETI
;
END
```

270609-17

Listing 1b - Measuring Periods

```
;
$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;       Variables
;
CAPTURE         DATA    30H
PERIOD          DATA    32H
FLAG            BIT     20H.0
;
ORG 0000H
JMP PCA_INIT
;
ORG 0033H
JMP PCA_INTERRUPT
;
;       Initialize PCA timer
PCA_INIT:   MOV CMOD, #00H              ; Input to timer = 1/12 x Fosc
            MOV CH, #00H
            MOV CL, #00
;
;       Initialize Module 0 in capture mode
            MOV CCAPM0, #21H            ; Capture rising edges on P1.3

            MOV CCAP0H, #00
            MOV CCAP0L, #00
;
            SETB EC                     ; Enable PCA interrupt
            SETB EA
            SETB CR                     ; Turn PCA timer on
            CLR FLAG                    ; Clear test flag
;
;*****************************************************************************************************
;               Test program only
;
WAIT:       JMP $                       ; Wait for PCA interrupt
            JMP WAIT
;*****************************************************************************************************
;
;       This code assumes only Module 0 is being used. If other modules
;       are being used, software must check which module's flag caused
;       the interrupt.
;
PCA_INTERRUPT:
            CLR CCF0                    ; Clear module 0's event flag
            JB FLAG, SECOND_CAPTURE
;
FIRST_CAPTURE:
            MOV CAPTURE, CCAP0L
            MOV CAPTURE+1, CCAP0H
```

270609-18

```
                SETB FLAG                   ; Signify first capture complete
                RETI
;
SECOND_CAPTURE:
                PUSH ACC
                PUSH PSW
                CLR C
                MOV A, CCAP0L               ; 16-Bit subtraction
                SUBB A, CAPTURE
                MOV PERIOD, A
                MOV A, CCAP0H
                SUBB A, CAPTURE+1
                MOV PERIOD+1, A
;
                CLR FLAG
                POP PSW
                POP ACC
                RETI
;
END
```

270609-19

```
;                Listing 2 - Measuring Frequencies
;
$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;       Variables
;
CAPTURE                 DATA        30H
PERIOD                  DATA        32H
SAMPLE_COUNT            DATA        34H
FLAG                    BIT         20H.0
;
ORG 0000H
JMP PCA_INIT
;
ORG 0033H
JMP PCA_INTERRUPT
;
;       Initialize PCA timer
PCA_INIT:       MOV CMOD, #00H              ; Input to PCA timer = 1/12 x Fosc
                MOV CH, #00
                MOV CL, #00
;
;       Initialize Module 0 in capture mode
                MOV CCAPM0, #21H            ; Capture positive edges on P1.3

                MOV CCAP0H, #00
                MOV CCAP0L, #00
;
                MOV SAMPLE_COUNT, #10D      ; N = 10 for this example
;
                SETB EC                     ; Enable PCA interrupt
                SETB EA
                SETB CR                     ; Turn PCA timer on
                CLR FLAG                    ; Test flag
;
;*******************************************************************************************************
;                       Test program only
;
WAIT:           JMP $                       ; Wait for PCA interrupt
                JMP WAIT
;*******************************************************************************************************
;
;       This code assumes only Module 0 is being used.
;
PCA_INTERRUPT:
                CLR CCF0                    ; Clear module 0's event flag
                JB FLAG, NEXT_CAPTURE
;
```

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```
FIRST_CAPTURE:
            MOV CAPTURE, CCAP0L
            MOV CAPTURE+1, CCAP0H
            SETB FLAG                   ; Signify first capture complete
            RETI
;
NEXT_CAPTURE:
            DJNZ SAMPLE_COUNT, EXIT
            PUSH ACC
            PUSH PSW
            CLR C
            MOV A, CCAP0L               ; 16-Bit subtraction
            SUBB A, CAPTURE
            MOV PERIOD, A
            MOV A, CCAP0H
            SUBB A, CAPTURE+1
            MOV PERIOD+1, A
;
            MOV SAMPLE_COUNT, #10D      ; Reload for next capture
            CLR FLAG
            POP PSW
            POP ACC
EXIT:       RETI
;
END
```

270609-21

Listing 3 - Measuring Duty Cycle

```
;
;
$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;       Variables
;
CAPTURE                 DATA        30H
PULSE_WIDTH             DATA        32H
PERIOD                  DATA        34H
;
FLAG_1                  BIT         20H.0
FLAG_2                  BIT         20H.1
;
ORG 0000H
JMP PCA_INIT
;
ORG 0033H
JMP PCA_INTERRUPT
;
;       Initialize PCA timer
PCA_INIT:       MOV CMOD, #00H              ; Input to PCA timer = 1/12 x Fosc
                MOV CH, #00
                MOV CL, #00
;
;       Initialize Module 0 in capture mode
                MOV CCAPM0, #21H            ; Capture positive edge first on P1.3

                MOV CCAP0H, #00
                MOV CCAP0L, #00
;
                CLR FLAG_1                  ; Clear test flags
                CLR FLAG_2
;
                SETB EC                     ; Enable PCA interrupt
                SETB EA
                SETB CR                     ; Turn PCA timer on
;
;*****************************************************************************************
;
;                       Test program only
;
WAIT:           JMP $                       ; Wait for PCA interrupt
                JMP WAIT
;*****************************************************************************************
;
;
;       This code assumes Module 0 is the only PCA module being used.
;
PCA_INTERRUPT:
                CLR CCF0                    ; Clear module 0's event flag
                JB FLAG_1, SECOND_CAPTURE
;
```

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```
FIRST_CAPTURE:
            MOV CAPTURE, CCAP0L
            MOV CAPTURE+1, CCAP0H
            SETB FLAG_1                 ; Signify first capture complete
            MOV CCAPM0, #31H            ; Capture either edge now
            RETI
;
SECOND_CAPTURE:
            PUSH ACC
            PUSH PSW
            JB FLAG_2, THIRD_CAPTURE
            CLR C                       ; Calculate pulse width
            MOV A, CCAP0L               ; 16-bit subtract
            SUBB A, CAPTURE
            MOV PULSE_WIDTH, A
            MOV A, CCAP0H
            SUBB A, CAPTURE+1
            MOV PULSE_WIDTH+1, A
;
            SETB FLAG_2                 ; Signify second capture complete
            POP PSW
            POP ACC
            RETI
;
THIRD_CAPTURE:
            CLR C                       ; Calculate period
            MOV A, CCAP0L               ; 16-bit subtract
            SUBB A, CAPTURE
            MOV PERIOD, A
            MOV A, CCAP0H
            SUBB A, CAPTURE+1
            MOV PERIOD+1, A
;
            MOV CCAPM0, #21H            ; Optional- reconfigure module to
            CLR FLAG_1                  ; capture positive edges for
            CLR FLAG_2                  ; next cycle
            POP PSW
            POP ACC
            RETI
;
END
```

270609-23

Listing 4 - Measuring Phase Differences

```
;
$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;       Variables
;
CAPTURE_0               DATA        30H
CAPTURE_1               DATA        32H
PHASE                   DATA        34H
;
FLAG_0                  BIT         20H.0
FLAG_1                  BIT         20H.1
;
ORG 0000H
JMP PCA_INIT
;
ORG 0033H
JMP PCA_INTERRUPT
;
;       Initialize PCA timer
PCA_INIT:   MOV CMOD, #00H              ; Input to PCA timer = 1/12 x Fosc
            MOV CH, #00
            MOV CL, #00
;
;       Initialize Modules 0 & 1 in capture mode
            MOV CCAPM0, #21H            ; Capture positive edges on P1.3

            MOV CCAP0H, #00
            MOV CCAP0L, #00
;
            MOV CCAPM1, #21H            ; Capture positive edges on P1.4
            MOV CCAP1H, #00
            MOV CCAP1L, #00
;
            MOV R0, #0FFH               ; Used for test program only
            MOV R1, #0FFH
;
            CLR FLAG_0                  ; Clear test flags
            CLR FLAG_1
;
            SETB EC                     ; Enable PCA interrupt
            SETB EA
            SETB CR                     ; Turn PCA timer on
;
```

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```
;*******************************************************************************
;                    Test program only
;
MAIN:       CALL TOG1                   ; Generate two waveforms
            CALL DELAY2                 ; with known phase difference
            CALL TOG2
            JMP MAIN
;
TOG1:       CPL P1.6                    ; These two waveforms are input to
            CALL DELAY1                 ; P1.3 and P1.4
            RET
;
TOG2:       CPL P1.5
            CALL DELAY1
            RET
;
DELAY1:     DJNZ R0, $
            RET
;
DELAY2:     DJNZ R1, $
            RET
;*******************************************************************************
;
;
;     This code assumes only Modules 0 and 1 are being used.
;
PCA_INTERRUPT:
            JB CCF0, MODULE_0           ; Determine which module's event
            JB CCF1, MODULE_1           ; caused the interrupt
;
MODULE_0:
            CLR CCF0                    ; Clear Module 0's event flag
            MOV CAPTURE_0, CCAP0L
            MOV CAPTURE_0+1, CCAP0H
            JB FLAG_1, CALCULATE_PHASE  ; If capture is complete on Module 1,
                                        ; go to calculation
            SETB FLAG_0                 ; Signify capture complete on
            RETI                        ; Module 0
;
MODULE_1:
            CLR CCF1                    ; Clear Module 1's event flag
            MOV CAPTURE_1, CCAP1L
            MOV CAPTURE_1+1, CCAP1H
            JB FLAG_0, CALCULATE_PHASE  ; If capture is complete on Module 0,
                                        ; go to calculation
            SETB FLAG_1                 ; Signify capture complete
            RETI                        ; Module 1
;
CALCULATE_PHASE:
            PUSH ACC                    ; This calculation does not have to
            PUSH PSW                    ; be completed in the interrupt
            CLR C                       ; service routine
;
            JB FLAG_0, MOD0_LEADING
```

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```
                JB FLAG_1, MOD1_LEADING
;
MOD0_LEADING:
                MOV A, CAPTURE_1            ; 16-bit subtraction
                SUBB A, CAPTURE_0
                MOV PHASE, A
                MOV A, CAPTURE_1+1
                SUBB A, CAPTURE_0+1
                MOV PHASE+1, A
                CLR FLAG_0
                JMP EXIT
;
MOD1_LEADING:
                MOV A, CAPTURE_0            ; 16-bit subtraction
                SUBB A, CAPTURE_1
                MOV PHASE, A
                MOV A, CAPTURE_0+1
                SUBB A, CAPTURE_1+1
                MOV PHASE+1, A
                CLR FLAG_1
EXIT:
                POP PSW
                POP ACC
                RETI
;
END
```

270609-26

Listing 5. Software Timer

```
;
$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;       Software Timer mode which interrupts every 20 msec with Fosc = 12 MHz.
;
ORG 0000H
JMP PCA_INIT
ORG 0033H
JMP PCA_INTERRUPT
;
;       Initialize PCA timer
PCA_INIT:       MOV CMOD, #00H                  ; Input to PCA timer = 1/12 x Fosc
                MOV CH, #00
                MOV CL, #00
;
                MOV CCAPM0, #49H                ; Software Timer mode with interrupt
                MOV CCAP0L, #LOW(20000)         ; Write to low byte first
                MOV CCAP0H, #HIGH(20000)
;
                SETB EC                         ; Enable PCA interrupt
                SETB EA
                SETB CR                         ; Turn PCA timer on
;
;*****************************************************************************************************
;               Test program only
;
WAIT:           JMP $                           ; Wait for PCA interrupt
                JMP WAIT
;*****************************************************************************************************
;
;       This code assumes Module 0 is the only module being used.  If
;       other PCA module's are being used, software must check which
;       module's event flag caused the interrupt.
;
PCA_INTERRUPT:
                CLR CCF0                        ; Clear module 0's event flag
                PUSH ACC
                PUSH PSW
                CLR EA                          ; Hold off interrupts
                MOV A, #LOW(20000)              ; 16-bit add
                ADD A, CCAP0L                   ; Next match will occur 20,000
                MOV CCAP0L, A                   ; counts later
                MOV A, #HIGH(20000)
                ADDC A, CCAP0H
                MOV CCAP0H, A
                SETB EA
                POP PSW
                POP ACC
                RETI
END
```

270609-27

```
;                    Listing 6. High Speed Output (without interrupt)

$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;
;       HSO mode without PCA interrupt.  Maximum frequency output = 30.5 Hz
;       at Fosc = 16 MHz.
;
ORG 0000H
JMP PCA_INIT
;
;       Initialize PCA timer
PCA_INIT:   MOV CMOD, #02H          ; Input to PCA timer = 1/4 x Fosc
            MOV CH, #00
            MOV CL, #00
;
            MOV CCAPM0, #4CH        ; HSO Mode without interrupt enabled
            MOV CCAP0L, #0FFH       ; Write to low byte first
            MOV CCAP0H, #0FFH       ; P1.3 will toggle every 65,536 counts
                                    ; or 16.4 msec at Fosc = 16 MHz
                                    ; Period = 30.5 Hz
            SETB CR                 ; Turn PCA timer on
;
END
```

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Listing 7. High Speed Output (with interrupts)

```
$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;
;       HSO mode with variable frequency.  This example outputs a 1KHz signal
;       with Fosc = 16 MHz.
;
ORG 0000H
JMP PCA_INIT
;
ORG 0033H
JMP PCA_INTERRUPT
;
;       Initialize PCA timer
PCA_INIT:       MOV CMOD, #02H          ; Input to PCA timer = 1/4 x Fosc
                MOV CH, #00
                MOV CL, #00
;
                MOV CCAPM0, #4DH        ; HSO mode with interrupt enabled
                MOV CCAP0L, #LOW(1000)  ; t = 1000 arbitrary
                MOV CCAP0H, #HIGH(1000)
                CLR P1.3
;
                SETB EC                 ; Enable PCA interrupt
                SETB EA
                SETB CR                 ; Turn PCA timer on
;
;*****************************************************************************************
;               Test program only
;
WAIT:           JMP $                   ; Wait for PCA interrupt
                JMP WAIT
;*****************************************************************************************
;
;       This code assumes Module 0 is the only module being used.  If
;       other PCA module's are being used, software must check which
;       module's event flag caused the interrupt.
;
PCA_INTERRUPT:
                CLR CCF0                ; Clear module 0's event flag
                PUSH ACC
                PUSH PSW
                CLR EA                  ; Hold off interrupts
                MOV A, #LOW(2000)       ; 16-bit add
                ADD A, CCAP0L           ; 2000 counts later P1.3
                MOV CCAP0L, A           ; will toggle
                MOV A, #HIGH(2000)
                ADDC A, CCAP0H
                MOV CCAP0H, A
                                                                    270609-29
                SETB EA
                POP PSW
                POP ACC
                RETI
;
END                                                                 270609-30
```

Listing 8. High Speed Output (Single Pulse)

```
$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;
;       HSO mode generates a single pulse width of 20 usecs with Fosc = 16 MHz.
;
ORG 0000H
JMP PCA_INIT
;
ORG 0033H
JMP PCA_INTERRUPT
;
;       Initialize PCA timer
PCA_INIT:       MOV CMOD, #02H          ; Input to PCA timer = 1/4 x Fosc
                MOV CH, #00
                MOV CL, #00
;
                MOV CCAPM0, #4DH        ; HSO mode with interrupt enabled
                MOV CCAP0L, #LOW(1000)  ; t = 1000 arbitrary
                MOV CCAP0H, #HIGH(1000)
                CLR P1.3
;
                SETB EC                 ; Enable PCA interrupt
                SETB EA
                SETB CR                 ; Turn PCA timer on
;
;
;*****************************************************************************************************
;               Test program only
;
WAIT:           JMP $                   ; Wait for PCA interrupt
                JMP WAIT
;*****************************************************************************************************
;
;       This code assumes Module 0 is the only module being used.  If
;       other PCA module's are being used, software must check which
;       module's event flag caused the interrupt.
;
PCA_INTERRUPT:
                CLR CCF0                ; Clear module 0's event flag
                JNB P1.3, DONE
;
                PUSH ACC
                PUSH PSW
                CLR EA                  ; Hold off interrupts
                MOV A, #LOW(80)         ; 16-bit add
                ADD A, CCAP0L           ; 80 counts later P1.3
                MOV CCAP0L, A           ; will toggle
                MOV A, #HIGH(80)
```

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```
                ADDC A, CCAP0H
                MOV CCAP0H, A
                SETB EA
                POP PSW
                POP ACC
                RETI
;
DONE:
                MOV CCAPM0, #00H        ; Disable HSO mode
                RETI
END
```

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```
;                    Listing 9. Watchdog Timer

$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;
ORG 0000H
JMP PCA_INIT
;
;       Initialize PCA timer
PCA_INIT:       MOV CMOD, #00H          ; Input to PCA timer = 1/12 x Fosc
                MOV CH, #00
                MOV CL, #00
;
                MOV CCAPM4, #4CH        ; Module 4 in compare mode
                MOV CCAP4L, #0FFH       ; Write to low byte first
                MOV CCAP4H, #0FFH       ; Before PCA timer counts up to FFFF Hex,
                                        ; these compare values must be changed
                ORL CMOD, #40H          ; Set the WDTE bit to enable watchdog timer
;
                SETB CR                 ; Turn PCA timer on
;
;*****************************************************************************************
;                               Test program only
;
START:          MOV R1, #120D           ; Delay for approx. 60 msec
                MOV R0, #0FFH
;
MAIN:           DJNZ R0, $              ; Check that watchdog never causes a reset
                DJNZ R1, MAIN
                CALL WATCHDOG
                JMP START
;
;*****************************************************************************************
;
WATCHDOG:
                CLR EA                  ; Hold off interrupts
                MOV CCAP4L, #00H        ; Next compare value is within
                MOV CCAP4H, CH          ; 255 counts of the current PCA
                SETB EA                 ; timer value
                RET
;
END
```

270609-33

```
;                    Listing 10.  Pulse Width Modulator

$nomod51
$nosymbols
$nolist
$include (reg252.pdf)
$list
;
;
;       PWM mode -- Maximum frequency output = 15.6 KHz with Fosc = 16 Mhz.
;
ORG 0000H
JMP PCA_INIT
;
;       Initialize PCA timer
PCA_INIT:   MOV CMOD, #02H          ; Input to PCA timer = 1/4 x Fosc
            MOV CH, #00             ; At 16 MHz, frequency = 15.6 KHz
            MOV CL, #00
;
            MOV CCAPM0, #42H        ; PWM Mode
            MOV CCAP0L, #00H        ; Write to low byte first
            MOV CCAP0H, #128D       ; 50 percent duty cycle
            SETB CR                 ; Turn PCA timer on
;
END
```

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APPENDIX B
Duty Cycle Calculation

```
$DEBUG

SHORT_DIVISION SEGMENT CODE

EXTRN DATA(PULSE_WIDTH, PERIOD, DUTY_CYCLE)
PUBLIC DUTY_CYCLE_CALCULATION

RSEG SHORT_DIVISION


;*******************************************************************************
;
;              DUTY_CYCLE_CALCULATION
;
;     CALCULATES DUTY_CYCLE = PULSE_WIDTH / PERIOD
;
;
; Inputs to this routine are 16-bit pulse width and period measurements of
; a rectangular waveform. The output is a 9-bit BCD number representing
; the duty cycle of the waveform. The low 8 bits of the result are
; returned in DUTY_CYCLE. The 9th bit is the carry bit in the PSW. If the
; duty cycle is between 0 and 99 percent, the carry bit is 0 and DUTY_CYCLE
; contains the two BCD digits representing the duty cycle as a percent.
; If the duty cycle is 100 percent, the carry bit is 1 and DUTY_CYCLE
; contains 0.
;
;
; INPUTS: PULSE_WIDTH   2 bytes in externally defined DATA
;         (low byte at PULSE_WIDTH, high byte at PULSE_WIDTH+1)
;
;           PERIOD              2 bytes in externally defined DATA
;         (low byte at PERIOD, high byte at PERIOD+1)
;
;
; OUTPUT: DUTY_CYCLE    1 byte in externally defined DATA
;
;
; VARIABLES AND REGISTERS MODIFIED:
;
;       PULSE_WIDTH, DUTY_CYCLE
;       ACC, B, PSW, R2, R3
;
; ERROR EXIT:  Exit with OV = 1 indicates PULSE_WIDTH > PERIOD.
;
;*******************************************************************************


DUTY_CYCLE_CALCULATION:
        MOV   A,PERIOD+1
        CJNE  A,PULSE_WIDTH+1,NOT_EQUAL
        MOV   A,PERIOD
        CJNE  A,PULSE_WIDTH,NOT_EQUAL
```

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```
EQUAL:
        SETB  C
        MOV   DUTY_CYCLE,#0
        CLR   OV
        RET

NOT_EQUAL:
        JNC   CONTINUE
        SETB  OV
        RET

CONTINUE:
        MOV   R2,#8
        MOV   DUTY_CYCLE,#0
        MOV   R3,#0

TIMES_TWO:
        MOV   A,PULSE_WIDTH
        RLC   A
        MOV   PULSE_WIDTH,A
        MOV   A,PULSE_WIDTH+1
        RLC   A
        MOV   PULSE_WIDTH+1,A
        MOV   A,R3
        RLC   A
        MOV   R3,A
COMPARE:
        CJNE  R3,#0,DONE
        MOV   A,PULSE_WIDTH+1
        CJNE  A,PERIOD+1,DONE
        MOV   A,PULSE_WIDTH
        CJNE  A,PERIOD,DONE
DONE:
        CPL   C

BUILD_DUTY_CYCLE:
        MOV   A,DUTY_CYCLE
        RLC   A
        MOV   DUTY_CYCLE,A
        JNB   ACC.0,LOOP_CONTROL
SUBTRACT:
        MOV   A,PULSE_WIDTH
        SUBB  A,PERIOD
        MOV   PULSE_WIDTH,A
        MOV   A,PULSE_WIDTH+1
        SUBB  A,PERIOD+1
        MOV   PULSE_WIDTH+1,A
        MOV   A,R3
        SUBB  A,#0
        MOV   R3,A
LOOP_CONTROL:
        DJNZ  R2,TIMES_TWO
```

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```
FINAL_TIMES_TWO:
        MOV   A,PULSE_WIDTH
        RLC   A
        MOV   PULSE_WIDTH,A
        MOV   A,PULSE_WIDTH+1
        RLC   A
        MOV   PULSE_WIDTH+1,A
        MOV   A,R3
        RLC   A
        MOV   R3,A
FINAL_COMPARE:
        CJNE  R3,#0,FINAL_DONE
        MOV   A,PULSE_WIDTH+1
        CJNE  A,PERIOD+1,FINAL_DONE
        MOV   A,PULSE_WIDTH
        CJNE  A,PERIOD,FINAL_DONE
FINAL_DONE:
        JC    CONVERT_TO_BCD
        MOV   A,DUTY_CYCLE
        ADD   A,#1
        MOV   DUTY_CYCLE,A
        JNC   CONVERT_TO_BCD
        CLR   OV
        RET

CONVERT_TO_BCD:
        MOV   A,DUTY_CYCLE
        MOV   B,#10
        MUL   AB
        XCH   A,B
        SWAP  A
        MOV   DUTY_CYCLE,A
        MOV   A,#10
        MUL   AB
        XCH   A,B
        ORL   DUTY_CYCLE,A
        MOV   A,#10
        MUL   AB
        MOV   A,B
        CJNE  A,#5,TEST
TEST:   JBC   CY,OUT
        MOV   A,DUTY_CYCLE
        ADD   A,#1
        DA    A
        MOV   DUTY_CYCLE,A
OUT:    RET

END
```

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APPENDIX C

A map of the Special Function Register (SFR) space is shown in Table A1. Those registers which are new or have new bits added for the 83C51FA and 83C51FB have been **boldfaced**.

Note that not all of the addresses are occupied. Unoccupied addresses are not implemented on the chip. Read accesses to these addresses will in general return random data, and write accesses will have no effect.

User software should not write 1s to these unimplemented locations, since they may be used in future 8051 family products to invoke new features. In that case the reset or inactive values of the new bits will always be 0, and their active values will be 1.

Table A1. Special Function Register Memory Map and Values After Reset

F8		**CH** **00000000**	**CCAP0H** **XXXXXXXX**	**CCAP1H** **XXXXXXXX**	**CCAP2H** **XXXXXXXX**	**CCAP3H** **XXXXXXXX**	**CCAP4H** **XXXXXXXX**		FF
F0	* B 00000000								F7
E8		**CL** **00000000**	**CCAP0L** **XXXXXXXX**	**CCAP1L** **XXXXXXXX**	**CCAP2L** **XXXXXXXX**	**CCAP3L** **XXXXXXXX**	**CCAP4L** **XXXXXXXX**		EF
E0	* ACC 00000000								E7
D8	**CCON** **00X00000**	**CMOD** **00XXX000**	**CCAPM0** **X0000000**	**CCAPM1** **X0000000**	**CCAPM2** **X0000000**	**CCAPM3** **X0000000**	**CCAPM4** **X0000000**		DF
D0	* PSW 00000000								D7
C8	T2CON 00000000	**T2MOD** **XXXXXXX0**	RCAP2L 00000000	RCAP2H 00000000	TL2 00000000	TH2 00000000			CF
C0									C7
B8	*** IP** **X0000000**	**SADEN** **00000000**							BF
B0	* P3 11111111								B7
A8	*** IE** **00000000**	**SADDR** **00000000**							AF
A0	* P2 11111111								A7
98	* SCON 00000000	* SBUF XXXXXXXX							9F
90	* P1 11111111								97
88	* TCON 00000000	* TMOD 00000000	* TL0 00000000	* TL1 00000000	* TH0 00000000	* TH1 00000000			8F
80	* P0 11111111	* SP 00000111	* DPL 00000000	* DPH 00000000				***PCON **** **00XX0000**	87

* = Found in the 8051 core (See 8051 Hardware Description in the Embedded Controller Handbook for explanations of these SFRs).
** = See description of PCON SFR. Bit PCON.4 is not affected by reset.
X = Undefined.

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APPLICATION NOTE

AP-425

September 1988

Small DC Motor Control

JAFAR MODARES
ECO APPLICATIONS

Order Number: 270622-001

SMALL DC MOTOR CONTROL

CONTENTS

INTRODUCTION

This application note shows how an 83C51FA can be used to efficiently control DC motors with minimum hardware requirements. It also discusses software implementation and presents helpful techniques as well as sample code needed to realize precision control of a motor.

There is also a brief overview of the new features of the 83C51FA. This new feature is called the Programmable Counter Array (PCA) and is capable of delivering Pulse Width Modulated signals (PWM) through designated I/O pins.

It is assumed that the reader is familiar with the MCS-51 architecture and its assembly language. For more information about the 8051 architecture and the PCA refer to the Embedded Controller Handbook Volume 1 (order no. 210918-006).

This document will not discuss stepper motors or motor control algorithms.

DC MOTORS

DC motors are widely used in industrial and consumer applications. In many cases, absolute precision in movement is not an issue, but precise speed control is. For example, a DC motor in a cassette player is expected to run at a constant speed. It does not have to run for precise increments which are fractions of a turn and stop exactly at a certain point.

However, some motor applications do require precise positioning. Examples are high resolution plotters, printers, disk drives, robotics, etc. Stepper motors are frequently used in those applications. There are also applications which require precise speed control along with some position accuracy. Video recorders, compact disk drives, high quality cassette recorders are examples of this category.

By controlling DC motors accurately, they can overlap many applications of stepper motors. The cost of the control system depends on the accuracy of the encoder and the speed of the processor.

The 83C51FA can control a DC motor accurately with minimum hardware at a very low cost. The microcontroller, as the brain of a system, can digitally control the angular velocity of the motor, by monitoring the feedback lines and driving the output lines. In addition it can perform other tasks which may be needed in the application.

Almost every application that uses a DC motor requires it to reverse its direction of rotation or vary its speed. Reversing the direction is simply done by changing the polarity of the voltage applied to the motor. Figure 1 shows a simplified symbolic representation of a driver circuit which is capable of reversing the polarity of the input to the motor.

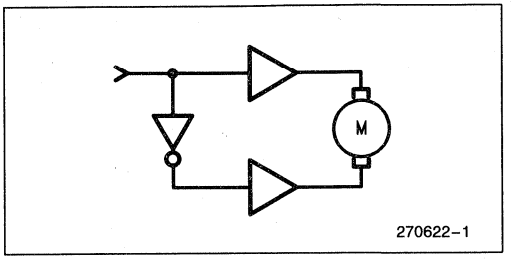


Figure 1. Reversible Motor Driver Circuit

Varying the speed requires changing the voltage level of the input to the motor, and that means changing the input level to the motor driver. In a digitally-controlled system, the analog signal to the driver must come from some form of D/A converter. But adding a D/A converter to the circuit adds to the chip count, which means more cost, higher power consumption, and reduced reliability of the system.

The other alternative is to vary the pulse width of a digital signal input to the motor. By varying the pulse width the average voltage delivered to the motor changes and so does the speed of the motor. A digital circuit that does this is called a Pulse Width Modulator (PWM). The 83C51FA can be configured to have up to 5 on-board pulse width modulators.

THE 83C51FA

The 83C51FA is an 8-bit microcontroller based on the 8051 architecture. It is an enhanced version of the 87C51 and incorporates many new features including the Programmable Counter Array (PCA).

Included in the Programmable Counter Array is a 16-bit free running timer and 5 separate modules.

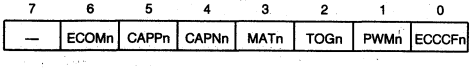
The PCA timer has two 8-bit registers called CL (low byte) and CH (high byte), and is shared by all modules. It can be programmed to take input from four different sources. The inputs provide flexibility in choosing the count rate of the timer. The maximum count rate is 4 MHz (¼ of the oscillator frequency).

Some of the port 1 pins are used to interface each module and the timer to the outside world. When the port pins are not used by the PCA modules, they may be used as regular I/O pins.

The modules of the PCA can be programmed to perform in one of the following modes: capture mode,

compare mode, high speed output mode, pulse width modulator (PWM) mode, or watchdog timer mode (only module 4).

Every module has an 8-bit mode register called CCAPMn (Figure 2), and a 16-bit compare/capture register called CCAPnL & CCAPnH, where n can be any value from 0 to 4 inclusive. By setting the appropriate bits in the mode register you can program each module to operate in one of the aforementioned modes.



CCAPMn

ECOMn — Enables the comparator function. Must be set for functions which require comparing of the compare/capture registers with the 16-bit timer, i.e., software timer, high-speed output, watchdog timer, and PWM.

CAPPn — Capture on positive edge of signal.

CAPNn — Capture on negative edge of signal.

MATn — Find a match between the capture/compare and 16-bit timer.

TOGn — Toggle I/O pin upon a match between capture/compare registers and 16-bit timer.

PWMn — Generate PWM on I/O pin upon a match between the low byte of capture/compare and the low byte of PCA timer.

ECCFn — Enables compare/capture flag CCFn in the CCON register to generate an interrupt.

Figure 2. CCAPMn Register

When a module is programmed in capture mode, an external signal on the corresponding port pin will cause a capture of the current value of the 16-bit timer. By setting bits CAPPn or CAPNn or both, the module can be programmed to capture on the rising edge, falling, edge, or either edge of the signal. If enabled, an interrupt is generated at the time of capture.

When module is to perform in one of the compare modes (software timer, high speed output, watch dog timer, PWM), the user loads the capture/compare registers with a calculated value, which is compared to the contents of the 16-bit timer, and causes an event as soon as the values match. It can also generate an interrupt.

PWM is one of the compare modes and is the only one which uses only 8 bits of the capture/compare register. The user writes a value (0 to FFH) into the high byte (CCAPnH) of the selected module. This value is transferred into the lower byte of the same module and is compared to the low byte of the PCA timer. While CL < CCAPnL the output on the corresponding pin is a logic 0. When CL > CCAPnL, the output is a logic 1.

In this application note we will see how a module can be programmed to perform as a PWM to control the speed and direction of a DC motor.

SETTING UP THE PCA

The 83C51FA has several Special Function Registers (SFRs) that are unknown to ASM51 versions before 2.4. The names of these SFRs must be defined by DATA directive or be defined in a separate file and be included at the time of compilation. Such a file has already been created and is included in the ASM51 package version 2.4.

Two special function registers are dedicated to the PCA timer to allow mode selection and control of the timer. These registers are CCON and CMOD and are shown in figure 3. CCON contains the PCA timer ON/OFF bit (CR), timer rollover flag (CF) and module flags (CCFn). Module flags are used to determine which module causes the PCA interrupt.

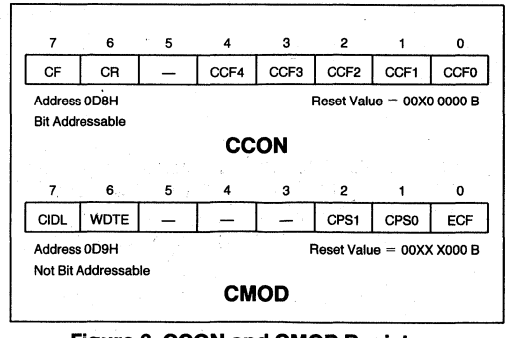


Figure 3. CCON and CMOD Registers

First the clock source for the PCA timer must be defined. The 16 bit timer may have one of four sources for its input. These sources are: osc freq/4, osc freq/12, timer 0 overflow, and external clock.

Two bits in the CMOD register are dedicated to selecting one of the sources for the PCA timer input. They are bits 1 and 2 of CMOD which are called CPS0 and CPS1. CMOD is not bit addressable, thus the value

must be loaded as a byte. Figure 4 shows all the sources and the corresponding values of CPS0 and CPS1.

CPS1	CPS0	TIMER INPUT SOURCE
0	0	Internal clock, Fosc/12
0	1	Internal clock, Fosc/4
1	0	Timer 0 overflow
1	1	External clock (input on P1.2)

Figure 4. Timer Input Source

Next the appropriate module must be programmed as a PWM. As it was noted earlier, the 8-bit mode register for each module is called CCAPMn (see figure 2). Bit 1 of each register is called PWMn. This bit along with ECOMn (bit 6 of the same register) must be set to program the module in the PWM mode. PWM is one of the compare functions of the PCA, and ECOMn enables the compare function. Thus, the hex value that must be loaded into the appropriate CCAPMn register is 42H.

Now that the module is programmed as a PWM, a value must be loaded in the high byte of the compare register to select the duty cycle. The value can be any number from 0 to 255. In the 83C51FA loading 0 in the CCAPnH will yield 100% duty cycle, and 255 (0FFh) will generate a 0.4% duty cycle. See figure 5.

The next step is to start the PCA timer. The bit that turns the timer on and off is called CR and is bit 6 of CCON register (Figure 3). Since this register is bit addressable, you can use bit instructions to turn the timer on and off.

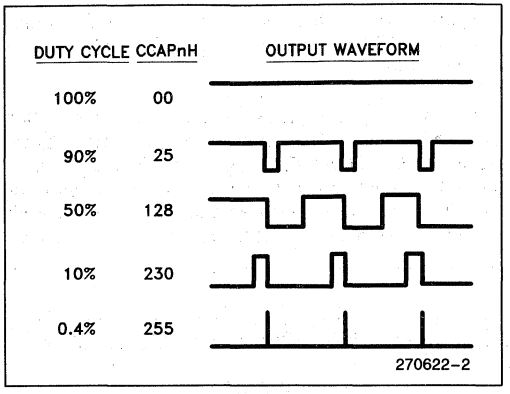


Figure 5. Selected Duty Cycles and Waveforms

In the following example module 2 has been selected to provide a PWM signal to a motor driver. An external clock will be provided for the timer input, so the value that needs to be loaded into CMOD is 06H.

HARDWARE REQUIREMENT

When using an 83C51FA, very little hardware is required to control a motor. The controller can interface to the motor through a driver as shown in figure 6.

```
  .
  .
  .
MOV   CMOD,#06      ; timer input external
MOV   CCAPM2,#42H   ; put the module in PWM mode.
MOV   CCAP2H,#0     ; 0 provides 100% duty cycle (5V)
SETB  CR            ; turn timer on
  .
  .
  .
END
```

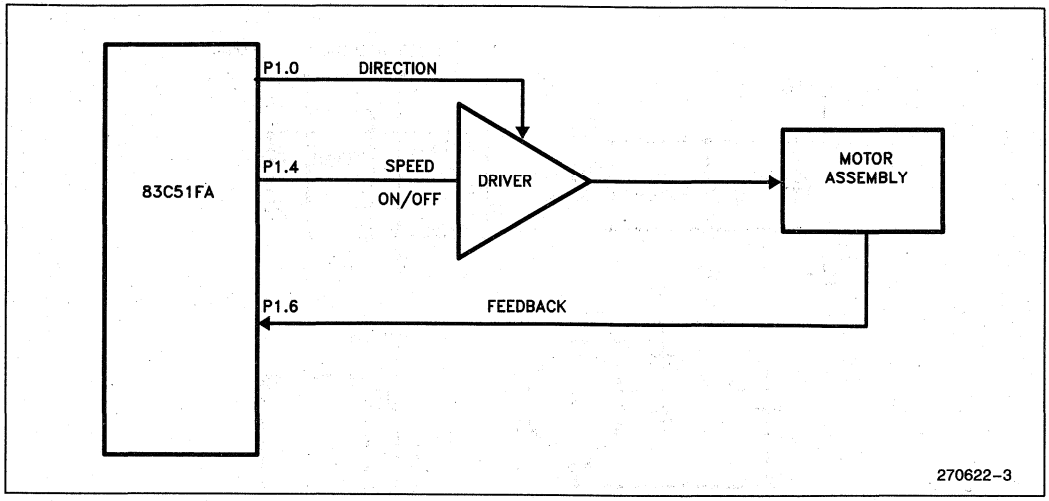


Figure 6. Simplified Circuit Diagram of a Closed Loop System

This configuration, a closed loop circuit, takes up only three I/O pins. The line controlling direction can be a regular port pin but the speed control line must be one of the port 1 pins which corresponds to a PCA module selected for PWM. Depending on how the feedback is generated and processed, it could be connected to a regular I/O, an external interrupt, or a PCA module. Feedback is discussed in more detail in the feedback section of this application note.

The diagram in Appendix A is an example of a DC motor circuit which has been built and bench-tested.

DRIVER CIRCUIT

Although some DC motors operate at 5 volts or less, the 83C51FA can not supply the necessary current to drive a motor directly. The minimum current requirements of any practical motor is higher than any microcontroller can supply. Depending on the size and ratings of the motor, a suitable driver must be selected to take the control signal from the 83C51FA and deliver the necessary voltage and current to the motor.

A motor draws its maximum current when it is fully loaded and starts from a stand still condition. This factor must be taken into account when choosing a driver. However, if the application requires reversing the motor, the current demand will even be higher. As the motor's speed increases, it's power consumption decreases. Once the speed of a motor reaches a steady state, the current depends on the load and the voltage across the motor.

Standard motor drivers are available in many current and voltage ratings. One example is the L293 series which can output up to 1 ampere per channel with a supply voltage of 36 V. It has separate logic supply and takes logical input (0 or 1) to enable or disable each channel. There are four channels per device. The L293D also includes clamping diodes needed for protecting the driver against the back EMF generated during the reversing of motor.

NOISE CONSIDERATIONS

Motors generate enough electrical noise to upset the performance of the controller. The source of the noise could be from the switching of the driver circuits or the motor itself. Whatever the cause of the noise may be, it must be isolated or bypassed.

Isolating the microcontroller from the driver circuit is helpful in keeping the noise limited.

Bypass capacitors help a great deal in suppressing the noise. They must be added to the power and ground (Figure 7 diagram a), on the driver circuit (diagram b), on the motor terminals (diagram c), and on the 83C51FA (diagram d). The capacitors must be as close to the component as possible. In fact the best location is under the chip or on top of it if packaging allows. The diagrams in figure 7 show the location and some typical values for the bypass capacitors.

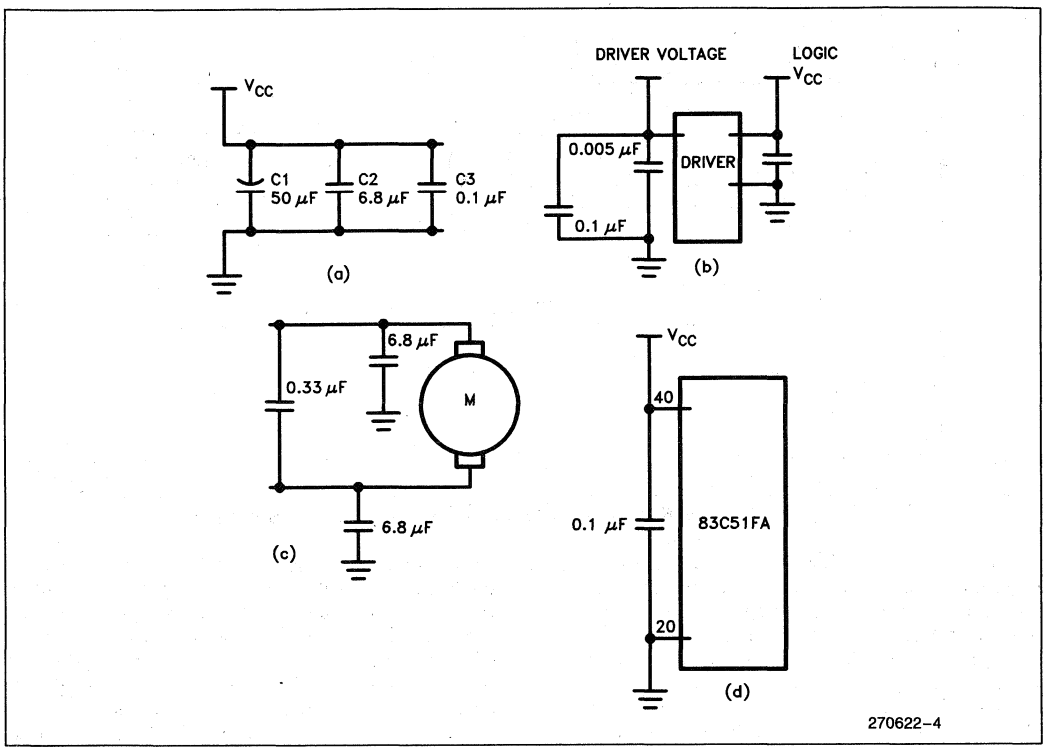


Figure 7. Typical Locations and Values for Bypass Capacitors

OPEN LOOP & CLOSED LOOP SYSTEMS

There are two types of motor control systems: open loop and closed loop.

In the open loop system the controller outputs a signal to turn the motor on/off or to change the direction of the rotation based on an input that does not come from the motor. For example, the position of a manual or timer switch becomes the input to the controller, which varies the input to the motor. In another case, the controller may take input from data tables in the program to run, vary the speed, reverse direction, or stop the motor.

Closed loop systems can use one or more of the above mentioned examples for the open loop system, plus at least one feedback signal from the motor. The feedback signal provides such information as speed, position, and/or direction of motion.

Many applications require that a motor run at a constant speed. The controller has to continuously make adjustments to keep the speed within the limits. In some cases the speed of the motor is synchronized to another motor or moving part of the system.

Depending on the type of feedback signal, the 83C51FA may have to use other modules of the PCA along with other on-chip peripherals such as Timer/Counters, Serial Port, and the interrupt system to precisely control a DC motor.

The example in the following section uses one PCA module to generate PWM, and another module (in capture mode) to receive feedback from a DC motor.

FEEDBACK

The feedback comes from a sensing device which can detect motion. The sensing device may be an optical encoder, infrared detector, Hall effect sensor, etc. Depending on the application, one or more of the above mentioned sensing devices may be suitable.

The optical sensors should be encapsulated for better reliability. If they are not enclosed, factors such as ambient light, dust, and dirt can lessen their sensitivity.

Hall effect sensors are insensitive to any type of light. They change logic levels going into and coming out of a magnetic field. The sensing device is normally mounted

on some stationary part of the system and the magnet is installed on the rotating part. The potential problem with the Hall effect sensors are that if the gap between the magnet and the sensing device is too big, the sensing device may not be affected by the magnetic field. Also the number of magnets is limited which means fewer feedback pulses will be provided.

Whatever the means of sensing, the result is a signal which is fed to the controller. The 83C51FA can use the feedback signal to determine the speed and position of the motor. Then it can make adjustments to increase or decrease the speed, reverse the direction, or stop the motor.

In the following example module 3 of PCA is set up to perform in the capture mode. In this mode module 3 will receive feedback signals from a Hall effect transistor fixed behind a wheel which is mounted on the shaft of a DC motor. Two magnets are embedded on this wheel in equal distances from each other (180 degrees apart). Every time that the Hall effect transistor passes through the magnetic field, it generates a pulse.

The signal is input to P1.6 which is the external interface for module 3 of the PCA. In this example, module 3 is programmed to capture on the rising edge of the input signal. The time between the two captures corresponds to ½ of a revolution. Thus, two consecutive captures can provide enough information to calculate the speed of the motor as explained in the next paragraph. By storing the value of the capture registers each time, and comparing it to its previous value, the controller can constantly measure and adjust the speed of the motor. Using this method one can run a motor at a precise speed, or synchronize it to another event.

In the PCA interrupt service routine, each capture value is stored in temporary locations to be used in a subtract operation. Subtracting the first capture from the second one will yield a 16-bit result. The resultant value, which will be referred to as "Result" in the rest of this document, is in PCA timer counts. An actual RPM can be calculated from Result. Although the 83C51FA can do the calculation, it would be much faster to provide a lookup table within the code. The table will contain values which have been calculated for a possible range of Results.

The following code is an example of how to measure the period of a signal input to module 3 of the 83C51FA. The diagram in figure 8 shows how the period corresponds to the rotation of the wheel. In the diagram "T" is the period and "t" is the time that the magnet is passing in front of the Hall effect transistor.

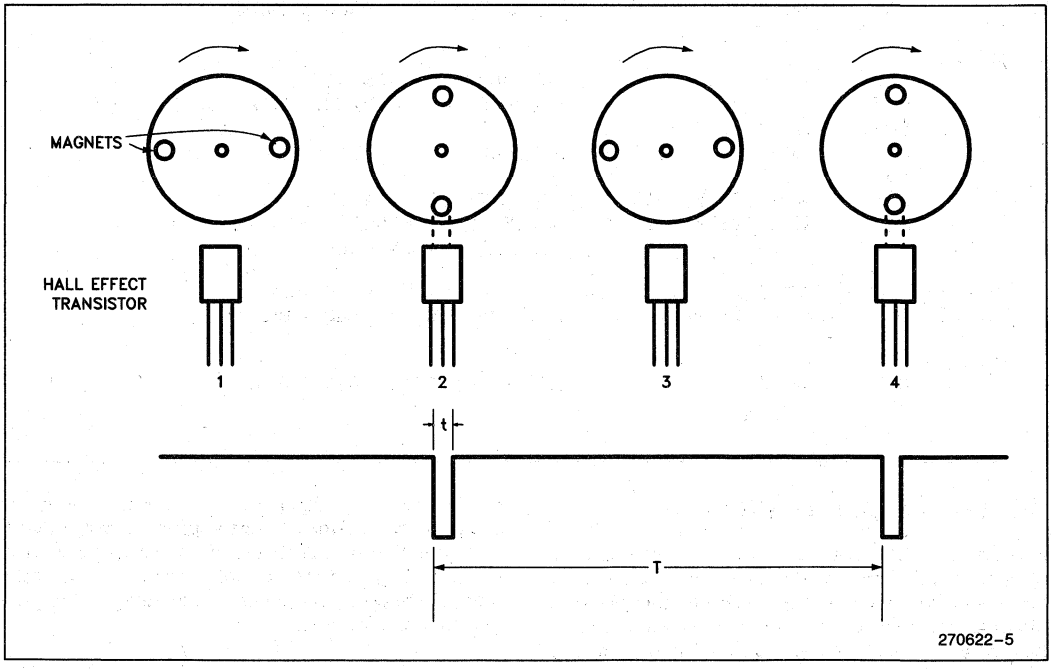


Figure 8. The Output Waveform of the Hall Effect Transistor as it goes Through the Magnetic Field

```
FLAG    BIT     0           ; test flag
HI_BYTE_TMP     DATA    45H
LO_BYTE_TMP     DATA    46H
HI_BYTE_RESULT  DATA    47H
LO_BYTE_RESULT  DATA    48H

        ORG     00H
        JMP     BEGIN

        ORG     33H
        JMP     PCA_ISR

BEGIN:
        MOV     CMOD,#0         ; SET PCA TIMER InPUT fOSC/12.
        MOV     CCAPM3,#21H     ; MODULE 3 IN POSITIVE CAPTURE MODE.
        MOV     CCAP3H,#9AH     ; PWM AT 60 PERCENT DUTY CYCLE.
        SETB    IP.6            ; SET PCA INT. AT HIGH PRIORITY.
        MOV     IE,#0C0H        ; ENABLE PCA INTERRUPT.
        CLR     FLAG
        SETB    CR              ; TURN PCA TIMER ON.
          .
          .
          .
PCA_ISR:
        JB      FLAG,CAP_2      ; FLAG BIT IS SET TO SIGNIFY 1st
        SETB    FLAG            ; CAPTURE COMPLETE.
        MOV     HI_BYTE_TMP,CCAP3H; SAVE FOR NEXT CALCULATION.
        MOV     LO_BYTE_TMP,CCAP3L
        CLR     CCF3            ; RESET PCA INT. FLAG MODULE 3
        RETI
CAP_2:
        CLR     C               ; FOR SUBTRACT OPERATION.
        MOV     A,CCAP3L        ; SUBTRACT OLD CAPTURE FROM NEW CAPTURE.
        SUBB    A,LO_BYTE_TMP
        MOV     LO_BYTE_RESULT,A ; SUBTRACTION RESULT OF LOW BYTE.
        MOV     A,CCAP3H
        SUBB    A,HI_BYTE_TMP   ; HIGH BYTE SUBTRACTION.
        MOV     HI_BYTE_RESULT,A ; SUBTRACTION RESULT OF HIGH BYTE.
        CLR     IE.6            ; DISABLE PCA INTERRUPT.

In this example only one measurement is taken. That is why
the PCA interrupt is disabled in the above line of instruction.

RET_PCA:
        CLR     CCF3            ; RESET PCA INT. FLAG MODULE 3
        RETI
        END
```

SOFTWARE/CPU OVERHEAD

It takes the 83C51FA no more than 250 bytes of code to control a DC motor. That is to run the motor at various speeds, monitor the feedback, use electrical braking, and even run it in steps. However, the CPU time spent on the above tasks can add up to 70 to 75% of the total time available (clock frequency 12 MHz).

The section of software which turns the motor on and off, or sets the speed is very short. In fact, all of that can be done in less than 30 instructions. Thus, in an open loop system, the controller spends an insignificant amount of time on controlling the motor. However, in a closed loop system the controller has to continuously monitor the speed and adjust it according to the program and the feedback.

The rest of this section talks about electrical braking, stepping a DC motor, and offers examples of code to implement these techniques.

ELECTRICAL BRAKING

Once a DC motor is running, it picks up momentum. Turning off the voltage to the motor does not make it stop immediately because the momentum will keep it turning. After the voltage is shut off, the momentum will gradually wear off due to friction. If the application does not require an abrupt stop, then by removing the driving voltage, the motor can be brought to a gradual stop.

An abrupt stop may be essential to an application where the motor must run a few turns and stop very quickly at a predetermined point. This could be achieved by electrical braking.

Electrical braking is done by reversing the direction of the motor. In order to run in reverse direction, the motor has to stop first, at which time the driving voltage is eliminated so that the motor does not start in the new direction. Therefore the length of time that the reversing voltage is applied must be precisely calculated to ensure a quick stop while not starting it in the reverse direction.

There is no simple formula to calculate when to start, and how long to maintain braking. It varies from motor to motor and application to application. But it can be perfected through trial and error.

In a closed loop system, the feedback can be used to determine where or when to start braking and when to discontinue.

During the electrical braking, or any time that the motor is being reversed, it draws its maximum current. To a motor which is turning at any speed, reversing is a heavy load. The current demand of a motor, when it has been reversed,is much higher than when it has just been powered on.

The following shows a code sample for electrical braking on a DC motor. The code is designed for the hardware shown in Appendix A. The subroutine DELAY provides the period that the reverse voltage is applied to the motor. The code for this subroutine is available in the TIME DELAYS section of this document.


```
BEGIN:
        MOV     CMOD,#0         ; SET PCA TIMER INPUT fOSC/12.
        MOV     CCAPM1,#42H     ; SETTING THE MODULE TO PWM MODE.
        SETB    CR              ; PCA TIMER RUN.

; DRIVE MOTOR CLOCKWISE
        CLR     P1.0            ; P1.0 AND THE PWM OF MODULE 1-
        MOV     CCAP1H,#00      ; CONTROL THE SPEED AND DIRECTION.

; 00 IN THIS REGISTER PUTS OUT MAX PWM (LOGICAL 1)
        CALL    STOP_MOTOR
          .
          .
          .
STOP_MOTOR:
        SETB    P1.0            ; REVERSING THE MOTOR.
        MOV     CCAP1H,#0FFH    ;
        CALL    DELAY           ; WAITING FOR 0.5 SECOND.
        CLR     P1.0            ; REDUCING VOLTAGE TO 0.
        RET                     ; RETURN FROM SUBROUTINE.
          .
          .
          .
```

STEPPING A DC MOTOR

Using the 83C51FA, it is possible to run a simple DC motor in small steps. The resolution of the steps will be as high as the resolution of the encoder. If this resolution is sufficient, here is a technique to run a DC motor in steps.

Using a gear box to gear down the motor will increase the resolution of steps. However, putting too much load through the gears will cause sluggish starts and stops.

Electrical braking is used in order to stop the motor at each step. Therefore, the routine that runs the motor in steps will consist of turning it on with full force, waiting for certain period, and stopping it as fast as possible. The wait period depends on the number of steps per revolution.

As the steps and the intervals between them become smaller, the average current demand of the motor increases. This is because the motor is operated at its maximum torque condition every time it starts to rotate and every time it is reversed for electrical braking.

The following code sample shows a continuous loop which runs the motor in steps. The number of steps per revolution depends on the duration of the delay generated by DELAY subroutine. Subroutine WAIT provides the time between the steps.

Subroutine DELAY is the period of time that the motor is kept in reverse. This period must be determined through trial and error for each type of motor and system.

TIME DELAYS

While the 83C51FA is controlling a motor it must frequently wait for the motor to move to certain position before it can proceed with the next task. For example, in the case of electrical braking when the controller reverses the polarity of voltage across the motor, depending on the type, size, and the speed of the motor, it may have up to a second of CPU time before it will turn the motor off.

The wait may be implemented in different ways. Any of the Timer/Counters or unused PCA modules could be utilized to provide accurate timing. The advantage in using the timers is that while the timer is counting, the processor can be taking care of some other tasks. When the timer times out and generates an interrupt the processor will go back and continue servicing the motor.

If there are no timers or PCA modules available for this purpose, a software timer maybe set up by decrementing some of the internal registers. In this method the processor will be tied up counting up or down and will not be able to do anything else. An example of such a timer is:

```
          .
          .
          .
LOOP:
        CLR     P1.0            ; SET DIRECTION CLOCKWISE
        MOV     CCAP1H,#0       ; MAX PWM

The above instruction sets the motor running clockwise. The controller can
be doing other tasks if need be, or just stay in a wait loop, then stop the
motor as shown below.

        SETB    P1.0            ; REVERSING THE MOTOR.
        MOV     CCAP1H,#0FFH    ;.
        CALL    DELAY           ; WAIT FOR IT TO STOP.
        CLR     P1.0            ; REDUCE VOLTAGE TO 0.
        CALL    WAIT            ; TIME BEFORE NEXT STEP.
        JMP     LOOP
          .
          .
          .
```

```
DELAY:
        MOV     R4,#25          ; (decimal)
        MOV     R5,#255         ; (decimal)
DELAY_LOOP:
        DJNZ    R5,DELAY_LOOP
        DJNZ    R4,DELAY_LOOP
        RET
```

Subroutine DELAY provides approximately 6.4 ms with a 12 MHz clock or 4.8 milliseconds with a 16 MHz clock. The length of this delay can be controlled by loading smaller or larger values to R4 to vary from 260 microseconds up to 65 milliseconds at 12 MHz or 48 milliseconds at 16 MHz oscillator frequency. Larger delays may be obtained by cascading another register and creating an outer loop to this one.

Let us assume that it will take a motor 500 milliseconds to stop from its CW rotation and we are going to use Timer/Counter 0 to provide the wait period. Subroutine DELAY1 will keep track of this timing. Module 1 of PCA is selected to provide the PWM.


```
        ORG     0BH
        JMP     TIMER_INTERRUPT_ROUTINE
          .
          .
          .
        CLR     P1.0            ; SET DIRECTION CW
        MOV     CCAP1H,#0       ; MAX PWM

Now the motor is running and the controller can do other tasks.
Some typical tasks are called in the following segment.

BUSY_LOOP:
        CALL    MONITOR_DISPLAY
        CALL    SCAN_KEY_BOARD
        CALL    SCAN_INPUT_LINES
        JNB     STOP_FLAG,BUSY_LOOP

STOP_FLAG gets set by a feedback signal and denotes that the motor must
stop.

        SETB    P1.0            ; REVERSING THE MOTOR
        MOV     CCAP1H,#0FFH    ;
        CALL    DELAY           ; WAIT TILL MOTOR STOPS
        CLR     P1.0            ; REDUCE VOLTAGE TO 0
          .
          .
          .
DELAY1:
        SETB    EA
        SETB    ET0             ; enable timer 0 interrupt
        MOV     TL0,#0D8H
        MOV     TH0,#5EH
```

```
            SETB        TR0         ; timer 0 on
            MOV         R7,#8       ; keep track of how many times
    ; timer 0 must roll over

;   continue performing other tasks

 MONITOR_LOOP:
            CALL        MONITOR_DISPLAY
            CALL        SCAN_KEY_BOARD
            CALL        SCAN_INPUT_LINES
            JB          TR0,MONITOR_LOOP
            RET

TIMER_INTERRUPT_ROUTINE:
            DJNZ        R7,FULL_COUNT
            CLR         TR0
FULL_COUNT
            RETI
```

To implement a 500 milliseconds delay, timer 0 is used here. In mode 1 timer 0 is a 16-bit timer which takes 65.535 milliseconds at 12 MHz to roll over. Dividing 500 milliseconds to 65.535 shows that timer has to overflow more than 7 times but less than 8 times. How much more than 7 times? The following calculation yields the initial load value of the timer.

500 ÷ 65.535 = 7.2695 taking it backward

65.535 × 7 = 458.745 milliseconds

500 − 458.745 = 41.255 milliseconds or 41255 microseconds.

In hexadecimal it is A127H. The initial load value is the complement of this value which is 5ED8H.

CONCLUSION

The 83C51FA with all its on-chip peripherals is a system on one chip. It can simplify the design of a control board and reduce the chip count. Up to 5 DC motors can be controlled while doing other tasks such as monitoring feedback lines, human interfacing (scanning a keyboard, displaying information), and communicating with other processors. The MCS-51 powerful instruction set provides maximum flexibility with minimum hardware.

With its onboard program memory capability, the need for the external EPROM and address latch is eliminated. The 83C51FA can have up to 8K bytes of code and the 83C51FB can have up to 16K bytes of code onboard.

This microcontroller can be used in industrial, commercial, and automotive applications.

APPENDIX A

Figure A-1 shows a symbolic view of the L293B driver. This driver has 4 channels but only two are shown here. Note the inputs A and B and how they are related to each other. You can input the PWM to either one of the inputs and by toggling the other input start or stop the motor. While running, the PWM input controls the speed. Pin P1.4 corresponds to module 1 of the PCA, and pin P1.0 is used as a regular I/O pin.

Figure A-2 shows the schematic of the motor driver, motor, feedback path, and the supporting components.

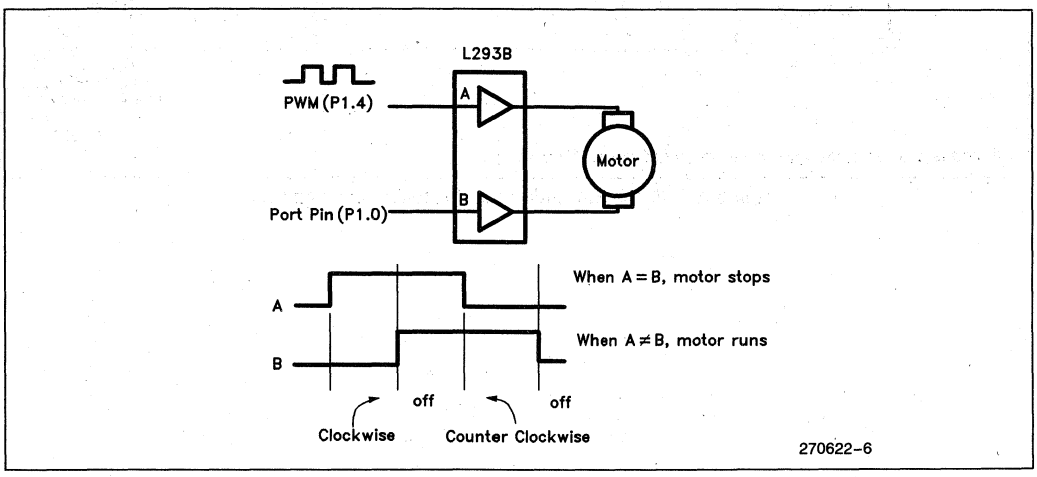
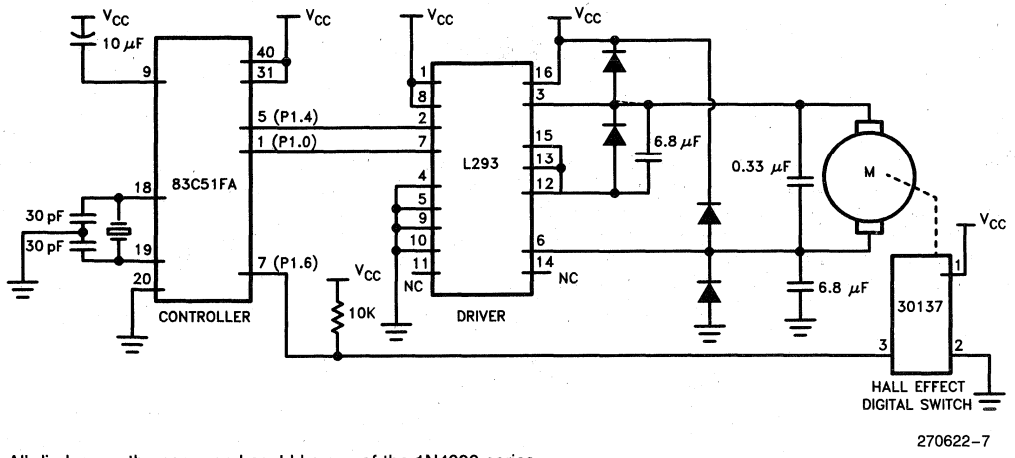


Figure A-1. The L293B Motor Driver



All diodes are the same and could be any of the 1N4000 series.

Figure A-2. Full Schematic of a Motor-Control System

IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. IE-32, NO. 4, NOVEMBER 1985

Using the 8051 Microcontroller with Resonant Transducers

TOM WILLIAMSON

Abstract—**Having to interface an analog transducer to a digital control system through an analog-to-digital converter represents an expensive bottleneck in the development of many systems. Some transducer companies are addressing this problem by developing proprietary families of resonant transducers.**

Resonant transducers are oscillators whose frequency depends in some known way on the physical property being measured. The electrical output from these devices is a train of rectangular pulses whose repetition rate encodes the value of the measurand. Changes in the measurand cause the frequency to shift. The microcontroller detects the frequency shift, runs a validity check on it, and converts it in software to the measurand value.

This paper discusses software interfacing techniques between resonant transducers and the 8051. Techniques for measuring frequency and period are discussed and compared for resolution and interrogation time. The 8051 is capable of performing these tasks in extremely short CPU time. Requirements for obtaining *n*-bit resolution in the measurement are discussed. It is determined that it is always faster to evaluate the measurand to a given level of resolution by measuring the period rather than the frequency, even if the measurand is proportional to the frequency rather than to the period. Numerical and software examples are presented to illustrate the concepts.

I. Resonant Transducers

MOST sensing transducers are not directly compatible with digital controllers, because they generate analog signals. A few transducer companies are developing proprietary families of sensors which generate signals that are more directly compatible with digital systems. These are not analog sensors with built-in A-D conversion, but oscillators whose frequency depends in some known way on the physical property being measured.

The technology is applicable to virtually any type of measurand: pressure, gas density, position, temperature, force, etc. The sensor and microcontroller can operate from the same supply voltage, so the sensor can in most cases connect directly to a port pin on the microcontroller.

The nominal reference frequency of the output signal from these devices is in the range of 20 Hz-500 kHz, depending on the design. A change in the measurand away from the reference condition causes the frequency to shift by an amount that is related to the change in the measurand value. Transducers are available that have a full-scale frequency shift of 2-1. The microcontroller detects the change in frequency or period and converts it in software to the measurand value.

II. Connecting the Digital Transducer to the 8051

Normally the transducer output can be connected directly to one of the 8051 port pins. An exception would occur when the transducer signal does not restrict itself to the voltage range of −0.5 to +5.5 V.

The 8051 is not sensitive to the rise and fall times of its input signals. It detects transitions by sampling its port pins at fixed intervals (once per machine cycle), and responds to a change in the sequence of samples. If the slew rate of the transducer signal is extremely slow, noise superimposed on the signal could cause the sequence of samples to show false transitions. There could on that account be situations in which the transducer signal should be buffered through a Schmitt Trigger to square it up.

III. Timer/Counter Structure in the 8051

The 8051 has two 16-bit timer/counters: Timer 0 and Timer 1. Both can be configured in software to operate either as timers or as event counters.

In the "timer" function, the register is automatically incremented every machine cycle. Since a machine cycle in the 8051 consists of 12 clock periods, the timer is being incremented at a constant rate of 1/12 the clock frequency.

In the "counter" function, the register is incremented in response to a 1-to-0 transition at its corresponding external input pin (*T0* or *T1*). The way this function works is the external input pin is sampled once each machine cycle (once every 12 clock periods), and when the samples show a high in one cycle and a low in the next, the count is incremented.

Note too that since it takes two machine cycles (24 clock periods) to recognize a 1-to-0 transition, the maximum count rate is 1/24 the clock frequency. If the clock frequency is 12 MHz, the maximum count rate is 500 kHz. There are no requirements on the duty cycle of the signal being counted.

The 8052, an enhanced version of the 8051, has three 16-bit timer/counters, two of which are identical to those in the 8051. The third timer/counter can operate either as a 16-bit timer/counter with automatic reload to a preset 16-bit value on rollover, or as a 16-bit timer/counter with a "capture" mode. In the capture mode a 1-to-0 transition at the T2EX pin causes the current value in the counting register to the "captured" into RAM. The third timer makes the 8052 particularly easy to interface with resonant transducers.

IV. Whether to Measure Frequency or Period

Measuring the frequency requires counting transducer pulses for a fixed sample time. Measuring the period requires measuring elapsed time for a fixed number of transducer pulses. For a given level of accuracy in the determination of the value of the measurand, it is usually faster to measure the period, rather than the frequency, even if the measurand is

Manuscript received October 25, 1984.

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proportional to frequency rather than period. However, both types of measurements will be discussed here.

Two timer/counters can be used, one to mark time and the other to count transducer pulses. If the frequency being counted does not exceed 50 kHz or so, one may equally well connect the transducer signal to an external interrupt pin, and count transducer pulses in software. That frees one timer, with very little cost in CPU time.

V. How to Measure Transducer Frequency

Measuring the frequency means counting transducer pulses for some desired sample time. The count that is directly obtained is $T \times F$, where T is the sample time and F is the frequency. The full scale range is $T \times (F\text{max} - F\text{min})$. For n-bit resolution

$$1\ \text{LSB} = \frac{T \times (F\text{max} - F\text{min})}{2^n}.$$

Therefore, the sample time required for n-bit resolution is

$$T = \frac{2^n}{F\text{max} - F\text{min}}.$$

For example, 8-bit resolution in the measurement of a frequency that varies between 5 and 10 kHz would require, according to this formula, a sample time of 51.2 ms. The maximum acceptable frequency count would be 51.2 ms × 10 kHz = 512 counts. The minimum would be 256 counts. Subtracting 256 from each frequency count would allow the frequency to be reported on a scale of 0 to *FF* in hex digits.

If *F*min and *F*max are closer together it takes more time to resolve them. 8-bit resolution in the measurement of a frequency that varies between 7 and 9 kHz would require a sample time of 128 ms. The maximum and minimum acceptable counts would be 1152 and 896. Subtracting 896 from each frequency count would allow the frequency to be reported on a scale of 0 to *FF* in hex digits.

To implement the measurement, one timer is used to establish the sample time. In this function it autoincrements every machine cycle. A machine cycle consists of 12 periods of the clock oscillator. The sample time can be converted to machine cycles by multiplying it by (*F*xtal)/12, where *F*xtal is the 8051 clock frequency. The timer needs to be preset so that it rolls over at the end of each sample time. Then it generates an interrupt, and the interrupt routine reads and clears the transducer pulse counter, and then reloads the timer with the correct preset value.

The preset or reload value is the two's complement negative of the sample time in machine cycles. For example, with a 12-MHz clock frequency, the reload value required to establish a 51.2 ms sample time is

$$-\frac{(51.2\ \text{ms}) \times (12000\ \text{kHz})}{12} = -51200 = 3800\ \text{H}.$$

In many cases the required sample time exceeds the capacity of a 16-bit timer. For example, establishing a 128 ms sample time with a 12-MHz clock frequency requires a 3-byte timer with a reload of FE0C00H. The 8051 timer, being only 2-bytes wide, can be augmented in software in the timer interrupt routine to three bytes. The 8051 has a DJNZ instruction (decrement and jump if not zero) which makes it easier to code the third timer byte to count down instead of up. If the third timer byte counts down, its reload value is the two's complement of what it would be for an up-counter. For example, if the two's complement of the sample time is FE0C00H, then the reload value for the third timer byte would be 02, instead of *FE*. The timer interrupt routine might then be

```
    DJNZ    THIRD_TIMER_BYTE,OUT
    MOV     TL0,#0
    MOV     TH0,#0CH
    MOV     THIRD_TIMER_BYTE,#02
  (Now read and clear the
    transducer pulse counter.)
OUT: RETI
```

Interrupt latency will have no effect on the measurement if the latency is the same for every sample time.

The trouble with measuring the frequency is it is not only slow, but a waste of the resolving power of the 8051's timers. A timer with microsecond resolution is being used to mark off 100-ms time periods. The technique is nevertheless useful if the timer is already serving other purposes (servicing a display, perhaps), so that the sample time is coming relatively free of charge. But in most cases it is faster and equally accurate to measure the frequency by deriving it from a measurement of the period.

VI. How to Measure the Period

Measuring the period of the transducer signal means measuring the total elapsed time over N-transducer pulses. The quantity that is directly measured is $N \times T$, where T is the period of the transducer signal in *machine cycles*. The relationship between T in machine cycles and the transducer frequency F in arbitrary frequency units is

$$T = \frac{F\text{xtal}}{F} \times (1/12).$$

where *F*xtal is the 8051 clock frequency, in the same unit as F.

The full scale range then is $N \times (T\text{max} - T\text{min})$. For n-bit resolution

$$1\ \text{LSB} = \frac{N \times (T\text{max} - T\text{min})}{2^n}.$$

Therefore, the number of periods over which the elapsed time should be measured is

$$N = \frac{2^n}{T\text{max} - T\text{min}}.$$

However, N must also be an integer. It is logical to evaluate the above formula (do not forget that *T*max and *T*min have to be in machine cycles) and select for N the next higher integer. This selection gives a period measurement that has somewhat more than n-bit resolution, which may or may not be acceptable, depending on the overall requirements of the

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system. It can be scaled back to n-bit resolution, if necessary, by the following computation:

$$\text{reported value} = \frac{NT - NT\text{min}}{NT\text{max} - NT\text{min}}$$

where NT is the elapsed time measured over N periods.

The computation can be done in math if a suitable divide routine is available in the software. For 8-bit resolution it is entirely reasonable to find the reported value in a look-up table, which would take up somewhat more than one page in ROM. In fact, the look-up table would contain $NT\text{max} - NT\text{min}$ entries.

For example, suppose we want 8-bit resolution in the measurement of the period of a signal whose frequency varies from 5 to 10 kHz. If the clock frequency is 12 MHz, then $T\text{max}$ is (12 000 kHz)/(12 × 5 kHz) = 200 machine cycles, and $T\text{min}$ is 100 machine cycles. The timer needs to be on then for $N = 2.56$ periods, according to the formula. Using $N = 3$ periods will give maximum and minimum NT values of 600 and 300 machine cycles. This is somewhat more than 8-bit resolution. It can be scaled to 8 bits with a 300-byte look-up table, if desired.

To implement the measurement, one timer is used to measure the elapsed time NT. Enabling its interrupt is optional. The timer interrupt could be used to indicate a short or open in the transducer circuit.

Then the transducer is connected to one of the external interrupt pins (INT0 or INT1), and this interrupt is configured to the transition-activated mode. In the transition-activated mode every 1-to-0 transition in the transducer output will generate an interrupt. The interrupt routine counts transducer pulses, and when it gets to the predetermined N, it reads and clears the timer. For example

```
    DJNZ    PULSES,OUT
    MOV     PULSES,#PERIODS
    (Read and clear timer.)
OUT: RETI
```

If other interrupts are also to be enabled, the one connected to the transducer should be set to Priority 1, and the others to Priority 0. This is to control the interrupt response time. The response time will not affect the measurement if it is the same for every measurement. Variations in the response time will, however, affect the measurement. Setting the pulse-counter interrupt to Priority 1 and all others to Priority 0 will minimize variations in the response time. The response time will then be limited to range from 3 to 8 machine cycles.

VII. Pulsewidth Measurements

The 8051 timers have an operating mode which is particularly suited to pulsewidth measurements, and may be useful here if the transducer has a fixed duty cycle, or if the transducer output is pulsewidth modulated instead of frequency modulated by the measurand.

In this mode the timer is turned on by the on-chip circuitry in response to an input high at the external interrupt pin, and off by an input low. The external interrupt itself is enabled, so the same 1-to-0 transition from the transducer that turns off the timer also generates an interrupt. The interrupt routine would then read and reset the timer.

The advantage of this method is that the transducer signal has direct access to the timer gate, with the result that variations in the interrupt response time cease to be a factor. The timer can be read and cleared any time before the next high in the transducer output.

VIII. Deriving Frequency From a Period Measurement

We now consider the problem of measuring the transducer frequency to n-bit resolution by deriving it from a direct measurement of the period. The advantage of this technique is speed. It is always faster to measure period than frequency. But it is important to end up with a frequency value that has the same resolution and accuracy as a directly measured frequency. Two questions need to be addressed.

1) To achieve n-bit resolution in the calculated frequency, how much resolution is required in the period?
2) Having measured the period to the required resolution, what is the most efficient way to calculate the frequency?

These questions will be addressed one at a time.

IX. Resolution Requirements

In general, n-bit resolution in the frequency derivation requires somewhat more than n-bit resolution in the period measurement. How much more? It will be demonstrated presently that if the transducer frequency varies over a 2-to-1 range, the frequency can be calculated with n-bit resolution from period measurements that have $(n + 1)$-bit resolution.

The more practical form of the question is over how many periods (N) must the transducer signal be sampled to obtain the required resolution in F? And so, we commence a calculation of N.

The basic calculation of frequency from $N \times T$ (which we shall call NT) is straightforward:

$$F = N/(NT).$$

The relationship between an increment dF in the calculated frequency due to an increment $d(NT)$ in the measured period is, therefore,

$$dF = -\frac{N}{(NT)^2}\, d(NT)$$

$$= -\frac{F^2}{N}\, d(NT).$$

This equation says the value of an LSB in the calculated frequency is $(F^2)/N \times$ the value of an LSB in NT. Then the maximum value that an LSB in the calculated frequency can have is $(F\text{max})^2/N \times$ the value of an LSB in NT. For the calculated frequency to have n-bit resolution over the entire range of frequencies, the value of its LSB must never exceed $(F\text{max} - F\text{min})/2^n$. Therefore, the measurement requires

$$\frac{(F\text{max})^2}{N} \times (1 \text{ LSB in } NT) \leq \frac{F\text{max} - F\text{min}}{2^n}.$$

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The required resolution in NT is, therefore,

$$1 \text{ LSB in } NT \le \frac{N \times (F\max - F\min)}{2^n \times (F\max)^2}.$$

Now, to say that NT is measured with m-bit resolution means

$$1 \text{ LSB in } NT = \frac{N \times (1/F\min - 1/F\max)}{2^m}.$$

Substituting this value for 1 LSB into the required resolution and solving for 2^m yields

$$2^m \ge \frac{F\max}{F\min} \times 2^n.$$

Then the requirement on m is

$$m \ge n + \frac{\ln (F\max/F\min)}{\ln (2)}.$$

It can be stated with some certainty, then, that if the transducer frequency varies over a range of 2-to-1, the frequency can be calculated with 8-bit resolution from a period measurement that has 9-bit resolution. If the frequency variation is less than 2-to-1, another full bit of resolution in the period measurement is not needed.

To obtain m-bit resolution in NT, N must satisfy

$$N \ge \frac{2^m}{T\max - T\min}.$$

Substituting for 2^m, and using $T\max = 1/F\min$ and $T\min = 1/F\max$, gives the result that

$$N \ge \frac{(F\max)^2}{F\max - F\min} \times 2^n.$$

It should be noted that the units of frequency here are periods/machine cycle, since the 8051 measures time by counting machine cycles. The conversion factor between Hz and periods/machine cycle is 12/(clock frequency). So the requirement on N can also be written

$$N \ge \frac{F\max}{F\max - F\min} \times \frac{F\max}{F\text{xtal}} \times 12 \times 2^n$$

where Fxtal is the 8051 clock frequency in the same units as Fmax and Fmin. This is the number of transducer pulses over which the transducer signal must be sampled to achieve the required solution in F.

For example, suppose that 8-bit resolution is required in F, where Fmax = 10 kHz and Fmin = 5 kHz, and that Fxtal = 12 MHz. Then the above calculation shows that N = 6 periods gives sufficient resolution in the period measurement to satisfy the resolution requirement in F. Six periods will take 0.6–1.2 ms of sampling time, on that frequency range. Recall that the sample time for a direct frequency measurement of the same signal and to the same resolution was earlier calculated to be 51.2 ms.

X. Computing the Frequency from the Period

The period measurement leaves one with a 16-bit integer, which is $N \times T$ (or NT) in machine cycles. The conversion to frequency is straightforward:

$$F = N/(NT) \text{ periods/machine cycle.}$$

The quantity of interest is probably not F, but a normalized measure of the amount by which F exceeds its minimum acceptable value. This quantity represents, through the transducer's transfer function, the "reported value" of the measurand, and this quantity is an n-bit integer whose value ranges from 0 (all bits = 0) to full scale (all bits = 1). This normalized frequency is

$$f = \frac{F - F\min}{F\max - F\min}$$

$$= \frac{F\min}{F\max - F\min} \times (F/F\min - 1)$$

Using $F = N/(NT)$ and F min $= N/(NT$ max) allows the normalized frequency to be written

$$f = \frac{F\min}{F\max - F\min} \times \frac{NT\max - NT}{NT}.$$

To get a handle on what kinds of numbers are involved here, consider the situation where 8-bit resolution is required in f, and in which Fxtal = 12 MHz, Fmax = 10 kHz, and Fmin = 5 kHz. We have previously determined that for this set of conditions, N = 6 periods gives sufficient resolution in the period measurement to satisfy the resolution requirement in F (and in f). With a 12 MHz clock frequency, Tmax in machine cycles is (12 000 kHz)/(12 × 5 kHz) = 200 machine cycles, so NTmax is 6 × 200 = 1200 machine cycles. The calculation for f then becomes

$$f = \frac{1200 - NT}{NT}.$$

The minimum acceptable value that NT can have is ($N \times T$min + 1), where Tmin = (12 000 kHz)/(12 × 10 kHz) = 100 machine cycles. Then $N \times T$min = 6 × 100 = 600 machine cycles. The allowable values for NT are then 601–1200 machine cycles, a total of 599 different values.

The fastest way to "calculate" f would be with a 599-byte look-up table. This method has the added advantage that nonlinearities in the transfer function between frequency and measurand can be built into the table. Look-up tables are facilitated in the 8051 by the MOVC A,@A + PC, and MOVC A,@A + DPTR instructions. DPTR is a 16-bit "data pointer" register in the 8051. Its two bytes can be individually addressed as DPL (low byte) and DPH (high byte).

In the example under discussion, it will be necessary to load DPTR with the address of the first byte of the look-up table, less 601, plus the 2-byte value of NT. The software that accesses the table might then take the following form:

```
TABLE EQU (address of first table entry)
```

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```
                        DIVIDE ROUTINE

This divide routine calculates

                        numerator
        quotient =  -----------
                       denominator

in which numerator and denominator are integers and
numerator . denominator  Quotient is of the form

        quotient - 0 q1 q2 q3     qN

where qn is the coefficient of 2**(-n)  The procedure is

   numerator  = 2 x numerator
   n  = 1
   while n . N+1 do
        if numerator   denominator then qn  = 0 else qn  = 1
        if qn = 0 then numerator  = 2 x numerator
                  else numerator  = 2 x numerator - denominator
        increment n
   end_while
```

Fig. 1. A divide algorithm.

```
MOV     A,#LOW(TABLE-601)
ADD     A,NT_LO
MOV     DPL,A
MOV     A,#HIGH(TABLE-601)
ADDC    A,NT_HI
MOV     DPH,A
CLR     A
MOVC    A,@A+DPTR.
```

At this point the accumulator contains the 8-bit value of f.

It is perfectly reasonable to decide that a 599-byte look-up table is unwieldy. Its advantages are speed and built-in error correction. But a reasonably fast divide algorithm can be written to this specific purpose, making use of *a priori* knowledge about the sizes of the numbers that are involved in the computation. It helps to know that in this example the numerator is never going to be larger than 599 and the denominator is always greater than the numerator.

A complete discussion of divide routines is beyond the scope of this paper, but a suitable divide algorithm for this specific application is shown in Fig. 1. Reference [1] calls this the Restoring division algorithm. It is particularly well suited to the 8051, because "<" comparisons are greatly facilitated by the 8051's CJNE (compare and jump if not equal) instruction. CJNE A,B,rel, executes a relative jump if A does not equal B. More importantly to this application, the instruction sets the carry flag if $A < B$.

XI. Accuracy and Resolution

The accuracy with which the 8051 will measure the frequency or period of the transducer signal depends on two things: the accuracy of the clock oscillator and variations in the interrupt response time.

Since the clock signal is normally generated by a crystal oscillator, the oscillator accuracy normally far exceeds the quantizing error inherent in the finite (n-bit) resolution.

As was previously mentioned, interrupt response time does not introduce an error into the measurement itself, but variations in the interrupt response time can. Interrupt response time in the 8051 can vary from 3 to 8 machine cycles, depending on what instruction is in progress at the time the interrupt is generated. This would represent an error of ± 5 counts in the measured value of NT during a period measurement. An error of ± 5 counts in NT does not necessarily translate to ± 5 LSB's in the final result, but it might still represent an error that exceeds the resolution.

In a direct frequency measurement variations in the interrupt response time would represent an error of ± 5 μs in the sample time.

If these kinds of errors are unacceptable there are ways to deal with them. In period measurements, if the duty cycle of the transducer is constant, the pulsewidth measurement technique, previously described, can be used. Its advantage is that it gates the timer off when the interrupt is generated, rather than when the interrupt is responded to.

In other cases one can simply increase the sample time above the minimum required to obtain the desired resolution. For example, if the measurement requires 8-bit resolution, one can design the software for an 11-bit resolution and truncate the result to 8 bits.

References

[1] Davio *et al.*, *Digital Systems with Algorithm Implementation.* New York: Wiley, 1983.

270434–5

ANALOG/DIGITAL PROCESSING WITH MICROCONTROLLERS

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Microcontrollers are rapidly becoming the backbone of silicon computing systems. From a technical standpoint, the most significant attribute, aside from the inclusion of RAM and ROM, that segregates a microcontroller from a microprocessor is I/O manipulation. In general, I/O manipulation is an intimate part of a microcontroller's architecture. The instruction set and architecture of a microcontroller allows the CPU to directly control the I/O facilities on the device. This is in direct contrast to a microprocessor where the I/O is essentially a "sea" of addresses and it is up to the hardware designer to place some type of I/O hardware in this I/O "sea". It should be obvious that simply adding ROM and RAM to a microprocessor WILL NOT create a microcontroller.

This intimate contact with I/O gives the microcontroller a distinct advantage over the microprocessor in applications that are I/O intensive. Microcontrollers can test, set, complement, or clear I/O port pins much faster than a microprocessor and they can also make decisions, based on the state of other hardware features, such as timer/counters with equal speed. This integration of I/O, in both hardware and software makes the microcontroller "ideal" for many types of intelligent instrumentation.

4K ROM/EPROM - 8K ROM ON 8052
128 BYTES OF RAM - 256 ON THE 8052
2-16 BIT TIMER/COUNTERS - 3 ON THE 8052
FULL DUPLEX UART
5 VECTORED INTERRUPTS - 6 ON THE 8052
4 REGISTER BANKS
BIT MANIPULATION (BOOLEAN PROCESSOR)
32 DIRECTLY ADDRESSABLE I/O PINS
MULTIPLY AND DIVIDE INSTRUCTIONS
SUPPORTS 64K OR RAM AND ROM-128K TOTAL

TABLE 1. A BREIF LISTING OF THE MCS-51'S FEATURE SET.

Intel's MCS-51 series of microcontrollers contain many features that can be integrated directly into many types of instruments. TABLE 1 is a brief listing of these features. To illustrate the power of the 8051 this paper will elaborate on two techniques for performing analog to digital (A to D) conversion. Both of these examples assume that some additional hardware is attached to the I/O pins of the 8051.

S/A CONVERSION TECHNIQUES

Successive approximation analog to digital conversion involves a "binary search" of an unknown voltage relative to a "fixed" known reference. The reference is selectively divided by multiples of two until the desired accuracy is reached. Figure 1 is a flowchart of a successive approximation converter. This technique usually requires a digital to analog converter to divide the reference voltage and a voltage comparator to compare the unknown voltage to the "divided" reference. Digital to analog converters and voltage comparators are readily available and relatively inexpensive. A block diagram of an 8051 based A to D converter is shown in Figure 2.

Many industrial A to D converters require 12 bits of accuracy. A 12 bit converter provides good "dynamic range" and is capable of resolving 1 part in 4096. If the applied input voltage ranges from 0 to 10 Volts, a 12 bit converter can resolve 2.4 millivolts within this range. The theoretical accuracy of a 12 bit converter is .024% +/- 1/2 least significant bit.

The power of the 8051 in this type of application is best revealed by examining the software required to implement the successive approximation algorithm. The routine for the 8051 is shown in Table 2.

The execution times given assume a 12 Mhz crystal. Compare this to the following routine which is a 4 Mhz Z-80

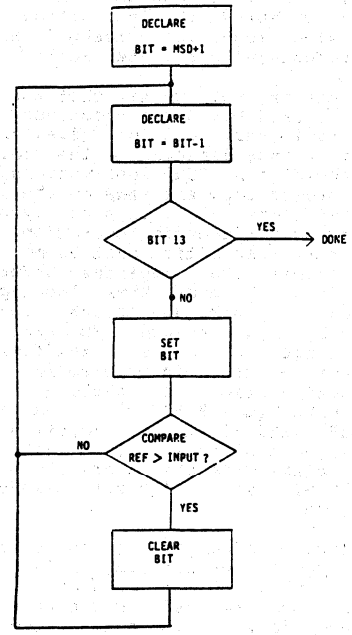

FIGURE 1. SUCCESSIVE APPROXIMATION CONVERSION ALGORITHM

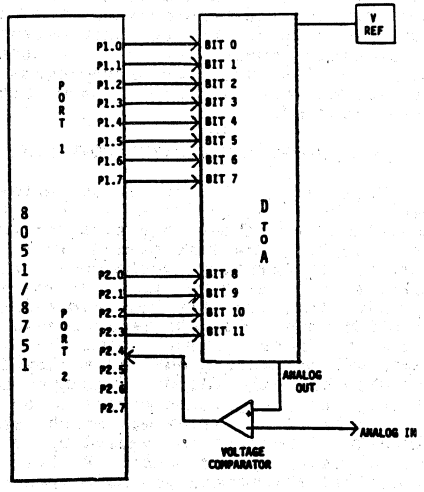

FIGURE 2. BLOCK DIAGRAM OR SUCCESSIVE APPROXIMATION A TO D CONVERTER

TABLE 2. SUCCESSIVE APPROXIMATION ROUTINE FOR THE 8051.

	INSTRUCTION		BYTES	TIME
	;			
	;CLEAR PORT PINS			
	;			
	MOV	P1,#0	3	2
	ANL	P2,#0F0H	3	2
	;			
	;START CONVERSION			
	;			
	SETB	P2.3	2	1
	JNB	P2.4,L1	3	2
	CLR	P2.3	2	1
L1:	SETB	P2.2	2	1
	JNB	P2.4,L2	3	2
	CLR	P2.2	2	1
L2:	SETB	P2.1	2	1
	JNB	P2.4,L3	3	2
	CLR	P2.1	2	1
L3:	SETB	P2.0	2	1
	JNB	P2.4,L4	3	2
	CLR	P2.0	2	1
L4:	SETB	P1.7	2	1
	JNB	P2.4,L5	3	2
	CLR	P1.7	2	1
L5:	SETB	P1.6	2	1
	JNB	P2.4,L6	3	2
	CLR	P1.6	2	1
L6:	SETB	P1.5	2	1
	JNB	P2.4,L7	3	2
	CLR	P1.5	2	1
L7:	SETB	P1.4	2	1
	JNB	P2.4,L8	3	2
	CLR	P1.4	2	1
L8:	SETB	P1.3	2	1
	JNB	P2.4,L9	3	2
	CLR	P1.3	2	1
L9:	SETB	P1.2	2	1
	JNB	P2.4,L10	3	2
	CLR	P1.2	2	1
L10:	SETB	P1.1	2	1
	JNB	P2.4,L11	3	2
	CLR	P1.1	2	1
L11:	SETB	P1.0	2	1
	JNB	P2.4,L12	3	2
	CLR	P1.0	2	1
	;			
L12:	CONVERSION COMPLETE			
	TOTAL		90	46 US

NOTE: TIMING IS TYPICAL
WORST CASE = 52 US
BEST CASE = 40 US

executing the same algorithm with the D to A hardware attached to an I/O port is shown in Table 3 (assume that all bits on PORT3 are grounded, except the comparator ihput).

TABLE 3. SUCCESSIVE APPROXIMATION ROUTINE FOR THE Z-80.

```
     INSTRUCTION          BYTES    TIME

     ;
     ;CLEAR PORT PINS
     ;
      LD      A,0           2       1.75
     OUT      (PORT1),A     2       2.75
     OUT      (PORT2),A     2       2.75
     ;
     ;START CONVERSION
     ;
      LD      A,08H         2       1.75
     OUT      (PORT2),A     2       2.75
      IN      A,(PORT3)     2       2.75
      OR      A             1       1.00
      IN      A,(PORT2)     2       2.75
      JP      Z,L1          3       2.50
     AND      0F7H          2       1.75
L1:   OR      04H           2       1.75
     OUT      (PORT2),A     2       2.75
      IN      A,(PORT3)     2       2.75
      OR      A             1       1.00
      IN      A,(PORT2)     2       2.75
      JP      Z,L2          3       2.50
     AND      0FBH          2       1.75
L2:   OR      02H           2       1.75

     REPEAT BETWEEN L1 AND L2 10
     MORE TIMES AND SET/RESET THE
     APPROPRIATE I/O BITS

-------------------------------------------

TOTAL                      179      180 US

AGAIN TIMING IS TYPICAL
      WORST CAST = 190.25 US
       BEST CASE = 169.25 US
```

One may argue that by "memory mapping" the Z-80's I/O ports the execution time could be enhanced because the user could take advantage of the Z-80's SET and RESET memory BIT instructions. In reality, a few bytes of memory are saved, but very little time!. This is because the Z-80's memory oriented BIT instructions are VERY slow, requiring between 3 and 5 microseconds with a 4 Mhz clock!

This is not to say that the Z-80 isn't a credible 8-bit processor. The weakness is that decisions (i.e. JUMPS) cannot be made directly on the state of a given I/O pin. JUMP instructions, on most processors, are made on the state of the flags - after some type of logical or arithmetic operation! This means that information must be moved to an internal CPU register before a decision can be made. This "moving" of information back and forth between internal registers and I/O makes the microprocessor quite inefficient, relative to the microcontroller when I/O manipulation is involved. Note that with the 8051 algorithm never "moves" data from one location to another - it directly sets, tests, and clears bits. This characteristic gives the 8051 its distinct execution advantage.

Another strength of the 8051 in this type of application, relates to the fact that I/O port pins can be set, cleared, complemented, and tested with the same speed that a microprocessor can act on it's internal registers. Note that the 8051 takes only 1 microsecond to fetch an opcode and set or clear a port pin. A microprocessor must first fetch and decode the opcode, then place the appropriate I/O or memory address on the bus, then perform the necessary operation. All of this "communication" over the microprocessor bus significantly slows down the microprocessor.

DUAL SLOPE INTEGRATING CONVERTER

Integrating A to D converters operate by an indirect method of converting a voltage to a time period, then measuring the time period with a counter. Integrating techniques are quite slow, relative to successive approximation, but they are capable of providing very accurate measurements - 5 1/2 or more decimal digits - if proper analog techniques are employed. They also have the added advantage of allowing the integration period to be a multiple of 60 Hz (16.67 ms) which can eliminate inaccuracies caused by the ever present "power line". Virtually all digital voltmeters use some type of integrating technique. Figure 3 is a block diagram of a typical integrating

A to D converter.

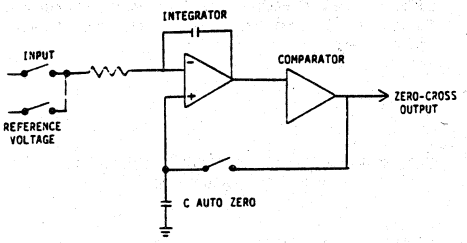

FIGURE 3. INTEGRATING A TO D CONVERTER

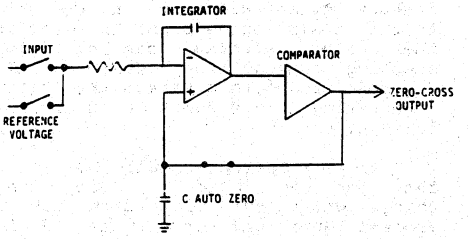

FIGURE 4A. AUTO ZERO PHASE

Figures 4A, 4B, and 4C show the three typical phases involved in the dual slope technique. Figure 4A illustrates the auto-zero phase. In this phase the integrating "loop" is closed and the offset of the analog integrator is accumlated in C auto zero. In Figure 4B, the input switch is closed and the integrator integrates the input voltage for a fixed time period T1. In figure 4C, the reference switch is closed and the integrator integrates the reference voltage until the comparator senses a zero crossing condition. The time it takes for this phase to occur is directly proportional to the amplitute of the input voltage. Additional circuitry can be added to determine the polarity of the input voltage, then switch in a reference of oppsite polarity, but the basic technique remains the same.

The 8051 is an ideal controller for an intelligent integrating A to D system. The 16 bit timer/counters can provide better than 4 1/2 decimal digits of accuracy, the serial port can be used to transmit the analog reading to a printer or another processor, the CPU can be interrupted by the 60 Hz line so conversions can start at percise intervals, and software can be used to calculate and save average, peak, or RMS readings.

Another "nice" benefit of this type of converter is that very few I/O port pins are required to control the A to D hardware, so opto-isolators can be used to completely isolate the 8051

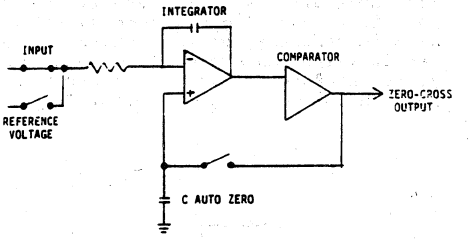

FIGURE 4B. INPUT INTEGRATION PHASE

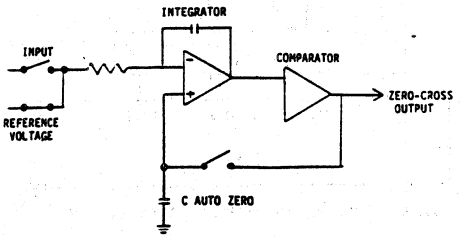

FIGURE 4C. REFERENCE INTEGRATION PHASE

"digital system" from the analog hardware. Opto-isolators provide an additional "bonus" in that they may provide logical level shifting if needed by the analog circuitry. Figure 5 shows how an 8051 might be connected to the analog sub-system. In practice, the analog switches can be almost anything ranging from CMOS to VFETs. The code needed to generate the "basic" integrating A to D function is shown in Table 4.

Timer interrupts could be used so that the CPU could be doing other things while the conversion was in process. Note that very little CPU time is needed to perform the actual A to D function.

CONCLUSION

This paper illustrated possible methods of using the 8051 in A to D "instrumentation" types of applications. The power of the 8051's microcontroller architecture relates to the fact that logical "decisions" can be made directly on the state of the resident I/O hardware. This fact alone gives the 8051 a distinct advantage in "bit intensive" applications. Software and hardware support tools include in-circuit emulators, an assembler, and a high level language, PLM-51. Presently, the 8051 is available in 3 technology "flavors"- HMOS II, HMOS-EPROM, and CHMOS, so depending on your individual application, you can have it your way.

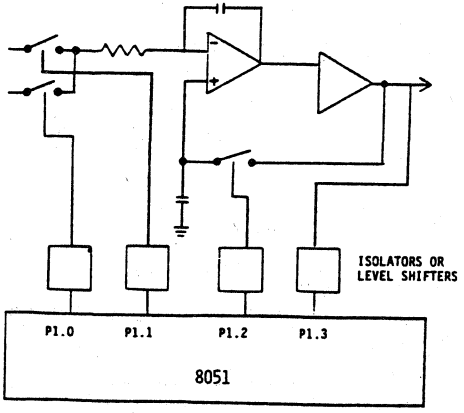

FIGURE 5. TYPICAL 8051 CONTROLLED ANALOG SUB-SYSTEM

TABLE 4. SOFTWARE FOR INTEGRATING A TO D CONVERTER

```
;
;START PROGRAM
;
CLR   TR0              ;TURN TIMER OFF
;
MOV   TH0,#HIGH TAZ    ;LOAD AUTO ZERO
MOV   TL0,#LOW TAZ     ;TIME
;
ANL   P1,#0F0H         ;MAKE A/D INACTIVE
SETB  P1.2             ;AUTO ZERO PHASE
SETB  TR0              ;TURN TIMER ON
JNB   TF0,$            ;LOOP TIL OVERFLOW
;
CLR   TR0              ;TURN TIMER OFF
CLR   TF0              ;RESET TOV FLAG
;
MOV   TH0,#HIGH INTT   ;LOAD INTEGRATION
MOV   TL0,#LOW INTT    ;TIME
;
CLR   P1.2             ;END AUTO ZERO
SETB  P1.1             ;START INTEGRATION
SETB  TR0              ;START TIMER
JNB   TF0,$            ;WAIT FOR OVERFLOW
;
CLR   P1.1             ;END INTEGRATION
;
; NOW, INTEGRATE THE REFERENCE
;
SETB  P1.0
;
;AT THIS POINT TIMER 0 HAS A VALUE OF
;TWO, THE TIMER IS EQUAL TO ZERO, WHEN
;IT OVERFLOWS AND IT WAS INCREMENTED
;TWICE DURING THE LAST TWO INSTRUCTIONS
;
;NOW, WAIT FOR ZERO CROSS
;
JNB   P1.3,$
;
;TURN THE TIMER OFF
;
CLR   TR0
;
;NOW, TIMER 0 ~ Vin + 3 COUNTS
;
```

ASIC Family Application Note & Article Reprint

3

July 1988

Using Intel's ASIC Core Cell to Expand the Capabilities of an 80C51-Based System

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USING INTEL'S ASIC CORE CELL TO EXPAND THE CAPABILITIES OF AN 80C51-BASED SYSTEM

CONTENTS

INTRODUCTION

Intel's new ASIC family of microcontroller core cells extends the capability of the MCS®-51 product, and allows the ASIC designer more flexibility than the popular microcontroller product. This note will discuss many of the new design possibilities inherent to the 80C51 cell-based controller. This family of cells is available with a variety of RAM and ROM configurations.

Cell Name	ROM	RAM
UC5100	No ROM	128 Bytes RAM
UC5104	4K ROM	128 Bytes RAM
UC5108	8K ROM	128 Bytes RAM
UC5116	16K ROM	128 Bytes RAM
UC5200	No ROM	256 Bytes RAM
UC5204	4K ROM	256 Bytes RAM
UC5208	8K ROM	256 Bytes RAM
UC5216	16K ROM	256 Bytes RAM

Other documentation will address Intel's ASIC design environment (see reference section).

The 80C51-based ASIC cell is part of a family of cell-based functions based on popular Intel standard products. Members of the 82Cxx microprocessor support peripheral family (SP8254, SP8237, SP8259, SP8284, SP82284, SP8288 and SP82288) are also available as library elements. The standard product ASIC cores are supported by a library of over 150 logic cells, representing a broad range of SSI, MSI, and I/O functions. Another class of cell library elements is designated Special Functions. These cells are predefined complex functions such as RAM, Serial I/O, A/D Converter, and a Voltage Comparator. The Special Function and general logic element cells can also be used without a standard product core in the ASIC design. Any of the available 80C51-based cores can be integrated with logic complexities up to 5000 gates.

80C51-BASED ASIC CORE

Although the 80C51-based core is functionally identical to the standard 80C51BH microcontroller, its use as a cell in the ASIC library allows more flexibility in system design and partitioning.

Figure 1 depicts the difference between the standard pinout of the MCS-51 family and the ASIC core. In order to understand the enhancements (in an applications sense) made to the core it is useful to compare its connections to the pinout of the standard product.

The MCS-51 family embodies a very powerful architecture. While it was intended as a "single chip solution" its addressing modes, clean bus interface, on-chip peripherals, and code efficient instruction set operations make it well suited to processor-like applications as well. For processor applications, a designer forgoes many of the "single chip" features in favor of the high performance CPU functions of this architecture.

In order to fit the MCS-51 family microcontrollers into an economical forty lead DIP or forty-four lead PLCC package, Intel designed the standard product with many of the device's functions sharing pins. The microcontroller designer must compare necessary functions against the economics and performance required for a given design. If external memory or memory mapped I/O is required, then the use of the port 0 function is not available. If the memory address is beyond the 256 byte boundary defined by the AD0–7 Bus then all or part of the port 2 function is not available. Likewise, using peripheral functions like the counter input pins, serial I/O, and interrupts eliminates port 3 functions. While the MCS-51 family is one of the most popular microcontrollers ever introduced, this shared functionality hinders its use in many applications. For example, a "fully loaded" MCS-51-based design would generally leave only one 8-bit port (Port 1) for the application's I/O requirements.

The standard cell version of the 80C51 provides the designer with 116 signals for connection to application specific logic. These signals represent the full function set of the MCS-51 architecture and virtually eliminate any design trade-offs required to implement an application. Notice from Figure 1 that all of the I/O ports are separated from the other functions. In the design example, the I/O are separated into their respective inputs and outputs, leaving 32 inputs and 32 outputs for port connections into the application's logic. The most immediate impact of demultiplexing the I/O of the device is that much of the logic required to complete an application is eliminated. For example, when separating the address from the data on the AD-bus, an octal latch is required. For an 80C51-based core application, the designer uses the A0–7 bus directly, thus saving approximately 100 gates. The fact that the 80C51-based core has so many connections available does not mean an application will be forced into higher pin count packages. A 80C51-based ASIC can implement many system functions more economically than a discrete implementation. The design example illustrates a system with over 280 interconnects that can be integrated into one ASIC device. This application note will illustrate the less obvious ways in which the core can be used.

The illustrations shown in this note are independent of the workstation platform used to implement the design.

Intel provides the complete test vectors necessary to test the 80C51-based ASIC core, which have been derived from the standard product 80C51 test vector set.

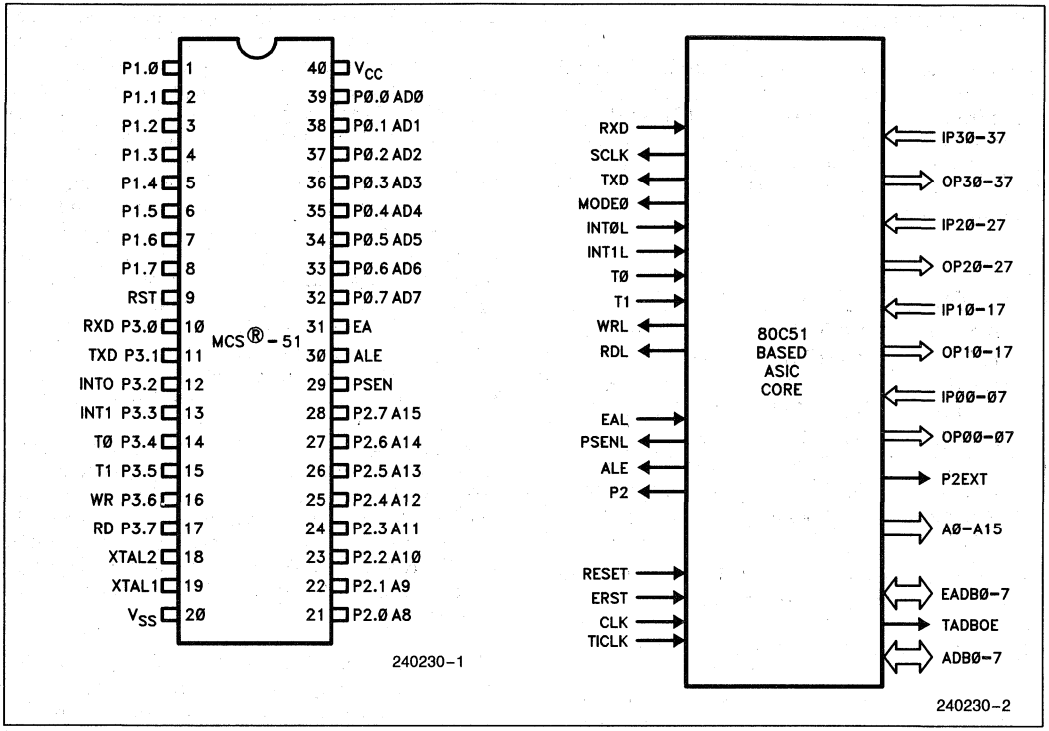

Figure 1. Comparing 80C51 Pin Assignments to Core Connections

RECONSTRUCTION OF STANDARD PRODUCT I/O

When designing the 80C51-based ASIC core, Intel removed the pin multiplexers and I/O functions of the 80C51, and restructured them as companion cells. Companion cells allow the ASIC designer to reconfigure the ASIC cell to function exactly like the standard product. Alternatively, the designer can choose to reconstruct a subset of the standard product I/O or select no reconstruction at all. Consult the references for more information about the use and function of Intel's companion cells.

MULTIPLE SOURCES OF RESET

Key to the 80C51's core-isolation test method is the ability to put the core into a condition that can verify the processor without the user's logic affecting the test. ERST is vital to controlling the ability to put the core based ASIC into test mode. It must be brought directly from the core to a package pin. Interface is via the PRESET companion cell. Because a dedicated reset pin may be restrictive in many applications, a second reset connection, RESET, has been included.

Including this second reset connection allows the designer to simplify the overall ASIC design. Many applications require two sources of reset, usually a power-on-clear with a watchdog timer. Previously, the designer was faced with "ORing" an RC time constant circuit with the timer logic, resulting in an implementation which was not straightforward or cost effective. Figure 2 shows an 80C51-based ASIC implementation.

A system reset, in many designs, employs an active low logic level. Since the 80C51's reset requires an active high level, there is usually an inverter in the path to the microcontroller. It was mentioned earlier in this section that ERST must be brought directly from the core to a package pin. This is not entirely true; the inclusion of the inverter is allowed.

I/O EXPANSION WITH THE 80C51-BASED CORE

For the standard MCS-51 product, the need for I/O expansion is often due to the need for external memory and/or port expansion. The designer's use of the on-chip peripherals (eg. Serial I/O or Interrupts) often leaves only Port 1 intact.

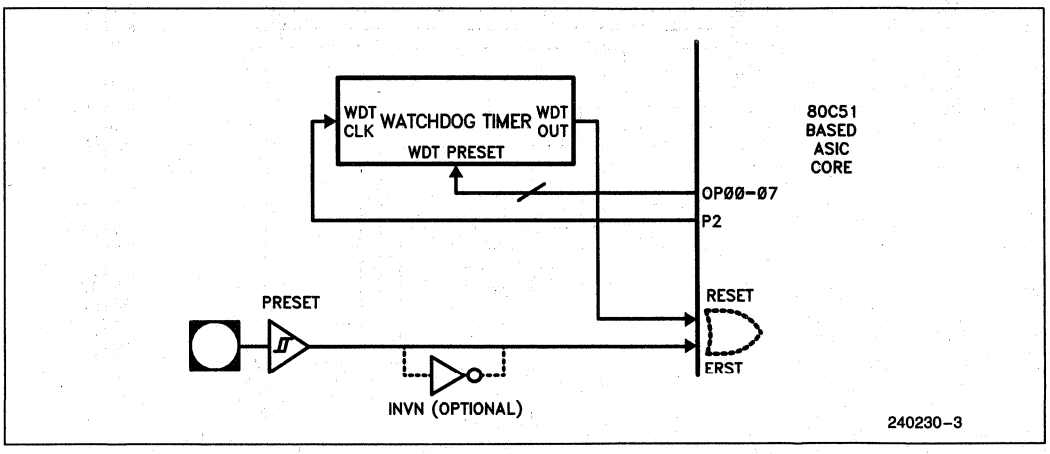

Figure 2. Multiple Sources of Reset for 80C51-Based ASIC Core

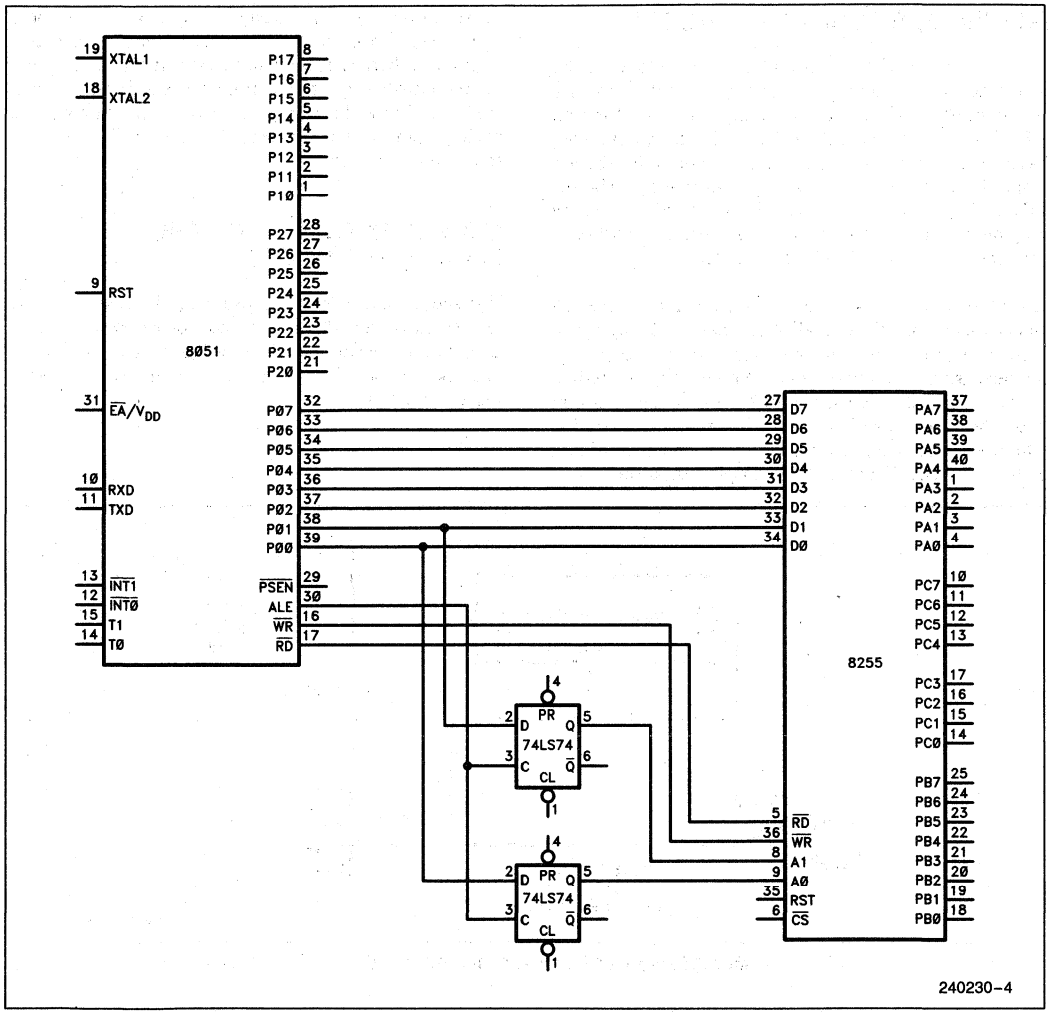

Figure 3. Simple MCS®-51 I/O Expansion with 8255

Figure 3 depicts one case where the 80C51 can gain an expanded set of I/O ports. In addition to requiring additional package pins, this implementation would require more power supply capacity and passive components (bypass capacitors) than would be necessary if the I/O expansion were to be included on-chip with the microcontroller. Not only is PC board size decreased, but the overall system reliability increases with the ASIC solution. In addition, the 8255 port expander, being a highly flexible device, requires software to configure the device to the application.

The simplest way to add I/O ports with the core is by way of a direct connection from the core's IP or OP signals through I/O functions selected from the cell library and connected to package pins. See Figure 4. In this example, decoding is very simple and the component count is minimal.

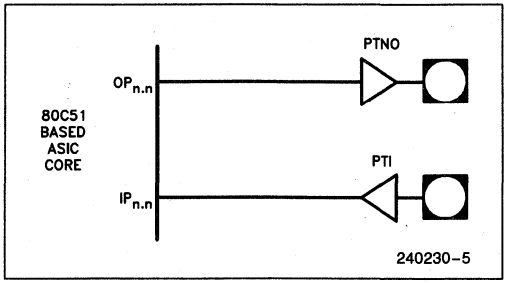

Figure 4. Direct Port Connections to ASIC Package Pins

This technique represents the most silicon and program code efficient way to implement I/O with the core. Program code is composed of MOV operations rather than the MOVX needed for any Memory mapped I/O implementations. Logical operations to the port (ANL, ORL, XRL) can still be used. It is not necessary to update or maintain indirect pointers. Since quasi-bidirectional cells are not used, it is not necessary to set a "1" to the port in order to set these cells. Eliminating MOVX and port setup operations could result in significant codespace savings.

The drawback to the direct approach is that program code written for the 80C51 using memory mapped I/O is not directly transportable to the core design. In most cases, however, implementing I/O expansion that allows code transportability is a simple task with a 80C51-based ASIC.

Most support peripherals are designed to be configurable for many different operating conditions. This is certainly true for a device like the 8255 as well; the port signals can be programmed as inputs, outputs, or bidirectional. In most applications the peripheral's setup is never changed after initialization. Port pins are set to either input, output or I/O. The peripheral's configuration is most often "set up" with data fields sent to a configuration or command register. This register is located at one of the peripheral's selectable addresses. For a cell-based implementation where code transportability is required, recreating an 8255-like function is straightforward. Since all setup information is written to one register and setup is not required because the port signal directions are fixed, that one register can become a "bit bucket". Figure 5 shows an example with one 8-bit input port, and one 8-bit output port, both memory-mapped. Note that while the 8255 contains three 8-bit ports, an ASIC can be implemented with the exact amount of functionality desired.

Implementing the full function set of the 8255 would result in an increased gate count (550 gates) included on the 80C51-based ASIC. While 550 gates can easily be included on the same silicon chip, implementing the "exact functionality" version using elements from the cell library would consume only 100 gates.

ON-CHIP CLOCK GENERATION

In many designs, the built-in crystal oscillator of the 80C51 is not utilized because the clock signal must be used for other system functions. However, the clock to the 80C51 still must be generated and driven into the X1/X2 pins. A clock generator is required somewhere in the system and is also used to clock many of the system functions surrounding the microcontroller.

For 80C51-based ASIC designs, all clocking functions, including the clock generator, can be brought on-chip. The advantages to doing so include enhanced reliability and a less costly, more noise free design. Clock generation is accomplished by the companion cell POSC (or POSC2 for frequencies between 16 MHz and 38 MHz) which can be used to drive the TICLK input connection to the core. The POSC output can be sent to user defined logic configured to generate other necessary

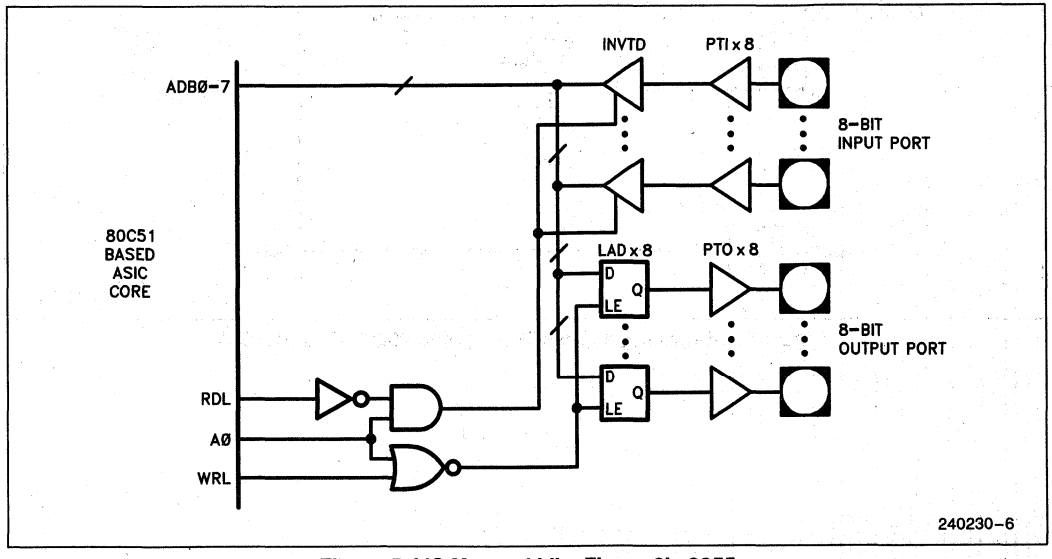

Figure 5. I/O Mapped Like Figure 3's 8255

clocks in a system. Where the POSC cell fan out is high and might cause concerns about clock edge skew, a cell like BUF2 can be used. For systems where it is required that the signal be brought off-chip (formerly off-board), the on-chip generated clocks can be sent to output cells and on to package pins. Figure 6 depicts generation flexibility and clock source for a 80C51-based ASIC design.

Figure 6 illustrates a design which requires a high frequency clock to operate on a section of user-defined logic. For this, cell POSC2 is selected for the ASIC design and is set to 24 MHz. In order to meet clock specifications for the core, this 24 MHz master clock is divided down in order to provide the required 12 MHz. As discussed in the 80C51-based ASIC data sheet, the ATE must be able to drive the core's clock directly. For test modes, the ATE-generated clock is driven to the core's TICLK connection.

Note that signal P2 is shown being used for the application's clocks. It is sent to other logic in the ASIC and to a package pin as well.

SHARING THE TEST BUS

In order for Automatic Test Equipment (ATE) to exercise the 80C51-based ASIC, the bus EADB must be brought directly to package pins. A specially designed I/O cell, PADB, must be directly connected to the EADB bus to ensure testability of the core as well as the user's logic.

Requiring the EADB bus to appear as package pins does not impose any design restrictions on 80C51-based ASICs designed to access external memory or peripherals. If your design does not call for the EADB to access external memory peripherals, the EADB may be multiplexed with user I/O. Contact your Intel Technology Center for the best implementation for your application.

Intel supplies all test programs required to completely test the ASIC core cell. Designers are required to supply test vectors that exercise their unique logic only.

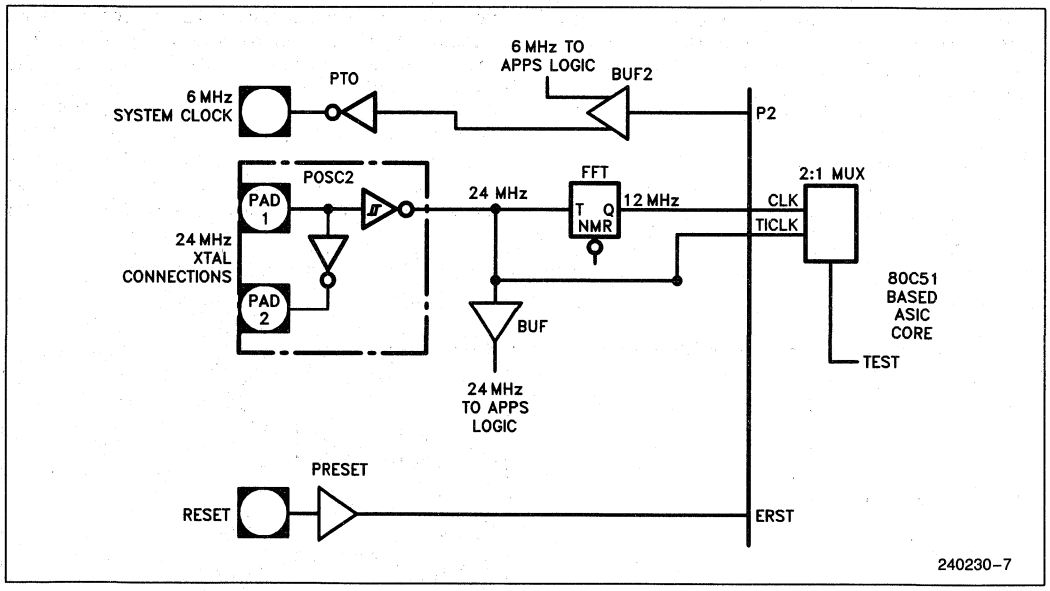

Figure 6. Integrating System Timing onto 80C51-Based ASIC

OBSERVING THE CONTENTS OF THE PROGRAM COUNTER

The 80C51-based ASIC core connections A0–A15 always display the contents of the program counter (except in the case of MOVX instructions.) This feature allows another level of real time control by monitoring instruction events within the core. By attaching comparator circuitry to the program counter contents, signals can be generated to depict events within the program. Figure 7 shows such a circuit.

The discussions in this note are not intended to be an exhaustive summary of the range of design possibilities available to the ASIC designer. Rather, it is hoped that it encourages the thought process toward even more innovative uses.

The following is an example of an actual system problem and how it was resolved using a 80C51-based ASIC. The example utilizes many of the techniques discussed above.

DESIGN EXAMPLE

Figure 8 shows a typical MCS-51-based design, which includes a port expander, timer/counter chip, a high speed event counter and a low-cost EPROM containing stable code. In this application, the 8031 controls a system based on numerous timed events. Many high speed clocks are involved, making for a potentially noisy environment, and a watchdog timer has been included to provide for soft recoveries if the microprocessor program flow is upset. The watchdog circuitry is shown as a high level block.

The design must take an accurate sample of events designated at the EVENT input. The 16-bit count is read and processed under a timed interrupt designated by and generated from one of the 8254 Timers. The counter chain must be clocked at 24 MHz in order for unique and accurate event samples to occur.

Another 8254 counter is programmed for single-shot mode to provide for a strobe window for some circuitry external to the PCB assembly. An 8-bit parallel data

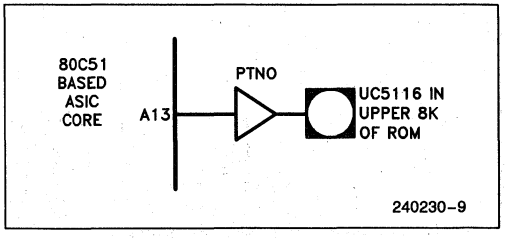

Figure 7. Signal which Designates when Program Execution is in Upper 8K ROM

input is required. The system must control peripherals external to this main assembly, resulting in a requirement for address decoder selection.

Note that adequate bypass capacitors are required due to the clock speeds and the high number of pin connections. (There are 272 pins, not including the WDT and Oscillator Blocks.) A multilayer PCB is also required to compensate for the amount of wires needed to connect all the components.

Figure 9 depicts the 80C51-based ASIC solution for the design in Figure 8. Note that all of the circuitry in Figure 8 is included on a single ASIC chip. Rather than use memory-mapped I/O, the design has been converted to use the core's direct ports. Note that the 8255 function has been removed and instead the UC5116 port connections are used. Some minor software changes are required, and signals required to access off-chip program memory have been provided. This figure does not show all test pin requirements; however, no additional package pins will be required. For this example, the designer could begin production runs with an EPROM. Once the application code stabilized, it could be developed and submitted to Intel for incorporation into the core. In this example, most of the high speed signals are contained within the ASIC, making the watchdog timer unnecessary. If needed, the overall cost of including it on the ASIC (=500 gates) makes the functions relatively inexpensive to keep.

Overall system pin requirements have decreased as well. This 80C51-based ASIC can be produced using a 68-pin PLCC which may reduce the bypass capacitor requirements as well as the need for a multilayer PCB.

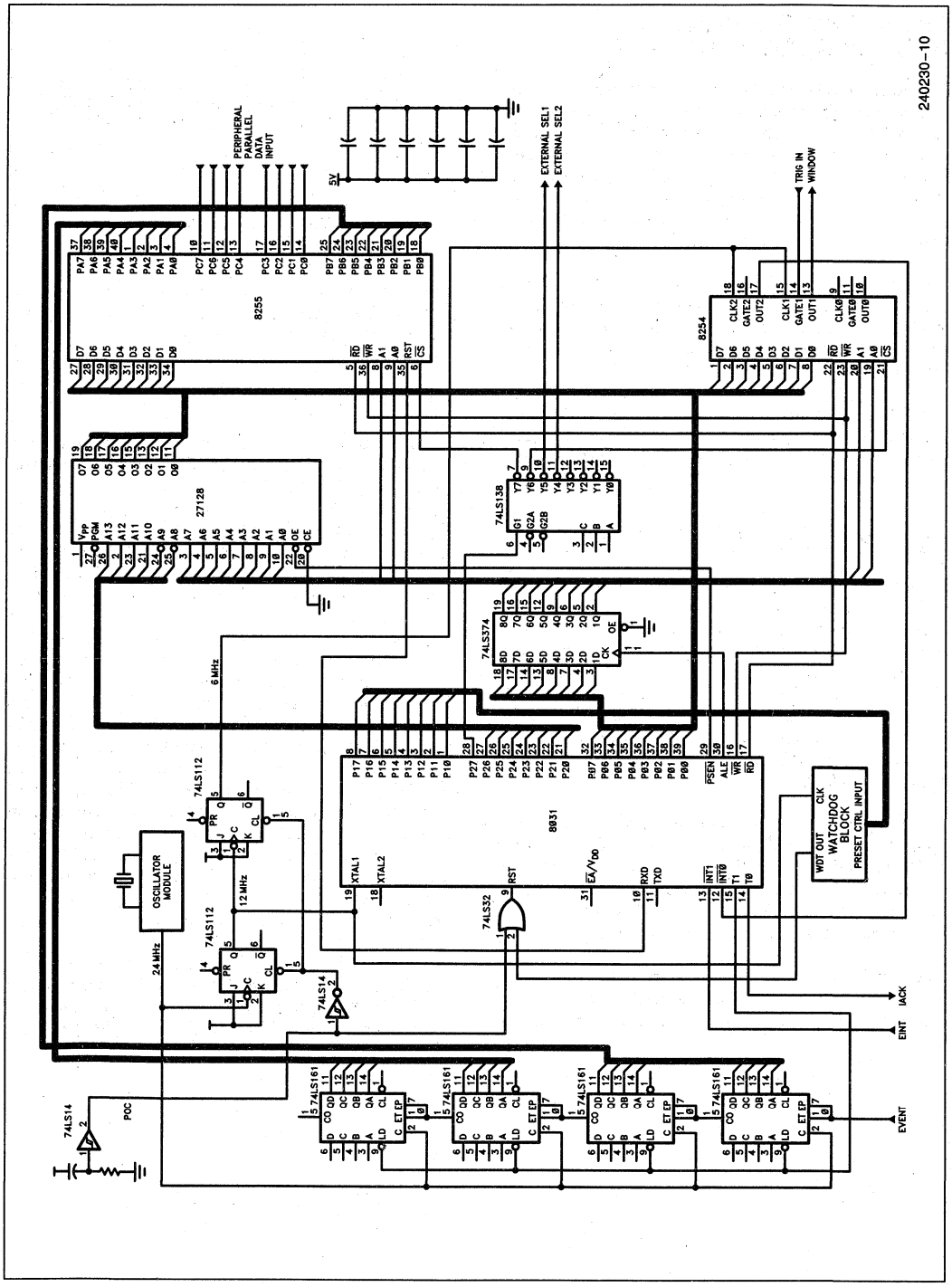

Figure 8. Typical MCS-51 Design, Which Includes a Port Expander, Timer/Counter Chip, a High-Speed Event Counter, and a Low-Cost EPROM

Comparing the two solutions:

	Discrete	80C51-ASIC
Component Count	~25	1
Minimum PCB Layers	3	1
System Reliability	Medium	High
Power Supply Current	~3A	~30 mA

REFERENCE DOCUMENTATION

Order Number	Description
231816	— Introduction to Cell-Based Design
83002	— Cell-Based Design—Daisy Environment
830000	— Cell-Based Design—Mentor Environment
210918	— Embedded Controller Handbook
270535	— Embedded Control Applications

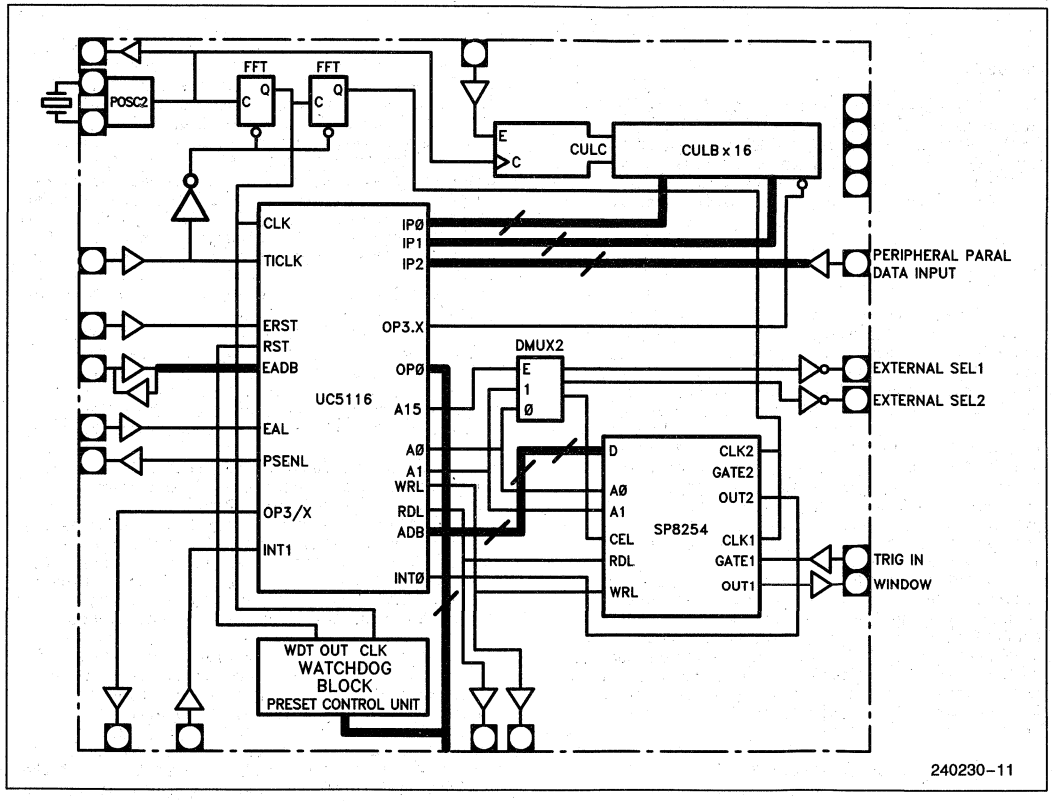

Figure 9. 80C51-Based ASIC Solutions

A Fast-Turnaround, Easily Testable ASIC Chip for Serial Bus Control

Don Ellis and Shailesh Trivedi

Intel Corp.

Chandler, AZ

ABSTRACT

This paper describes the standard cell ASIC design methodology for a serial bus controller chip. This is a prototype CMOS chip which was designed in 19 weeks for an automotive application. The chip includes testability circuits which help attain 98% fault coverage.

INTRODUCTION

Fast-turnaround chip design has become important in the application-specific integrated circuit (ASIC) marketplace, where low production volumes preclude long design cycles. To address this market, the ASIC design methodology relies upon automatic layout software to generate fast chip layouts, at the expense of larger die sizes and somewhat lower performance. Pre-designed standard circuit cells eliminate the need for extensive circuit simulation, further shortening the design cycle. These design techniques can produce fast prototype chips for system demonstration and debug, or production parts for low-volume applications.

Intel's Automotive Operation in Chandler, Arizona recently employed standard cell ASIC technology to produce a prototype serial bus controller chip for an automotive customer. In this paper we will describe the design methodology used to meet the 19-week design schedule for this chip, along with the testability strategy which was implemented in order to achieve a 98% fault grade.

CHIP OVERVIEW AND CONSTRUCTION

The serial bus controller is a standard cell CMOS chip that interfaces a microprocessor to a serial communication bus in an automobile. The chip performs both transmit and receive functions. The transmit function consists of a first-in, first-out (FIFO) data buffer feeding a parallel-in, serial-out (PISO) shift register, and the receive function consists of a serial-in, parallel-out (SIPO) shift register driving one port of a dual-port random access memory (DPRAM). The block diagram is shown in Figure 1.

The transmit function requires a decidedly non-standard 64 x 18 bit FIFO buffer. This is constructed with a 64 x 18 bit RAM and two address counters, as shown in Figure 2. The standard cell library did not contain a 64 x 18 bit RAM cell, so we had to construct it using an existing 64 x 8 RAM cell. We modified this cell, adding two more bits to create a 64 x 10 RAM cell, then connected it in parallel with the original 64 x 8 RAM, thus extending the word length to 18 bits. Before the 64 x 10 RAM cell could be added to the standard cell library, we had to fully characterize it using circuit simulation, like every other cell in the library. Two additional RC delay cells were also created to generate RAM read and write timings in the absence of microprocessor control signals.

The receive function requires a 1K x 8 bit dual-port RAM, but the standard cell library contained only single-port RAM cells. Fortunately, no cell modifications were necessary in this case. We used the existing 1K x 8 RAM cell, multiplexing its data and address buses to simulate dual-port operation, as shown in Figure 3. RAM read and write timings are once again generated using the RC delay cells mentioned above.

The final chip was manufactured in both single-layer metal (SLM) and double-layer metal (DLM) versions on a 1.5 micron CMOS process, resulting in a 355 x 294 mil chip with 68 I/O pins. It consists of 3 RAM arrays (9.3K bits total) and about 3,000 logic gates of control logic, for a total of 76,735 transistors. Of the 8,715 transistors contributed by the control logic, 11% belong to testability circuits which were added to increase the testability of the chip (i.e., shorten test program development time and tester run time). The testability strategy will be discussed later.

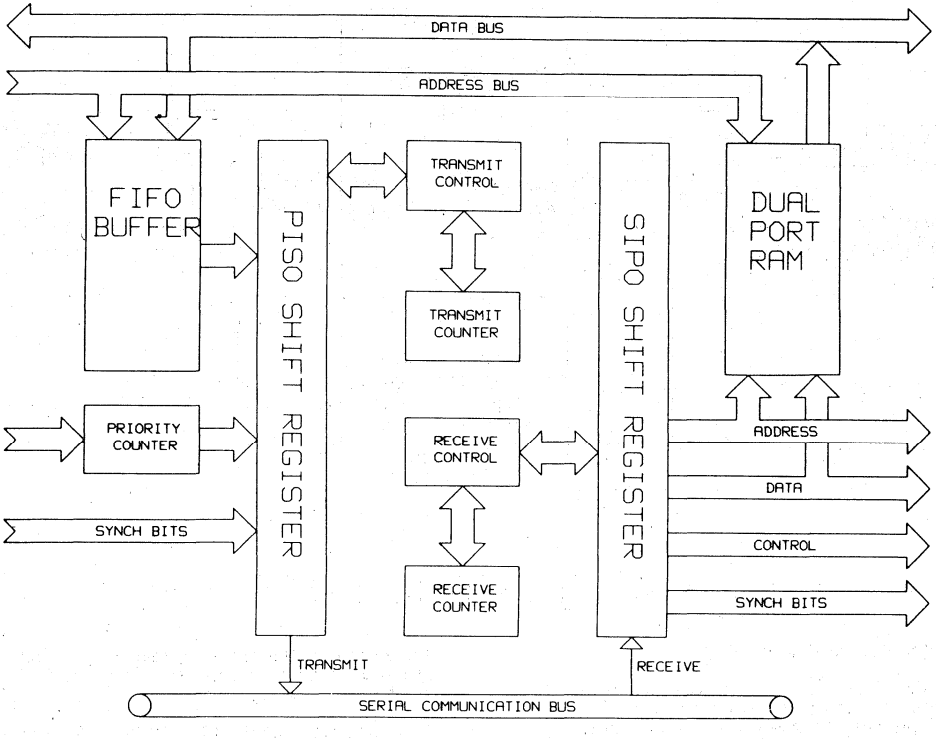

FIGURE 1. SERIAL BUS CONTROLLER BLOCK DIAGRAM

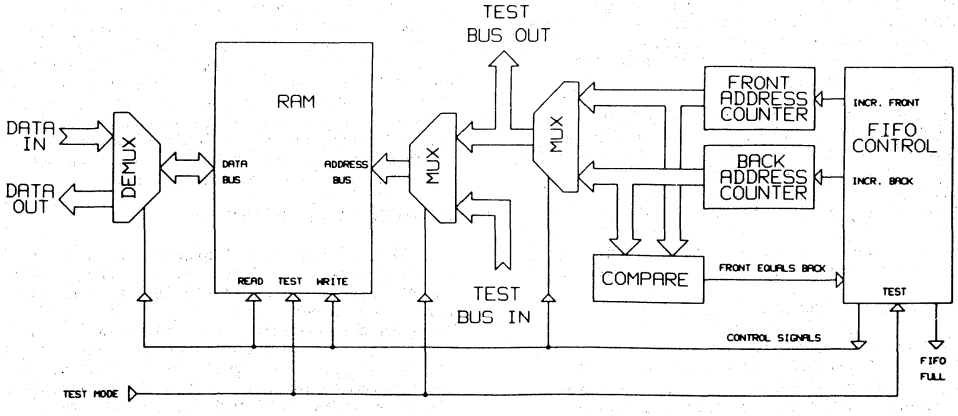

FIGURE 2. FIFO (FIRST-IN, FIRST-OUT) BUFFER

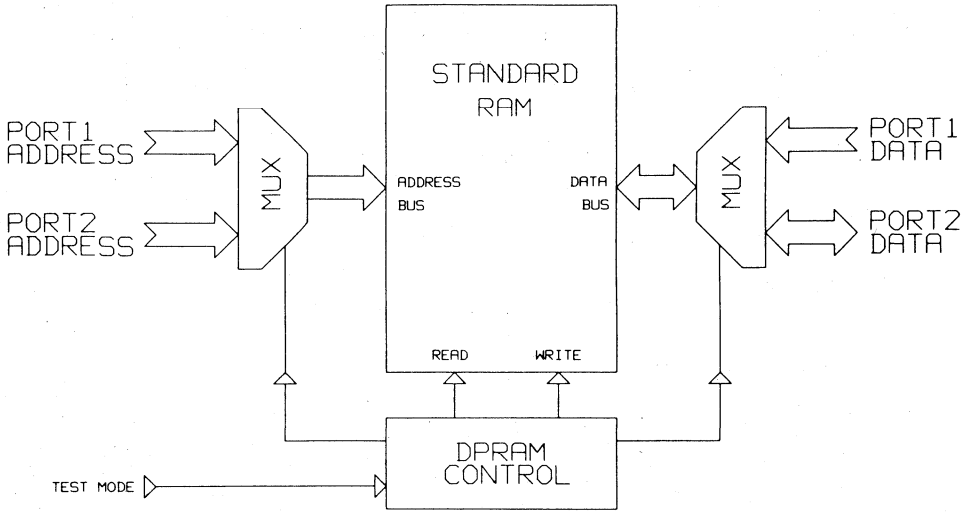

FIGURE 3. DUAL PORT RAM

STANDARD CELL DESIGN METHODOLOGY

The 19 week design schedule for this chip dictated the use of design automation tools. Since the chip included 3 large RAM arrays, gate arrays were impractical, so standard cells were used with automatic placement and routing software. The automatically generated layout was transferred into Intel's full custom design system for some final edits, and the usual design rule checking and verification procedures were followed prior to mask making and processing.

A standard cell design usually proceeds through the following steps:

1. Translation of the logic into standard cells.
2. Schematic capture into a computer database.
3. Extraction of a cell interconnection "netlist".
4. Logic and timing simulation.
5. Automatic layout generation.
6. Parasitic extraction and re-simulation.

The entire design procedure is outlined in Figure 4, and each step is described briefly below.

TRANSLATION INTO STANDARD CELLS

Our first task was to translate our customer's board-level schematics into a logic design consisting of subcircuits from the standard cell library. Since the customer's schematics referenced IC packages only, this involved the detailed design of the FIFO and DPRAM blocks (described above). A major part of the task was the design of the extra standard cells mentioned above, with their characterization and inclusion in the cell library.

SCHEMATIC CAPTURE, NETLIST EXTRACTION, SIMULATION

We performed schematic capture on a Daisy Personal Logician (PC-AT based) workstation, where each of the standard cells was available as a basic circuit element. We "compiled" each schematic separately to verify its integrity, then linked them together into a complete design database. Finally, we generated a "netlist", or device interconnection list, from this database. This netlist served as input to Intel's logic simulator on our VAX, which we used to verify design correctness. The logic simulator flagged several timing and glitch problems which were corrected before proceeding to layout.

AUTOMATIC LAYOUT GENERATION

We performed layout generation using the CAL-MP program from Silvar-Lisco. Working from the netlist, the program placed the three RAM arrays according to our instructions, then arranged the remaining standard cells in rows according to its own optimization algorithm. At this point prior to signal routing, we instructed the program to further iterate its optimization steps, as we manually modified several cell placements from the graphics terminal. Once all cell placements were determined, the program performed signal and power routing automatically.

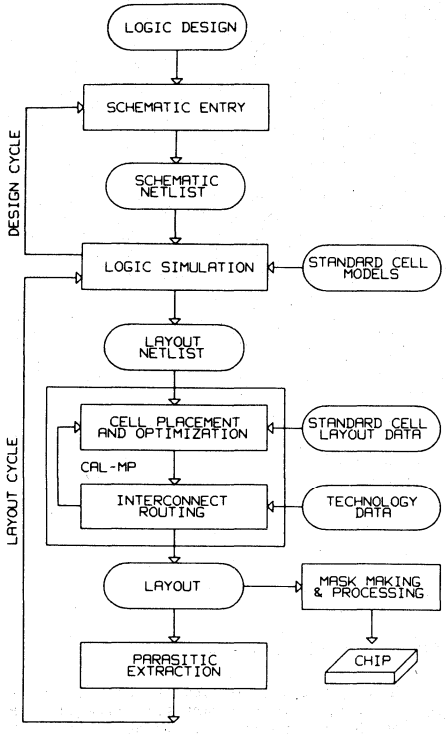

FIGURE 4. STANDARD CELL DESIGN FLOW

The CAL-MP program accepted layout constraints in a variety of forms. In addition to the netlist information, we defined pad placements and the number of standard cell rows, and constrained a few critical signals (such as clocks) to two vertical metal buses traversing the right and left sides of the chip. Furthermore, several unconstrained signals were assigned numerical "strengths" greater than the default of 1.0, which weighted their consideration in the optimization algorithm, tending to shorten them. We ultimately generated more than 20 layouts with widely varying signal strengths, until we were satisfied that very little further improvement was possible.

PARASITIC EXTRACTION

After a layout is generated, it must be proven to work in the presence of parasitic resistances and capacitances contributed by the signal interconnects. These parasitics are extracted from the layout and added to the netlist for a post-layout simulation cycle. In principle, each iterated layout should be re-simulated, but after about 10 layout generations we could easily predict simulation performance from the raw parasitic values.

Because the first version of this chip was fabricated in single-layer metal with a great deal of polysilicon interconnection, parasitic series resistances were just as important in limiting performance as are parasitic capacitances. Unfortunately, series resistors are difficult to systematically insert into a netlist, so we had to simulate the resulting RC delays using Intel's circuit simulator. For the double-layer metal version, we could safely ignore series resistances since the metal sheet resistance is three orders of magnitude smaller than that of polysilicon.

DESIGN FOR TESTABILITY

Our test goal for this part was a 98% fault grade, and since this was a fast-turnaround project with little time for test program development, we included a variety of testability circuits on the chip. An added benefit to this approach was that the testability circuits simplified our debugging procedures. This strategy ultimately paid off, because we were able to quickly isolate and correct a RAM timing problem on the first silicon.

Since this chip has a relatively small node count, we adopted an "ad hoc" rather than "structured" testability strategy. This means that we added test circuits on a case by case basis to improve the controllability and observability of the overall chip, rather than implementing a scan path, a built-in self test, or some other more elaborate scheme. Ad hoc testability design is appropriate for small chips having relatively low transistor/pin ratios. This chip has 8,715 transistors (excluding those in the RAMs) versus 68 pins, for a transistor/pin ratio of 128. In contrast, Intel's 80386 microprocessor has 275,000 transistors versus 132 pins for a ratio of 2,083, clearly requiring structured testability techniques.

Two pins are allocated for test purposes, which are used to select among four modes: a normal operating mode, and three test modes. This test mode strategy is shown in Figure 5. The test modes are used to partition the chip into three isolated subcircuits to be tested independently. In each mode, signals with poor visibility internal to the active subcircuit are brought out to the pads, and the non-active subcircuits are turned off by disabling their clock inputs. The test program can then exercise the active circuit, with the goal of toggling each internal node for maximum fault coverage.

Eleven of the 28 chip inputs provide test inputs in the three test modes, and 16 of the 23 chip outputs serve double duty as test outputs. Although input pins can be connected to several internal test points in parallel (usually multiplexer inputs), only one signal at a time can drive an output pin. These outputs are multiplexed using three stages of 2:1 multiplexers (one for each mode), and the outputs are collected into a 16 bit "test bus" which circumnavigates the chip.

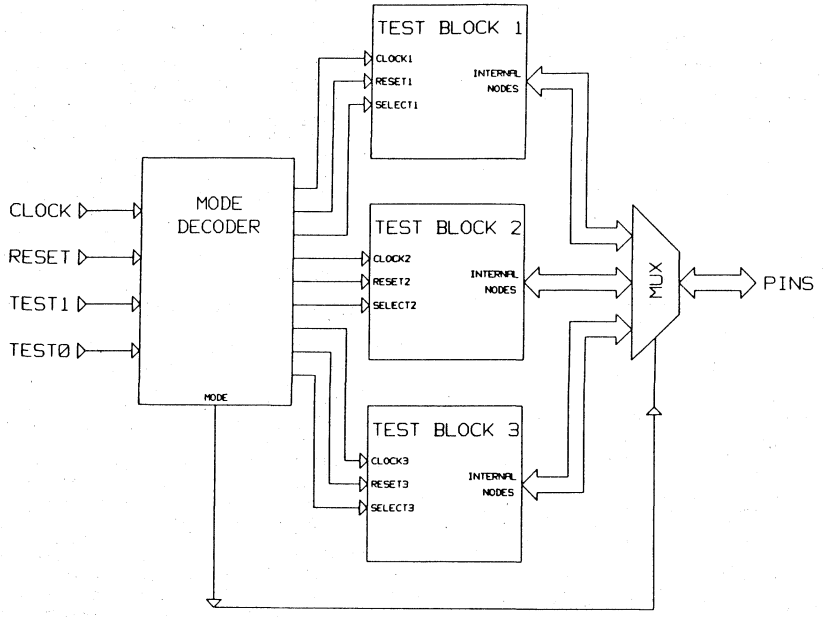

FIGURE 5. TEST MODE STRATEGY

RAM TESTABILITY

RAM testability is a special case, because a RAM is inherently fully testable provided its data and address buses are accessible, along with the necessary control signals. The difficulty here is that the RAMs are embedded in functional blocks which, especially in the FIFO, tends to disguise the inherent RAM accessibility.

Inside the DPRAM, the 1K x 8 RAM is read directly by the microprocessor using the external data and address buses, so observability is no problem. Writes, however, occur from the SIPO during serial reception. It would be particularly painful to test a 1K RAM using serial writes, so a modification was necessary to improve RAM controllability. In test mode, the address multiplexer is held to the address bus by overriding the select line, and a set of eight extra multiplexers were added to the data demultiplexer to allow bidirectional data flow into and out of the RAM. Thus, the SIPO circuit is completely bypassed in test mode.

The FIFO RAM is addressed by one of two counters in the operating mode, which presents a problem unless we are willing to accept sequential test addressing, or at least a very complex address setup procedure. The solution was to override the address bus with a multiplexer fed by input pin signals. The data bus presented the same problem as the DPRAM, but in reverse: data is written by the microprocessor using the external buses, but reads are serialized in the PISO. We decided that serial output was acceptable in FIFO test mode, however, because the FIFO has only 64 locations to test (versus 1024 in the DPRAM), and the words are 18 bits long, which would require 18 extra multiplexers. Thus, for the FIFO data, we left well enough alone.

CONCLUSION

This serial bus controller chip was designed using ASIC techniques in a very short time, resulting in a quick prototype chip which our automotive customer could use to evaluate his system design in a timely manner. The inclusion of testability circuits further shortened the engineering debug time as well as the manufacturing test time. This project demonstrates that standard cell design is an attractive fast-turnaround methodology, and that a good testability strategy provides additional benefits which outweigh the extra design effort.

ACKNOWLEDGEMENT

The authors would like to thank Graham Tubbs, for guiding us through the maze of ASIC design tools, Dinesh Maheshwari and Keith Steele, who helped prepare our final layout for processing, and Mukund Patel and Magdiel Galan who helped us test and debug the final chip.

RUPI™ Application Notes 4

September 1989

UPI-452 Accelerates iAPX 286 Bus Performance

Order Number: 292018-001

UPI-452 ACCELERATES iAPX 286 BUS PERFORMANCE

CONTENTS

LIST OF FIGURES, TABLES AND EQUATIONS

FIGURES:

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INTRODUCTION

The UPI-452 targets the leading problem in peripheral to host interfacing, the interface of a slow peripheral with a fast Host or "bus utilization". The solution is data buffering to reduce the delay and overhead of transferring data between the Host microprocessor and I/O subsystem. The Intel CMOS UPI-452 solves this problem by combining a sophisticated programmable FIFO buffer and a slave interface with an MSC-51 based microcontroller.

The UPI-452 is Intel's newest Universal Peripheral Interface family member. The UPI-452 FIFO buffer enables Host—peripheral communications to be through streams or bursts of data rather than by individual bytes. In addition the FIFO provides a means of embedding commands within a stream or block of data. This enables the system designer to manage data and commands to further off-load the Host.

The UPI-452 interfaces to the iAPX 286 microprocessor as a standard Intel slave peripheral device. READ, WRITE, CS and address lines from the Host are used to access all of the Host addressable UPI-452 Special Function Registers (SFR).

The UPI-452 combines an MSC-51 microcontroller, with 256 bytes of on-chip RAM and 8K bytes of ROM, twice that of the 80C51, a two channel DMA controller and a sophisticated 128 byte, two channel, bidirectional FIFO in a single device. The UPI-452 retains all of the 80C51 architecture, and is fully compatible with the MSC-51 instruction set.

This application note is a description of an iAPX 286 to UPI-452 slave interface. Included is a discussion of the respective timings and design considerations. This application note is meant as a supplement to the UPI-452 Advance Data Sheet. The user should consult the data sheet for additional details on the various UPI-452 functions and features.

UPI-452 iAPX 286 SYSTEM CONFIGURATION

The interface described in this application note is shown in Figure 1, iAPX 286 UPI-452 System Block Diagram. The iAPX 286 system is configured in a local bus architecture design. DMA between the Host and the UPI-452 is supported by the 82258 Advanced DMA Controller. The Host microprocessor accesses all UPI-452 externally addressable registers through address decoding (see Table 3, UPI-452 External Address Decoding). The timings and interface descriptions below are given in equation form with examples of specific calculations. The goal of this application note is a set of interface analysis equations. These equations are the tools a system designer can use to fully utilize the features of the UPI-452 to achieve maximum system performance.

HOST-UPI-452 FIFO SLAVE INTERFACE

The UPI-452 FIFO acts as a buffer between the external Host 80286 and the internal CPU. The FIFO allows the Host - peripheral interface to achieve maximum decoupling of the interface. Each of the two FIFO channels is fully user programmable. The FIFO buffer ensures that the respective CPU, Host or internal CPU, receives data in the same order as transmitted. Three slave bus interface handshake methods are supported by the UPI-452; DMA, Interrupt and Polled.

The interface between the Host 80286 and the UPI-452 is accomplished with a minimum of signals. The 8 bit data bus plus READ, WRITE, CS, and A0-2 provide access to all of the externally addressable UPI-452 registers including the two FIFO channels. Interrupt and DMA handshaking pins are tied directly to the interrupt controller and DMA controller respectively.

DMA transfers between the Host and UPI-452 are controlled by the Host processors DMA controller. In the example shown in Figure 1, the Host DMA controller is the 82258 Advanced DMA Controller. An internal DMA transfer to or from the FIFO, as well as between other internal elements, is controlled by the UPI-452 internal DMA processor. The internal DMA processor can also transfer data between Input and Output FIFO channels directly. The description that follows details the UPI-452 interface from both the Host processor's and the UPI-452's internal CPU perspective.

One of the unique features of the UPI-452 FIFO is its ability to distinguish between commands and data embedded in the same data block. Both interrupts and status flags are provided to support this operation in either direction of data transfer. These flags and interrupts are triggered by the FIFO logic independent of, and transparent to either the Host or internal CPUs. Commands embedded in the data block, or stream, are called Data Stream Commands.

Programmable FIFO channel Thresholds are another unique feature of the UPI-452. The Thresholds provide for interrupting the Host only when the Threshold number of bytes can be read or written to the FIFO buffer. This further decouples the Host UPI-452 interface by relieving the Host of polling the buffer to determine the number of bytes that can be read or written. It also reduces the chances of overrun and underrun errors which must be processed.

The UPI-452 also provides a means of bypassing the FIFO, in both directions, for an immediate interrupt of either the Host or internal CPU. These commands are called Immediate Commands. A complete description of the internal FIFO logic operation is given in the FIFO Data Structure section.

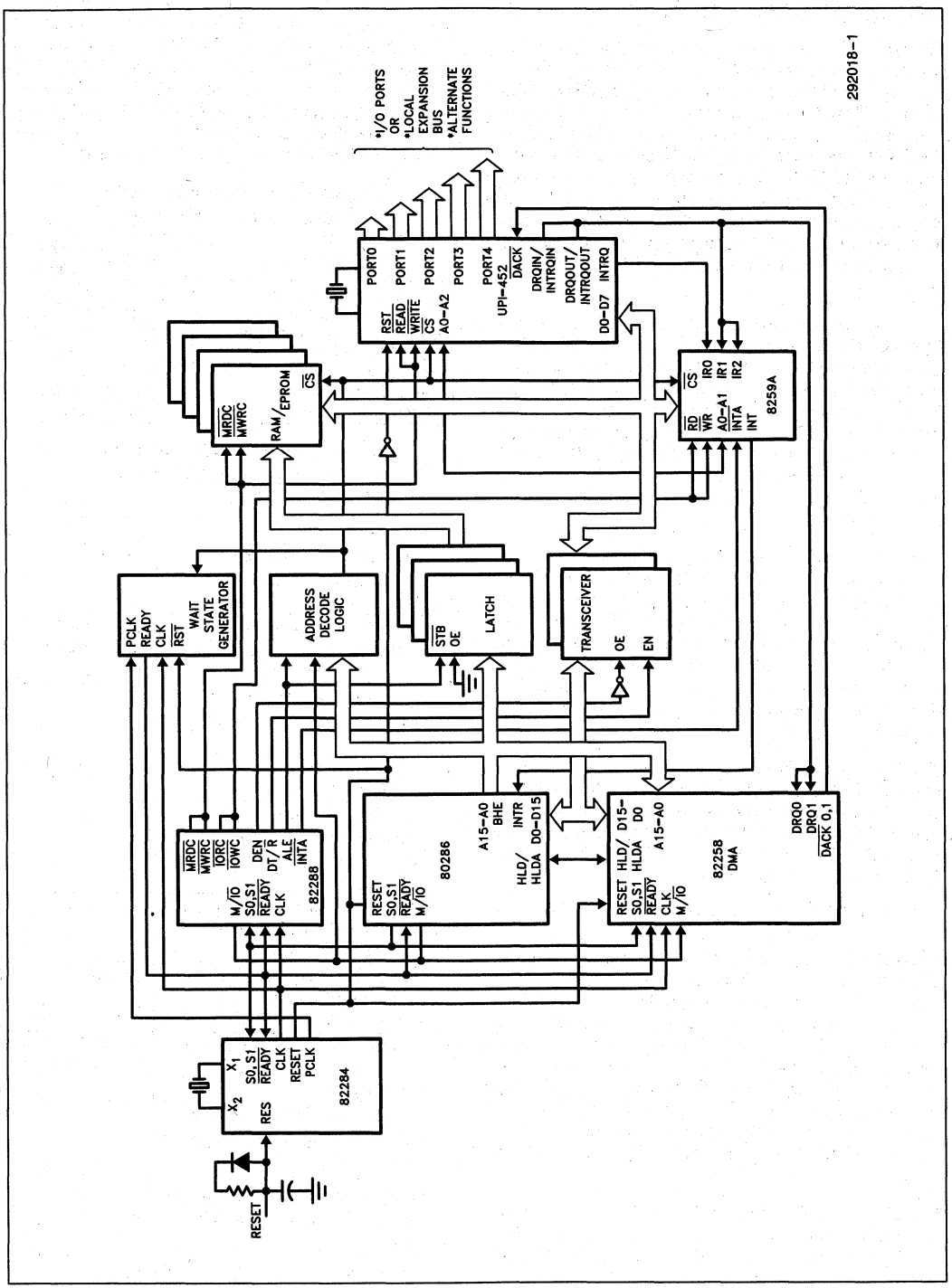


Figure 1. iAPX 286 UPI-452 System Block Diagram

UPI-452 INITIALIZATION

The UPI-452 at power-on reset automatically performs a minimum initialization of itself. The UPI-452 notifies the Host that it is in the process of initialization by setting a Host Status SFR bit. The user UPI-452 program must release the UPI-452 from initialization for the FIFO to be accessible by the Host. This is the minimum Host to UPI-452 initialization sequence. All further initialization and configuration of the UPI-452, including the FIFO, is done by the internal CPU under user program control. No interaction or programming is required by the Host 80286 for UPI-452 initialization.

At power-on reset the UPI-452 automatically enters FIFO DMA Freeze Mode by resetting the Slave Control (SLCON) SFR FIFO DMA Freeze/Normal Mode bit to FIFO DMA Freeze Mode (FRZ = "0"). This forces the Slave Status (SSTAT) and Host Status (HSTAT) SFR FIFO DMA Freeze/Normal Mode bits to FIFO DMA Freeze Mode In Progress. FIFO DMA Freeze Mode allows the FIFO interface to be configured, by the internal CPU, while inhibiting Host access to the FIFO.

The MODE SFR is forced to zero at reset. This disables, (tri-states) the DRQIN/INTRQIN, DRQOUT/INTRQOUT and INTRQ output pins. INTRQ is inhibited from going active to reflect the fact that a Host Status SFR bit, FIFO DMA Freeze Mode, is active. If the MODE SFR INTRQ configure bit is enabled (='1'), before the Slave Control and Host Status SFR FIFO DMA Freeze/Normal Mode bit is set to Normal Mode, INTRQ will go active immediately.

The first action by the Host following reset is to read the UPI-452 Host Status SFR Freeze/Normal Mode bit to determine the status of the interface. This may be done in response to a UPI-452 INTRQ interrupt, or by polling the Host Status SFR. Reading the Host Status SFR resets the INTRQ line low.

Any of the five FIFO interface SFRs, as well as a variety of additional features, may be programmed by the internal CPU following reset. At power-on reset, the five FIFO Special Function Registers are set to their default values as listed in Table 1. All reserved location bits are set to one, all other bits are set to zero in these three SFRs. The FIFO SFRs listed in Table 1 can be programmed only while the UPI-452 is in FIFO DMA Freeze Mode. The balance of the UPI-452 SFRs default values and descriptions are listed in the UPI-452 Advance Data Sheet in the Intel Microsystems Component Handbook Volume II and Microcontroller Handbook.

The above sequence is the minimum UPI-452 internal initialization required. The last initialization instruction must always set the UPI-452 to Normal Mode. This causes the UPI-452 to exit Freeze Mode and enables Host read/write access of the FIFO. The internal CPU sets the Slave Control (SLCON) SFR FIFO DMA Freeze/Normal Mode (FRZ) bit high (=1) to activate Normal Mode. Ths causes the Slave Status (SSTAT) and Host Status (HSTAT) SFR FIFO DMA Freeze Mode bits to be set to Normal Mode. Table 2, UPI-452 Initialization Event Sequence Example, shows a summary of the initialization events described above.

Table 1. FIFO Special Function Register Default Values

SFR Name	Label	Reset Value
Channel Boundary Pointer	CBP	40H/64D
Output Channel Read Pointer	ORPR	40H/64D
Output Channel Write Pointer	OWPR	40H/64D
Input Channel Read Pointer	IRPR	00H/0D
Input Channel Write Pointer	IWPR	00H/0D
Input Threshold	ITH	00H/0D
Output Threshold	OTH	01H/1D

Table 2. UPI-452 Initialization Event Sequence Example

Event Description	SFR/bit
Power-on Reset	
UPI-452 forces FIFO DMA Freeze Mode (Host access to FIFO inhibited)	SLCON FRZ = 0
UPI-452 forces Slave Status and Host Status SFR to FIFO DMA Freeze Mode In Progress	SSTAT SST5 = 0 HSTAT HST1 = 1
UPI-452 forces all SFRs, including FIFO SFRs, to default values.	
* UPI-452 user program enables INTRQ, INTRQ goes active, high	MODE MD4 = 1
* Host $\overline{\text{READ}}$'s UPI-452 Host Status (HSTAT) SFR to determine interrupt source, INTRQ goes low	
* UPI-452 user program initializes any other SFRs; FIFO, Interrupts, Timers/Counters, etc.	
User program sets Slave Control SFR to Normal Mode (Host access to FIFO enabled)	SLCON FRZ = 1
UPI-452 forces Slave and Host Status SFRs bits to Normal Operation	SSTAT SST5 = 1 HSTAT HST1 = 0
* Host polls Host Status SFR to determine when it can access the FIFO - or - * Host waits for UPI-452 Request for Service interrupt to access FIFO	

* user option

FIFO DATA STRUCTURES

Overview

The UPI-452 provides three means of communication between the Host microprocessor and the UPI-452 in either direction;

Data
Data Stream Commands
Immediate Commands

Data and Data Stream Commands (DSC) are transferred between the Host and UPI-452 through the UPI-452 FIFO buffer. The third, Immediate Commands, provides a means of bypassing the FIFO entirely. These three data types are in addition to direct access by either Host or Internal CPU of dedicated Status and Control Special Function Registers (SFR).

The FIFO appears to both the Host 80286 and the internal CPU as 8 bits wide. Internally the FIFO is logically nine bits wide. The ninth bit indicates whether the byte is a data or a Data Stream Command (DSC) byte; 0 = data, 1 = DSC. The ninth bit is set by the FIFO logic in response to the address specified when writing to the FIFO by either Host or internal CPU. The FIFO uses the ninth bit to condition the UPI-452 interrupts and status flags as a byte is made available for a Host or internal CPU read from the FIFO. Figures 2 and 3 show the structure of each FIFO channel and the logical ninth bit.

It is important to note that both data and DSCs are actually entered into the FIFO buffer (see Figures 2 and 3). External addressing of the FIFO determines the state of the internal FIFO logic ninth bit. Table 3 shows the UPI-452 External Address Decoding used by the Host and the corresponding action. The internal CPU interface to the FIFO is essentially identical to the external Host interface. Dedicated internal Special Function Registers provide the interface between the FIFO, internal CPU and the internal two channel DMA processor. FIFO read and write operations by the Host and internal CPU are interleaved by the UPI-452 so they appear to be occurring simultaneously.

The ninth bit provides a means of supporting two data types within the FIFO buffer. This feature enables the Host and UPI-452 to transfer both commands and data while maintaining the decoupled interface a FIFO buffer provides. The logical ninth bit provides both a means of embedding commands within a block of data and a means for the internal CPU, or external Host, to discriminate between data and commands. Data or DSCs may be written in any order desired. Data Stream Commands can be used to structure or dispatch the data by defining the start and end of data blocks or packets, or how the data following a DSC is to be processed.

A Data Stream Command (DSC) acts as an internal service routine vector. The DSC generates an interrupt to a service routine which reads the DSC. The DSC byte acts as an address vector to a user defined service routine. The address can be any program or data memory location with no restriction on the number of DSCs or address boundaries.

A Data Stream Command (DSC) can also be used to clear data from the FIFO or "FLUSH" the FIFO. This is done by appending a DSC to the end of a block of data entered in the FIFO which is less than the programmed threshold number of bytes. The DSC will cause an interrupt, if enabled, to the respective receiving CPU. This ensures that a less than Threshold number of bytes in the FIFO will be read. Two conditions force a Request for Service interrupt, if enabled, to the Host. The first is due to a Threshold number of bytes having been written to the FIFO Output channel; the second is if a DSC is written to the Output FIFO channel. If less than the Threshold number of bytes are written to the Output FIFO channel, the Host Status SFR flag will not be set, and a Request for Service interrupt will not be generated, if enabled. By appending a DSC to end of the data block, the FIFO Request for Service flag and/or interrupt will be generated.

An example of a FIFO Flush application is a mass storage subsystem. The UPI-452 provides the system interface to a subsystem which supports tape and disk storage. The FIFO size is dynamically changed to provide the maximum buffer size for the direction of transfer. Large data blocks are the norm in this application. The FIFO Flush provides a means of purging the FIFO of the last bytes of a transfer. This guarantees that the block, no matter what its size, will be transmitted out of the FIFO.

Immediate Commands allow more direct communication between the Host processor and the UPI-452 by bypassing the FIFO in either direction. The Immediate Command IN and OUT SFRs are two more unique address locations externally and internally addressable. Both DSCs and Immediate Commands have internal interrupts and interrupt priorities associated with their operation. The interrupts are enabled or disabled by setting corresponding bits in the Slave Control (SLCON), Interrupt Enable (IEC), Interrupt Priority (IPC) and Interrupt Enable and Priority (IEP) SFRs. A detailed description of each of these may be found in the UPI-452 Advance Information Data Sheet.

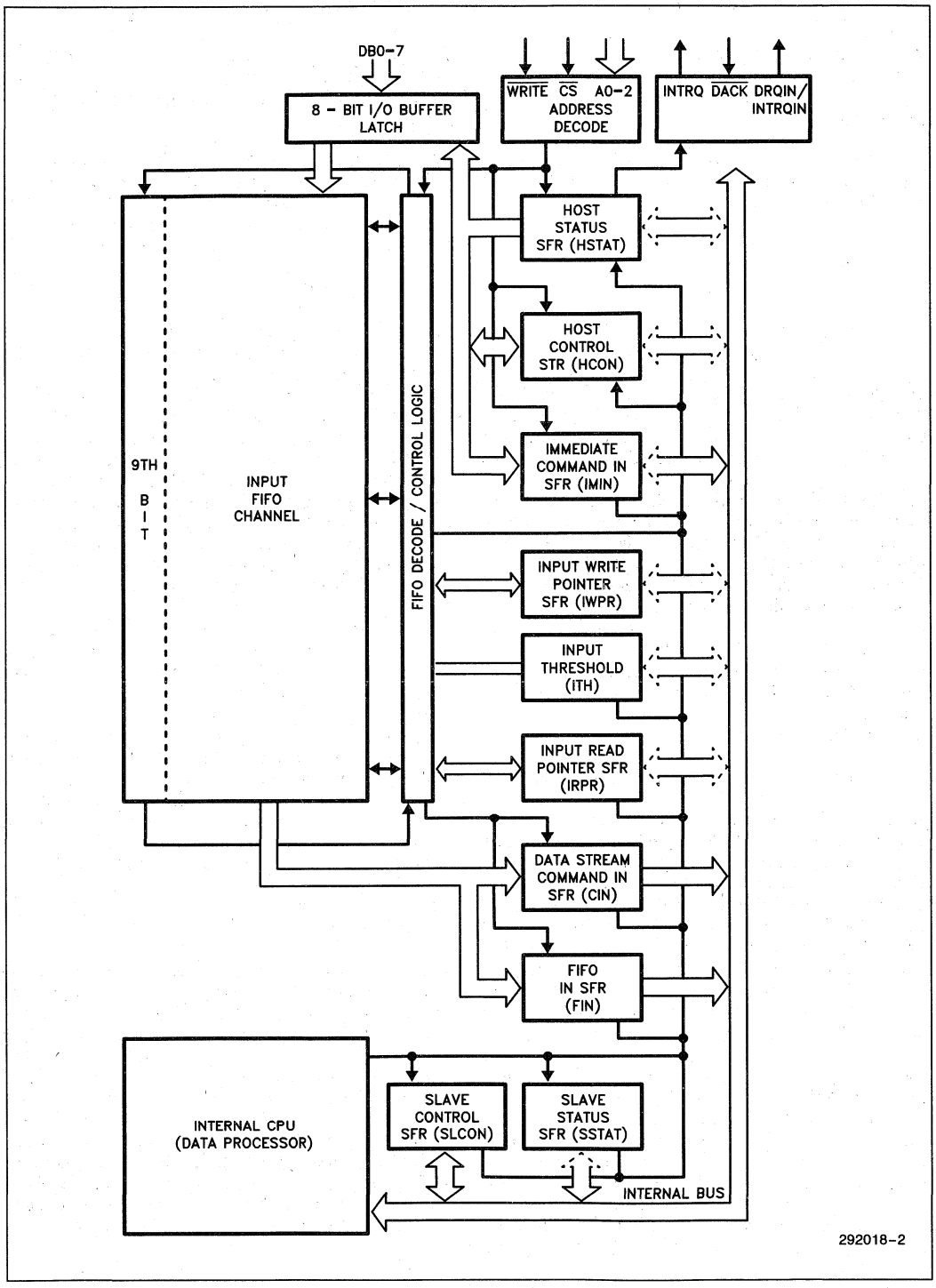


Figure 2. Input FIFO Channel Functional Diagram

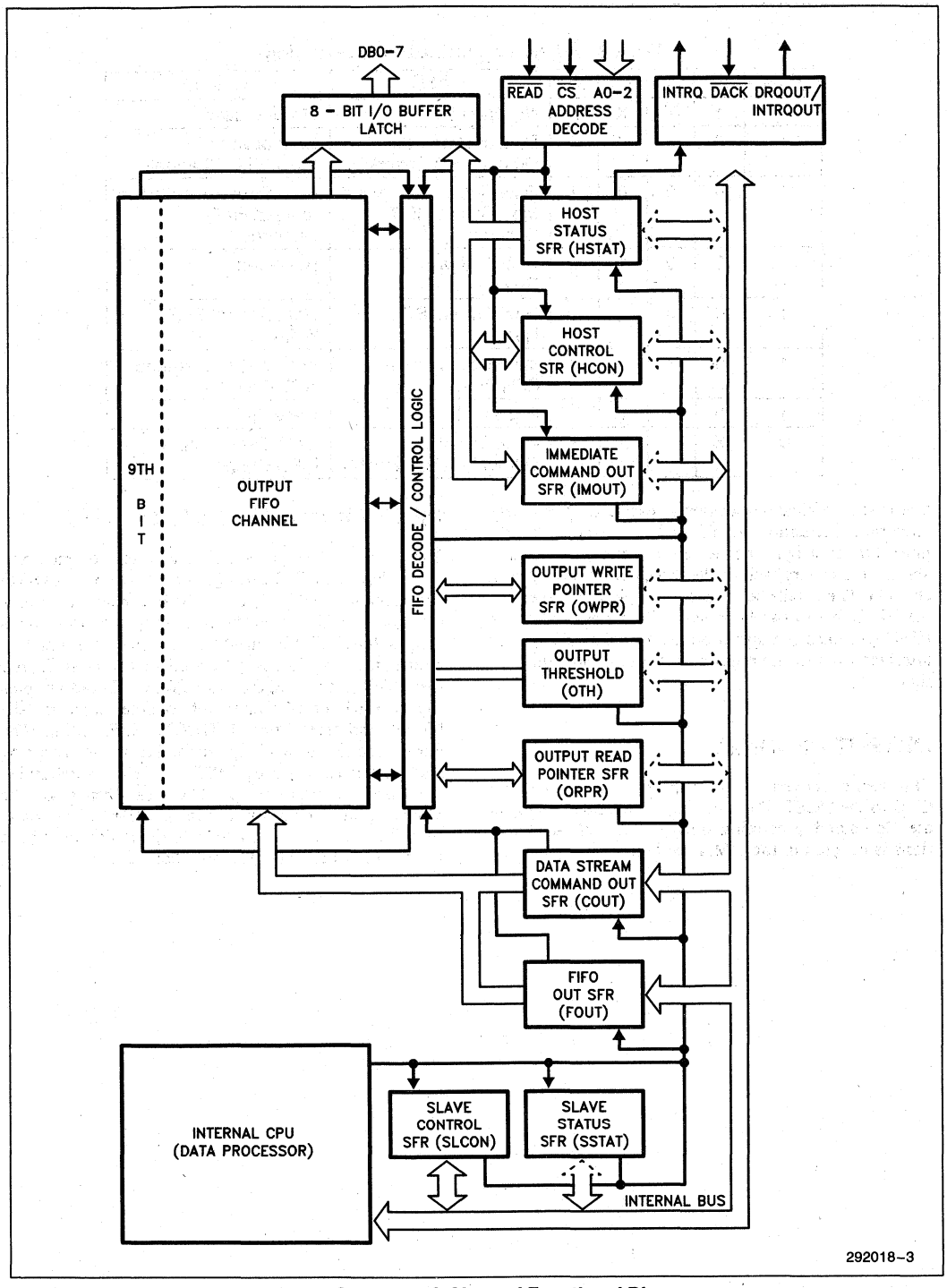


Figure 3. Output FIFO Channel Functional Diagram

Table 3. UPI-452 External Address Decoding

$\overline{DACK}$	$\overline{CS}$	A2	A1	A0	$\overline{READ}$	$\overline{WRITE}$
1	1	X	X	X	No Operation	No Operation
1	0	0	0	0	Data or DMA from Output FIFO Channel	Data or DMA to Input FIFO Channel
1	0	0	0	1	Data Stream Command from Output FIFO Channel	Data Stream Command to Input FIFO Channel
1	0	0	1	0	Host Status SFR Read	Reserved
1	0	0	1	1	Host Control SFR Read	Host Control SFR Write
1	0	1	0	0	Immediate Command SFR Read	Immediate Command SFR Write
1	0	1	1	X	Reserved	Reserved
0	X	X	X	X	DMA Data from Output FIFO Channel	DMA Data to Input FIFO Channel

Below is a detailed description of each FIFO channel's operation, including the FIFO logic response to the ninth bit, as a byte moves through the channel. The description covers each of the three data types for each channel. The details below provide a picture of the various FIFO features and operation. By understanding the FIFO structure and operation the user can optimize the interface to meet the requirements of an individual design.

OUTPUT CHANNEL

This section covers the data path from the internal CPU to the HOST. Data Stream Command or Immediate Command processing during Host DMA Operations is covered in the DMA section.

UPI-452 Internal Write to the FIFO

The internal CPU writes data and Data Stream Commands into the FIFO through the FIFO OUT (FOUT) and Command OUT (COUT) SFRs. When a Threshold number of bytes has been written, the Host Status SFR Output FIFO Request for Service bit is set and an interrupt, if enabled, is generated to the Host. Either the INTRQ or DRQOUT/INTRQOUT output pins can be used for this interrupt as determined by the MODE and Host Control (HCON) SFR setting. The Host responds to the Request for Service interrupt by reading the Host Status (HSTAT) SFR to determine the source of the interrupt. The Host then reads the Threshold number of bytes from the FIFO. The internal CPU may continue to write to the FIFO during the Host read of the FIFO Output channel.

Data Stream Commands may be written to the Output FIFO channel at any time during a write of data bytes. The write instruction need only specify the Command Out (COUT) SFR in the direct register instruction used. Immediate Commands may also be written at any time to the Immediate Command OUT (IMOUT) SFR. The Host reads Immediate Commands from the Immediate Command OUT (IMOUT).

The internal CPU can determine the number of bytes to write to the FIFO Output channel in one of three ways. The first, and most efficient, is by utilizing the internal DMA processor which will automatically manage the writing of data to avoid Underrun or Overrun Errors. The second is for the internal CPU to read the Output FIFO channels Read and Write Pointers and compare their values to determine the available space. The third method for determining the available FIFO space is to always write the programmed channel size number of bytes to the Output FIFO. This method would use the Overrun Error flag and interrupt to halt FIFO writing whenever the available space was less than the channel size. The interrupt service routine could read the channel pointers to determine or monitor the available channel space. The time required for the internal CPU to write data to the Output FIFO channel is a function of the individual instruction cycle time and the number of bytes to be written.

Host Read from the FIFO

The Host reads data or Data Stream Commands (DSC) from the FIFO in response to the Host Status (HSTAT) SFR flags and interrupts, if enabled. All Host read operations access the same UPI-452 internal I/O Buffer Latch. At the end of the previous Host FIFO read cycle a byte is loaded from the FIFO into the I/O Buffer Latch and Host Status (HSTAT) SFR bit 5 is set or cleared (1 = DSC, 0 = data) to reflect the state of the byte's FIFO ninth bit. If the FIFO ninth bit is set (= 1) indicating a DSC, an interrupt is generated to the external Host via INTRQ pin or INTRQIN/INTRQOUT pins as determined by Host Control (HCON) SFR bit 1. The Host then reads the Host Status (HSTAT) SFR to determine the source of the interrupt.

The most efficient Host read operation of the FIFO Output channel is through the use of Host DMA. The UPI-452 fully supports external DMA handshaking. The MODE and Host Control SFRs control the configuration of UPI-452 Host DMA handshake outputs. If Host DMA is used the Threshold Request for Service interrupt asserts the UPI-452 DMA Request (DRQOUT) output. The Host DMA processor acknowledges with $\overline{\text{DACK}}$ which acts as a chip select of the FIFO channels. The DMA transfer would stop when either the threshold byte count had been read, as programmed in the Host DMA processor, or when the DRQOUT output is brought inactive by the UPI-452.

INPUT CHANNEL

This section covers the data path from the HOST to the internal CPU or internal DMA processor. The details of Data Stream Command or Immediate Command processing during internal DMA operations are covered in the DMA section below.

Host Write to the FIFO

The Host writes data and Data Stream Commands into the FIFO through the FIFO IN (FIN) and Command IN (CIN) SFRs. When a Threshold number of bytes has been read out of the Input FIFO channel by the internal CPU, the Host Status SFR Input FIFO Request for Service bit is set and an interrupt, if enabled, is generated to the Host. The Input FIFO Threshold interrupt tells the Host that it may write the next block of data into the FIFO. Either the INTRQ or DRQIN/INTRQIN output pins can be used for this interrupt as determined by the MODE and Host Control (HCON) SFR settings. The Host may continue to write to the FIFO Input channel during the internal CPU read of the FIFO. Data Stream Commands may be written to the FIFO Input channel at any time during a write of data bytes. Immediate Commands may also be written at any time to the Immediate Command IN (IMIN) SFR.

The Host also has three methods for determining the available FIFO space. Two are essentially identical to that of the internal CPU. They involve reading the FIFO Input channel pointers and using the Host Status SFR Underrun and Overrun Error flags and Request for Service interrupts these would generate, if enabled in combination. The third involves using the UPI-452 Host DMA controller handshake signals and the programmed Input FIFO Threshold. The Host would receive a Request for Service interrupt when an Input FIFO channel has a Theshold number of bytes able to be written by the Host. The Host service routine would then write the Threshold number of bytes to the FIFO.

If a Host DMA is used to write to the FIFO Input channel, the Threshold Request for Service interrupt could assert the UPI-452 DRQIN output. The Host DMA processor would assert $\overline{DACK}$ and the FIFO write would be completed by Host the DMA processor. The DMA transfer would stop when either the Threshold byte count had been written or the DRQIN output was removed by the UPI-452. Additional details on Host and internal DMA operation is given below.

Internal Read of the FIFO

At the end of an internal CPU read cycle a byte is loaded from the FIFO buffer into the FIFO IN/Command IN SFR and Slave Status (SSTAT) SFR bit 1 is set or cleared (1 = data, 0 = DSC) to reflect the state of the FIFO ninth bit. If the byte is a DSC, the FIFO ninth bit is set (= 1) and an interrupt is generated, if enabled, to the Internal CPU. The internal CPU then reads the Slave Status (SSTAT) SFR to determine the source of the interrupt.

Immediate Commands are written by the Host and read by the internal CPU through the Immediate Command IN (IMIN) SFR. Once written, an Immediate Command sets the Slave Status (SSTAT) SFR flag bit and generates an interrupt, if enabled, to the internal CPU. In response to the interrupt the internal CPU reads the Slave Status (SSTAT) SFR to determine the source of the interrupt and service the Immediate Command.

FIFO INPUT/OUTPUT CHANNEL SIZE

Host

The Host does not have direct control of the FIFO Input or Output channel sizes or configuration. The Host can, however, issue Data Stream Commands or Immediate Commands to the UPI-452 instructing the UPI-452 to reconfigure the FIFO interface by invoking FIFO DMA Freeze Mode. The Data Stream Command or Immediate Command would be a vector to a service routine which performs the specific reconfiguration.

UPI-452 Internal

The default power-on reset FIFO channel sizes are listed in the "Initialization" section and can be set only by the internal CPU during FIFO DMA Freeze Mode. The FIFO channel size is selected to achieve the optimum application performance. The entire 128 byte FIFO can be allocated to either the Input or Output channel. In this case the other channel consists of a single SFR; FIFO IN/Command IN or FIFO OUT/Command OUT SFR. Figure 4 shows a FIFO division with a portion devoted to each channel. Figure 5 shows a FIFO configuration with all 128 bytes assigned to the Output channel.

The FIFO channel Threshold feature allows the user to match the FIFO channel size and the performance of the internal and Host data transfer rates. The programmed Threshold provides an elasticity to the data transfer operation. An example is if the Host FIFO

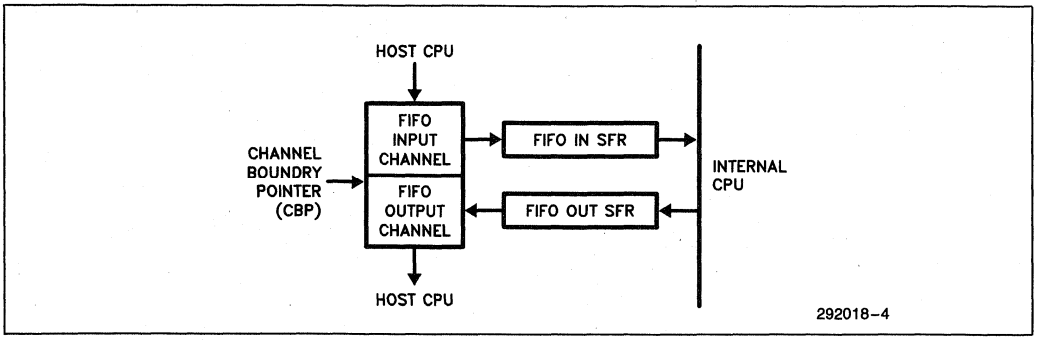


Figure 4. Full Duplex FIFO Operation

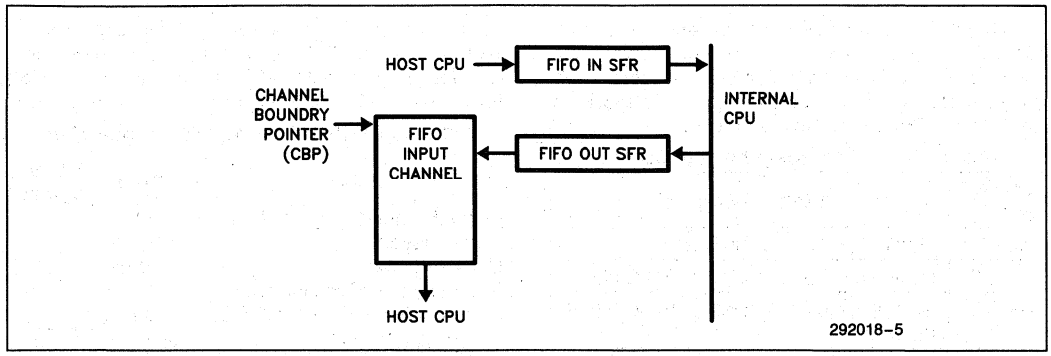


Figure 5. Entire FIFO Assigned to Output Channel

data transfer rate is twice as fast as the internal FIFO DMA data transfer rate. In this example the FIFO Input channel size is programmed to be 64 bytes and the Input channel Threshold is programmed to be 20 bytes. The Host writes the first 64 bytes to the Input FIFO. When the internal DMA processor has read 20 bytes the Threshold interrupt, or DMA request (DRQIN), is generated to signal the Host to begin writing more data to the Input FIFO channel. The internal DMA processor continues to read data from the Input channel as the Host, or Host DMA processor, writes to the FIFO. The Host can write 40 bytes to the FIFO Input channels in the time it takes for the internal DMA processor to read 20 more bytes from it. This will keep both the Host and internal DMA operating at their maximum rates without forcing one to wait for the other.

Two methods of managing the FIFO size are possible; fixed and variable channel size. A fixed channel size is one where the channel is configured at initialization and remains unchanged throughout program execution. In a variable FIFO channel size, the configuration is changed dynamically to meet the data transmission requirements as needed. An example of a variable channel size application is the mass storage subsystem described earlier. To meet the demands of a large data block transfer the FIFO size could be fully allocated to the Input or Output channel as needed. The Thresholds are also reprogrammed to match the respective data transfer rates.

An example of a fixed channel size application might be one which uses the UPI-452 to directly control a series of stepper motors. The UPI-452 manages the motor operation and status as required. This would include pulse train, acceleration, deceleration and feedback. The Host transmits motor commands to the UPI-452 in blocks of 6–10 bytes. Each block of motor command data is preceded by a command to the UPI-452 which selects a specific motor. The UPI-452 transmits blocks of data to the Host which provides motor and overall system status. The data and embedded commands structure, indicating the specific motor, is the same. In this example the default 64 bytes per channel might be adequate for both channels.

INTERRUPT RESPONSE TIMING

Interrupts enable the Host UPI-452 FIFO buffer interface and the internal CPU FIFO buffer interface to operate with a minimum of overhead on the respective CPU. Each CPU is "interrupted" to service the FIFO on an as needed basis only. In configuring the FIFO buffer Thresholds and choosing the appropriate internal DMA Mode the user must take into account the interrupt response time for both CPUs. These response times will affect the DMA transfer rates for each channel. By choosing FIFO channel Thresholds which reflect both the respective DMA transfer rate and the interrupt response time the user will achieve the maximum data throughput and system bus decoupling. This in turn will mean the overall available system bus bandwidth will increase.

The following section describes the FIFO interrupt interface to the Host and internal CPU. It also describes an analysis of sample interrupt response times for the Host and UPI-452 internal CPU. These equations and the example times shown are then used in the DMA section to further analyze an optimum Host UPI-452 interface.

HOST

Interrupts to the Host processor are supported by the three UPI-452 output pins; INTRQ, DRQIN/INTRQIN and DRQOUT/INTRQOUT. INTRQ is a general purpose Request For Service interrupt output. DRQIN/INTRQIN and DRQOUT/INRQOUT pins are multiplexed to provide two special "Request for Service" FIFO interrupt request lines when DMA is disabled. A FIFO Input or Output channel Request for Service interrupt is generated based upon the value programmed in the respective channel's Threshold SFRs; Input Threshold (ITHR), and Output Threshold

(OTHR) SFRs. Additional interrupts are provided for FIFO Underrun and Overrun Errors, Data Stream Commands, and Immediate Commands. Table 4 lists the eight UPI-452 interrupt sources as they appear in the HSTAT SFR to the Host processor.

Table 4. UPI-452 to Host Interrupt Sources

HSTAT SFR Bit	Interrupt Source
HST7	Output FIFO Underrun Error
HST6	Immediate Command Out SFR Status
HST5	Data Stream Command/Data at Output FIFO Status
HST4	Output FIFO Request for Service Status
HST3	Input FIFO Overrun Error Condition
HST2	Immediate Command In SFR Status
HST1	FIFO DMA Freeze/Normal Mode Status
HST0	Input FIFO Request for Service

The interrupt response time required by the Host processor is application and system specific. In general, a typical sequence of Host interrupt response events and the approximate times associated with each are listed in Equation 1.

The example assumes the hardware configuration shown in Figure 1, iAPX 286/UPI-452 Block Diagram, with an 8259A Programmable Interrupt Controller. The timing analysis in Equation 1 also assumes the following; no other interrupt is either in process or pending, nor is the 286 in a LOCK condition. The current instruction completion time is 8 clock cycles (800 ns @ 10 MHz), or 4 bus cycles. The interrupt service routine first executes a PUSHA instruction, PUSH All General Registers, to save all iAPX 286 internal registers. This requires 19 clocks (or 2.0 μs @ 10 MHz), or 10 bus cycles (rounded to complete bus cycle). The next service routine instruction reads the UPI-452 Host Status SFR to determine the interrupt source.

It is important to note that any UPI-452 INTRQ interrupt service routine should ALWAYS mask for the Freeze Mode bit first. This will insure that Freeze Mode always has the highest priority. This will also save the time required to mask for bits which are forced inactive during Freeze Mode, before checking the Freeze Mode bit. Access to the FIFO channels by the Host is inhibited during Freeze Mode. Freeze Mode is covered in more detail below.

To initiate the interrupt the UPI-452 activates the INTRQ output. The interrupt acknowledge sequence requires two bus cycles, 400 ns (10 MHz iAPX 286), for the two INTA pulse sequence.

Equation 1. Host Interrupt Response Time

Action	Time	Bus Cycles*
Current instruction execution completion	800 ns	4
INTA sequence	400 ns	2
Interrupt service routine (time to host first $\overline{\text{READ}}$ of UPI-452)	2000 ns	10
Total Interrupt Response Time	2.3 μs	16

NOTE:
10 MHz iAPX 286 bus cycle, 200 ns each

UPI-452 Internal

The internal CPU FIFO interrupt interface is essentially identical to that of the Host to the FIFO. Three internal interrupt sources support the FIFO operation; FIFO-Slave bus Interface Buffer, DMA Channel 0 and DMA Channel 1 Requests. These interrupts provide a maximum decoupling of the FIFO buffer and the internal CPU. The four different internal DMA Modes available add flexibility to the interface.

The FIFO-Slave Bus Interface interrupt response is also similar to the Host response to an INTRQ Request for Service interrupt. The internal CPU responds to the interrupt by reading the Slave Status (SSTAT) SFR to determine the source of the interrupt. This allows the user to prioritize the Slave Status flag response to meet the users application needs.

The internal interrupt response time is dependent on the current instruction execution, whether the interrupt is enabled, and the interrupt priority. In general, to finish execution of the current instruction, respond to the interrupt request, push the Program Counter (PC) and vector to the first instruction of the interrupt service routine requires from 38 to 86 oscillator periods (2.38 to 5.38 μs @ 16 MHz). If the interrupt is due to an Immediate Command or DSC, additional time is required to read the Immediate Command or DSC SFR and vector to the appropriate service routine. This means two service routines back to back. One service routine to read the Slave Status (SSTAT) SFR to determine the source of the Request for Service interrupt, and second the service routine pointed to by the Immediate Command or DSC byte read from the respective SFR.

DMA

DMA is the fastest and most efficient way for the Host or internal CPU to communicate with the FIFO buffer. The UPI-452 provides support for both of these DMA paths. The two DMA paths and operations are fully independent of each other and can function simultaneously. While the Host DMA processor is performing a DMA transfer to or from the FIFO, the UPI-452 internal DMA processor can be doing the same.

Below are descriptions of both the Host and internal DMA operations. Both DMA paths can operate asynchronously and at different transfer rates. In order to make the most of this simultaneous asynchronous operation it is necessary to calculate the two transfer rates and accurately match their operations. Matching the different transfer rates is done by a combination of accurately programmed FIFO channel size and channel Thresholds. This provides the maximum Host and internal CPU to FIFO buffer interface decoupling. Below is a description of each of the two DMA operations and sample calculations for determining transfer rates. The next section of this application note, "Interface Latency", details the considerations involved in analyzing effective transfer rates when the overhead associated with each transfer is considered.

HOST FIFO DMA

DMA transfers between the Host and UPI-452 FIFO buffer are controlled by the Host CPU's DMA controller, and is independent of the UPI-452's internal two channel DMA processor. The UPI-452's internal DMA processor supports data transfers between the UPI-452 internal RAM, external RAM (via the Local Expansion Bus) and the various Special Function Registers including the FIFO Input and Output channel SFRs.

The maximum DMA transfer rate is achieved by the minimum DMA transfer cycle time to accomplish a source to destination move. The minimum Host UPI-452 FIFO DMA cycle time possible is determined by the $\overline{\text{READ}}$ and $\overline{\text{WRITE}}$ pulse widths, UPI-452 command recovery times in relation to the DMA transfer timing and DMA controller transfer mode used. Table 5 shows the relationship between the iAPX-286, iAPX-186 and UPI-452 for various DMA as well as non-DMA byte by byte transfer modes versus processor frequencies.

Host processor speed vs wait states required with UPI-452 running at 16 MHz:

Table 5. Host UPI-452 Data Transfer Performance

Processor & Speed	Wait States: Back to Back $\overline{\text{READ}}$/$\overline{\text{WRITE}}$'s	DMA: Single Cycle	Two Cycle
iAPX-186* 8 MHz	0	N/A*	0
10 MHz	0	N/A*	0
12.5 MHz	1	N/A*	0
iAPX-286** 6 MHz	0	0	0
8 MHz	1	1	0
10 MHz	2	2	0

NOTES:
* iAPX 186 On-chip DMA processor is two cycle operation only.
** iAPX 286 assumes 82258 ADMA (or other DMA) running 286 bus cycles at 286 clock rate.

In this application note system example, shown in Figure 1, DMA operation is assumed to be two bus cycle I/O to memory or memory to I/O. Two cycle DMA consists of a fetch bus cycle from the source and a store bus cycle to the destination. The data is stored in the DMA controller's registers before being sent to the destination. Single cycle DMA transfers involve a simultaneous fetch from the source and store to the destination. As the most common method of I/O-memory DMA operation, two cycle DMA transfers are the focus of this application note analysis. Equation 2 illustrates a calculation of the overall transfer rate between the FIFO buffer and external Host for a maximum FIFO size transfer. The equation does not account for the latency of initiating the DMA transfer.

Equation 2. Host FIFO DMA Transfer Rate—Input or Output Channel

2 Cycle DMA Transfer-I/O (UPI-452) to System Memory
= FIFO channel size* (DMA $\overline{\text{READ}}$/$\overline{\text{WRITE}}$ FIFO time + DMA $\overline{\text{WRITE}}$/$\overline{\text{READ}}$ Memory Time)
= 128 bytes* (200 ns + 200 ns)
= 51.2 μs
= 256 bus cycles*

NOTES:
*10 MHz iAPX 286, 200 ns bus cycles.

The UPI-452 design is optimized for high speed DMA transfers between the Host and the FIFO buffer. The

UPI-452 internal FIFO buffer control logic provides the necessary synchronization of the external Host event and the internal CPU machine cycle during UPI-452 $\overline{RD}/\overline{WR}$ accesses. This internal synchronization is addressed by the TCC AC specification of the UPI-452 shown in Figure 6. TCC is the time from the leading or trailing edge of a UPI-452 $\overline{RD}/\overline{WR}$ to the same edge of the next UPI-452 $\overline{RD}/\overline{WR}$. The TCC time is effectively another way of measuring the system bus cycle time with reference to UPI-452 accesses.

In the iAPX-286 10 MHz system depicted in this application note the bus cycle time is 200 ns. Alternate cycle accesses of the UPI-452 during two cycle DMA operation yields a TCC time of 400 ns which is more than the TCC minimum time of 375 ns. Back to back Host UPI-452 $\overline{READ}/\overline{WRITE}$ accesses may require wait states as shown in Table 5. The difference between 10 MHz iAPX-186 and 10 MHz iAPX 286 required wait states is due to the number of clock cycles in the respective bus cycle timings. The four clocks in a 10 MHz iAPX 186 bus cycle means a minimum TCC time of 400 ns versus 200 ns for a 10 MHz iAPX 286 with two clock cycle zero wait state bus cycle.

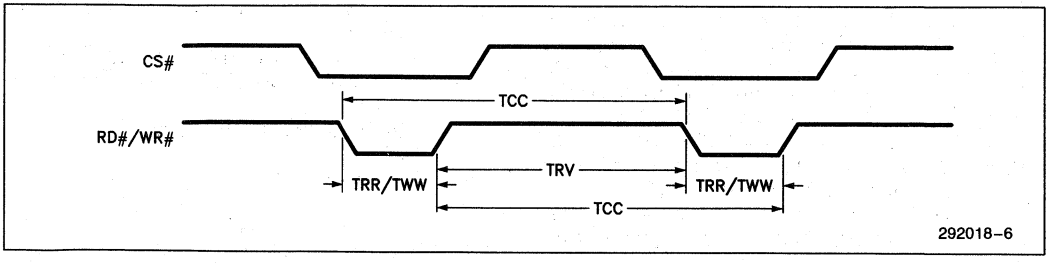
DMA handshaking between the Host DMA controller and the UPI-452 is supported by three pins on the UPI-452; DRQIN/INTRQIN, DRQOUT/INTRQOUT and $\overline{DACK}$. The DRQIN/INTRQIN and DRQOUT/INTRQOUT outputs are two multiplexed DMA or interrupt request pins. The function of these pins is controlled by MODE SFR bit 6 (MD6). DRQIN and DRQOUT provide a direct interface to the Host system DMA controller (see Figure 1). In response to a DRQIN or DRQOUT request, the Host DMA controller initiates control of the system bus using HLD/HLDA. The FIFO Input or Output channel transfer is accomplished with a minimum of Host overhead and system bus bandwidth.

The third handshake signal pin is $\overline{DACK}$ which is used as a chip select during DMA data transfers. The UPI-452 Host $\overline{READ}$ and $\overline{WRITE}$ input signals select the respective Input and Output FIFO channel during DMA transfers. The $\overline{CS}$ and address lines provide DMA acknowledge for processors with onboard DMA controllers which do not generate a $\overline{DACK}$ signal.

The iAPX 286 Block I/O Instructions provide an alternative to two cycle DMA data transfers with approximately the same data rate. The String Input and Output instructions (INS & OUTS) when combined with the Repeat (REP) prefix, modifies INS and OUTS to provide a means of transferring blocks of data between I/O and Memory. The data transfer rate using REP INS/OUTS instructions is calculated in the same way as two cycle DMA transfer times. Each $\overline{READ}$ or $\overline{WRITE}$ would be 200 ns in a 10 MHz iAPX 286 system. The maximum transfer rate possible is 2.5 MBytes/second. The Block I/O FIFO data transfer calculation is the same as that shown in Equation 2 for two cycle DMA data transfers including TCC timing effects.

FIFO Data Structure and Host DMA

During a Host DMA write to the FIFO, if a DSC is to be written, the DMA transfer is stopped, the DSC is written and the DMA restarted. During a Host DMA read from the FIFO, if a DSC is loaded into the I/O Buffer Latch the DMA request, DRQOUT, will be deactivated (see Figure 2 above). The Host Status (HSTAT) SFR Data Stream Command bit is set and the INTRQ interrupt output goes active, if enabled. The Host responds to the interrupt as described above.



Symbol	Description	Var. Osc.	@16 MHz
TCC	Command Cycle Time	6 * Tclcl	375 ns min
TRV	Command Recovery Time	75	75 ns min

Figure 6. UPI-452 Command Cycle Timing

Once INTRQ is deactivated and the DSC has been read by the Host, the DMA request, $\overline{DRQOUT}$, is reasserted by the UPI-452. The DMA request then remains active until the transfer is complete or another DSC is loaded into the I/O Buffer Latch.

An Immediate Command written by the internal CPU during a Host DMA FIFO transfer also causes the Host Status flag and INTRQ to go active if enabled. In this case the Immediate Command would not terminate the DMA transfer unless terminated by the Host. The INTRQ line remains active until the Host reads the Host Status (HSTAT) SFR to determine the source of the interrupt.

The net effect of a Data Stream Command (DSC) on DMA data transfer rates is to add an additional factor to the data transfer rate equation. This added factor is shown in Equation 3. An Immediate Command has the same effect on the data transfer rate if the Immediate Command interrupt is recognized by the Host during a DMA transfer. If the DMA transfer is completed before the Immediate Command interrupt is recognized, the effect on the DMA transfer rate depends on whether the block being transmitted is larger than the FIFO channel size. If the block is larger than the programmed FIFO channel size the transfer rate depends on whether the Immediate Command flag or interrupt is recognized between partial block transfers.

The FIFO configuration shown in Equation 3 is arbitrary since there is no way of predicting the size relative to when a DSC would be loaded into the I/O Buffer Latch. The Host DMA rate shown is for a UPI-452 (Memory Mapped or I/O) to 286 System Memory transfer as described earlier. The equations do not account for the latency of intiating the DMA transfer.

Equation 3. Minimum host FIFO DMA Transfer Rate Including Data Stream Command(s)

Minimum Host/FIFO DMA Transfer Rate w/ DSC
= FIFO size* Host DMA 2 cycle time transfer rate + iAPX 286 interrupt response time (Eq. #1)
= (32 bytes* (200 ns + 200 ns)) + 2.3 μs
= 15.1 μs
= 75.5 bus cycles (@10 MHz iAPX286, 200 ns bus cycle)

UPI-452 INTERNAL DMA PROCESSOR

The two identical internal DMA channels allow high speed data transfers from one UPI-452 writable memory space to another. The following UPI-452 memory spaces can be used with internal DMA channels:

Internal Data Memory (RAM)
External Data Memory (RAM)
Special Function Registers (SFR)

The FIFO can be accessed during internal DMA operations by specifying the FIFO IN (FIN) SFR as the DMA Source Address (SAR) or the FIFO OUT (FOUT) SFR as the Destination Address (DAR). Table 6 lists the four types of internal DMA transfers and their respective timings.

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Table 6. UPI-452 Internal DMA Controller Cycle Timings

Source	Destination	Machine Cycles**	@12 MHz	@16 MHz
Internal Data Mem. or SFR	Internal Data Mem. or SFR	1	1 μs	750 ns
Internal Data Mem. or SFR	External Data Mem.	1	1 μs	750 ns
External Data Mem.	Internal Data Mem. or SFR	1	1 μs	750 ns
*External Data Memory	External Data Memory	2	2 μs	1.5 μs

NOTES:
*External Data Memory DMA transfer applies to UPI-452 Local Bus only.
**MSC-51 Machine cycle = 12 clock cycles (TCLCL).

FIFO Data Structure and Internal DMA

The effect of Data Stream Commands and Immediate Commands on the internal DMA transfers is essentially the same as the effect on Host FIFO DMA transfers. Recognition also depends upon the programmed DMA Mode, the interrupts enabled, and their priorities. The net internal effect is the same for each possible internal case. The time required to respond to the Immediate or Data Stream Command is a function of the instruction time required. This must be calculated by the user based on the instruction cycle time given in the MSC-51 Instruction Set description in the Intel Microcontroller Handbook.

It is important to note that the internal DMA processor modes and the internal FIFO logic work together to automatically manage internal DMA transfers as data moves into and out of the FIFO. The two most appropriate internal DMA processor modes for the FIFO are FIFO Demand Mode and FIFO Alternate Cycle Mode. In FIFO Demand Mode, once the correct Slave Control and DMA Mode bits are set, the internal Input FIFO channel DMA transfer occurs whenever the Slave Control Input FIFO Request for Service flag is set. The DMA transfer continues until the flag is cleared or when the Input FIFO Read Pointer SFR (IRPR) equals zero. If data continues to be entered by the Host, the internal DMA continues until an internal interrupt of higher priority, if enabled, interrupts the DMA transfer, the internal DMA byte count reaches zero or until the Input FIFO Read Pointer equals zero. A complete description of interrupts and DMA Modes can be found in the UPI-452 Data Sheet.

DMA Modes

The internal DMA processor has four modes of operation. Each DMA channel is software programmable to operate in either Block Mode or Demand Mode. Demand Mode may be further programmed to operate in Burst or Alternate Cycle Mode. Burst Mode causes the internal processor to halt its execution and dedicate its resources exclusively to the DMA transfer. Alternate Cycle Mode causes DMA cycles and instruction cycles to occur alternately. A detailed description of each DMA Mode can be found in the UPI-452 Data Sheet.

INTERFACE LATENCY

The interface latency is the time required to accommodate all of the overhead associated with an individual data transfer. Data transfer rates between the Host system and UPI-452 FIFO, with a block size less than or equal to the programmed FIFO channel size, are calculated using the Host system DMA rate. (see Host DMA description above). In this case, the entire block could be transferred in one operation. The total latency is the time required to accomplish the block DMA transfer, the interrupt response or poll of the Host Status SFR response time, and the time required to initate the Host DMA processor.

A DMA transfer between the Host and UPI-452 FIFO with a block size greater than the programmed FIFO channel size introduces additional overhead. This additional overhead is from three sources; first, is the time to actually perform the DMA transfer. Second, the overhead of initializing the DMA processor, third, the handshaking between each FIFO block required to transfer the entire data block. This could be time to wait for the FIFO to be emptied and/or the interrupt response time to restart the DMA transfer of the next portion of the block. A fourth component may also be the time required to respond to Underrun and Overrun FIFO Errors.

Table 7 shows six typical FIFO Input/Output channel sizes and the Host DMA transfers times for each. The timings shown reflect a 10 MHz system bus two cycle I/O to Memory DMA transfer rate of 2.5 MBytes/second as shown in Equation 1. The times given would be the same for iAPX 286 I/O block move instructions REP INS and REP OUTS as described earlier.

Table 7. Host DMA FIFO Data Transfer Times

FIFO Size:	32	43	64	85	96	128	bytes
Full or Empty	1/4	1/3	1/2	2/3	3/4	Full or Empty	
Time	12.8	17.2	25.6	34.0	38.4	51.2	μs

Table 8 shows six typical FIFO Input/Output channel sizes and the internal DMA processor data transfers times for each. The timings shown are for a UPI-452 single cycle Burst Mode transfer at 16 MHz or 750 ns per machine cycle in or out of the FIFO channels. The

machine cycle time is that of the MSC-51 CPU; 6 states, 2 XTAL2 clock cycles each or 12 clock cycles per machine cycle. Details on the MSC-51 machine cycle timings and operation may be found in the Intel Microcontroller Handbook.

Table 8. UPI-452 Internal DMA FIFO Data Transfer Times

FIFO Size:	32	43	64	85	96	128	bytes
Full or Empty	1/4	1/3	1/2	2/3	3/4	Full or Empty	
Time	24.0	32.3	48.0	64.6	72.0	96.0	μs

A larger than programmed FIFO channel size data block internal DMA transfer requires internal arbitration. The UPI-452 provides a variety of features which support arbitration between the two internal DMA channels and the FIFO. An example is the internal DMA processor FIFO Demand Mode described above. FIFO Demand Mode DMA transfers occur continuously until the Slave Status Request for Service Flag is deactivated. Demand Mode is especially useful for continuous data transfers requiring immediate attention. FIFO Alternate Cycle Mode provides for interleaving DMA transfers and instruction cycles to achieve a maximum of software flexibility. Both internal DMA channels can be used simultaneously to provide continuous transfer for both Input and Output FIFO channels.

Byte by byte transfers between the FIFO and internal CPU timing is a function of the specific instruction cycle time. Of the 111 MCS-51 instructions, 64 require 12 clock cycles, 45 require 24 clock cycles and 2 require 48 clock cycles. Most instructions involving SFRs are 24 clock cycles except accumulator (for example, MOV direct, A) or logical operations (ANL direct, A). Typical instruction and their timings are shown in Table 9.

Oscillator Period: @ 12 MHz = 83.3 ns
@ 16 MHz = 62.5 ns

Table 9. Typical Instruction Cycle Timings

Instruction	Oscillator Periods	@12 MHz	@16 MHz
MOV direct†, A	12	1 μs	750 ns
MOV direct, direct	24	2 μs	1.5 μs

NOTE:
† Direct = 8-bit internal data locations address. This could be an Internal Data RAM location (0–255) or a SFR [i.e., I/O port, control register, etc.]

Byte by byte FIFO data transfers introduce an additional overhead factor not found in internal DMA operations. This factor is the FIFO block size to be transferred; the number of empty locations in the Output channel, or the number of bytes in the Input FIFO channel. As described above in the FIFO Data Structure section, the block size would have to be determined by reading the channel read and write pointer and calculating the space available. Another alternative uses the FIFO Overrun and Underrun Error flags to manage the transfers by accepting error flags. In either case the instructions needed have a significant impact on the internal FIFO data transfer rate latency equation.

A typical effective internal FIFO channel transfer rate using internal DMA is shown in Equation 4. Equation 5 shows the latency using byte by byte transfers with an arbitrary factor added for internal CPU block size calculation. These two equations contrast the effective transfer rates when using internal DMA versus individual instructions to transfer 128 bytes. The effective transfer rate is approximately four times as fast using DMA versus using individual instructions (96 μs with DMA versus 492 μs non-DMA).

Equation 4. Effective Internal FIFO Transfer Time Using Internal DMA

Effective Internal FIFO Transfer Rate with DMA
= FIFO channel size * Internal DMA Burst Mode Single Cycle DMA Time
= 128 Bytes * 750 ns
= 96 μs

Equation 5. Effective FIFO Transfer Time Using Individual Instructions

Effective Internal FIFO Transfer Rate without DMA
= FIFO channel size * Instruction Cycle Time + Block size calculation Time
= 128 Bytes * (24 oscillator periods @ 16 MHz) + 20 instructions (24 oscillator period each @ 16 MHz)
= 128 * 1.5 μs + 300 μs
= 492 μs

FIFO DMA FREEZE MODE INTERFACE

FIFO DMA Freeze Mode provides a means of locking the Host out of the FIFO Input and Output channels. FIFO DMA Freeze Mode can be invoked for a variety of reasons, for example, to reconfigure the UPI-452 Local Expansion Bus, or change the baud rate on the serial channel. The primary reason the FIFO DMA Freeze Mode is provided is to ensure that the Host does not read from or write to the FIFO while the FIFO interface is being altered. ONLY the internal CPU has the capability of altering the FIFO Special Function Registers, and these SFRs can ONLY be altered during FIFO DMA Freeze Mode. FIFO DMA Freeze Mode inhibits Host access of the FIFO while the internal CPU reconfigures the FIFO.

FIFO DMA Freeze Mode should not be arbitrarily invoked while the UPI-452 is in normal operation. Because the external CPU runs asynchronously to the internal CPU, invoking freeze mode without first properly resolving the FIFO Host interface may have serious consequences. Freeze Mode may be invoked only by the internal CPU.

The internal CPU invokes Freeze Mode by setting bit 3 of the Slave Control SFR (SC3). This automatically forces the Slave and Host Status SFR FIFO DMA Freeze Mode to In Progress (SSTAT SST5 = 0, HSTAT SFR HST1 = 1). INTRQ goes active, if enabled by MODE SFR bit 4, whenever FIFO DMA Freeze Mode is invoked to notify the Host. The Host reads the Host Status SFR to determine the source of the interrupt. INTRQ and the Slave and Host Status FIFO DMA Freeze Mode bits are reset by the Host $\overline{\text{READ}}$ of the Host Status SFR.

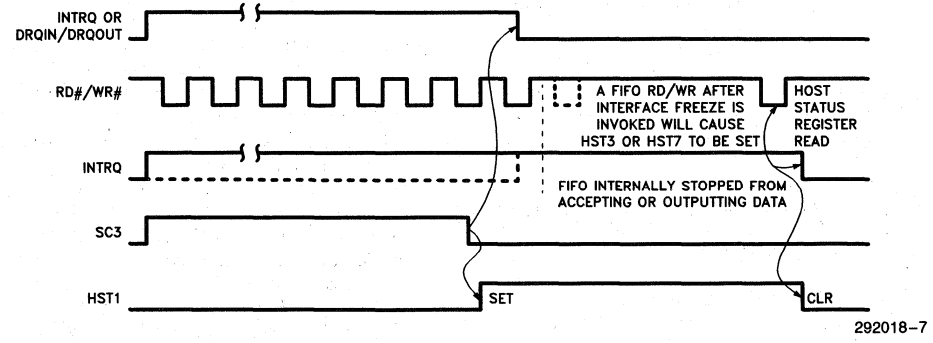
During FIFO DMA Freeze Mode the Host has access to the Host Status and Control SFRs. All other Host FIFO interface access is inhibited. Table 10 lists the FIFO DMA Freeze Mode status of all slave bus interface Special Function Registers. The internal DMA processor is disabled during FIFO DMA Freeze Mode and the internal CPU has write access to all of the FIFO control SFRs (Table 11).

If FIFO DMA Freeze Mode is invoked without stopping the host, only the last two bytes of data written into or read from the FIFO will be valid. The timing diagram for disabling the FIFO module to the external Host interface is illustrated in Figure 7. Due to this synchronization sequence, the UPI-452 might not go into FIFO DMA Freeze Mode immediately after the Slave Control SFR FIFO 7 DMA Freeze Mode bit (SC3) is set = 0. A special bit in the Slave Status SFR (SST5) is provided to indicate the status of the FIFO DMA Freeze Mode. The FIFO DMA Freeze Mode operations described in this section are only valid after SST5 is cleared.

Either the Host or internal CPU can request FIFO DMA Freeze Mode. The first step is to issue an Immediate Command indicating that FIFO DMA Freeze Mode will be invoked. Upon receiving the Immediate Command, the external CPU should complete servicing all pending interrupts and DMA requests, then send an Immediate Command back to the internal CPU acknowledging the FIFO DMA Freeze Mode request. After issuing the first Immediate Command, the internal CPU should not perform any action on the FIFO until FIFO DMA Freeze Mode is invoked. The handshaking is the same in reverse if the HOST CPU initiates FIFO DMA Freeze Mode.

After the slave bus interface is frozen, the internal CPU can perform the operations listed below on the FIFO Special Function Registers. These operations are allowed only during FIFO DMA Freeze Mode. Table 11 summarizes the characteristics of all the FIFO Special Function Registers during Normal and FIFO DMA Freeze Modes.

For FIFO Reconfiguration	1. Changing the Channel Boundary Pointer SFR.
	2. Changing the Input and Output Threshold SFR.
To Enhance the testability	3. Writing to the read and write pointers of the Input and Output FIFO's.
	4. Writing to and reading the Host Control SFRs.
	5. Controlling some bits of Host and Slave Status SFRs.
	6. Reading the Immediate Command Out SFR and Writing to the Immediate Command in SFR.



NOTE:
Timing Diagram of disabling of FIFO Module—External Host Interface.

Figure 7. Disabling FIFO to Host Slave Interface Timing Diagram

The sequence of events for invoking FIFO DMA Freeze Mode are listed in Figure 8.

1. Immediate Command to request FIFO DMA Freeze Mode (interrupt)
2. Host/internal CPU interrupt response/service
3. Host/internal CPU clear/service all pending interrupts and FIFO data
4. Internal CPU sets Slave Control (SLCON) FIFO DMA

   Freeze Mode bit = 0, FIFO DMA Freeze Mode, Host Status SFR FIFO DMA Freeze Mode Status bit = 1, INTRQ active (high)
5. Host $\overline{\text{READ}}$ Host Status SFR
6. Internal CPU reconfigures FIFO SFRs
7. Internal CPU resets Slave Control (SLCON) FIFO DMA

   Freeze Mode bit = 1, Normal Mode, Host Status FIFO DMA Freeze Mode Status bit = 0.
8. Internal CPU issues Immediate Command to Host indicating that FIFO DMA Freeze Mode is complete

   or

   Host polls Host Status SFR FIFO DMA Freeze Mode bit to determine end of reconfiguration

Figure 8. Sequence of Events to Invoke FIFO DMA Freeze Mode

EXAMPLE CONFIGURATION

An example of the time required to reconfigure the FIFO 180 degrees, for example from 128 bytes Input to 128 bytes Output, is shown in Figure 9. The example approximates the time based on several assumptions;

1. The FIFO Input channel is full-128 bytes of data
2. Output FIFO channel is empty-1 byte
3. No Data Stream Commands in the FIFO.
4. The Immediate Command interrupt is responded to immediately—highest priority—by Host and internal CPU.
5. Respective interrupt response times
   a. Host (Equation 3 above) = approximately 1.6 μs
   b. Internal CPU is 86 oscillator periods or approximately 5.38 μs worst case.

Event	Time
Immediate Command from Host to UPI-452 to request FIFO DMA Freeze Mode (iAPX286 $\overline{\text{WRITE}}$)	0.30 μs
Internal CPU interrupt response/service	5.38 μs
Internal CPU clears FIFO-128 bytes DMA	96.00 μs
Internal CPU sets Slave Control Freeze Mode bit	0.75 μs
Immediate Command to Host-Freeze Mode in progress Host Immediate Command interrupt response	2.3 μs
Internal CPU reconfigures FIFO SFRs	
Channel Boundary Pointer SFR	0.75 μs
Input Threshold SFR	0.75 μs
Output Threshold SFR	0.75 μs
Internal CPU resets Slave Control (SLCON) Freeze Mode bit = 1, Normal Mode, and automatically resets Host Status FIFO DMA Freeze Mode bit	2.3 μs
Internal CPU writes Immediate Command Out	0.75 μs
Host Immediate Command interrupt service	2.3 μs
Total Minimum Time to Reconfigure FIFO	112.33 μs

Figure 9. Sequence of Events to Invoke FIFO DMA Freeze Mode and Timings

Table 10. Slave Bus Interface Status During FIFO DMA Freezer Mode

Interface Pins;							Operation In Normal Mode	Status In Freeze Mode
$\overline{DACK}$	$\overline{CS}$	A2	A1	A0	$\overline{READ}$	$\overline{WRITE}$		
1	0	0	1	0	0	1	Read Host Status SFR	Operational
1	0	0	1	1	0	1	Read Host Control SFR	Operational
1	0	0	1	1	1	0	Write Host Control SFR	Disabled
1	0	0	0	0	0	1	Data or DMA data from Output Channel	Disabled
1	0	0	0	0	1	0	Data or DMA data to Input Channel	Disabled
1	0	0	0	1	0	1	Data Stream Command from Output Channel	Disabled
1	0	0	0	1	1	0	Data Stream Command to Input Channel	Disabled
1	0	1	0	0	0	1	Read Immediate Command Out from Output Channel	Disabled
1	0	1	0	0	1	0	Write Immediate Command In to Input Channel	Disabled
0	X	X	X	X	0	1	DMA Data from Output Channel	Disabled
0	X	X	X	X	1	0	DMA Data to Input Channel	Disabled

NOTE:
X = don't care

Table 11. FIFO SFR's Characteristics During FIFO DMA Freeze Mode

Label	Name	Normal Operation (SST5 = 1)	Freeze Mode Operation (SST5 = 0)
HCON	Host Control	Not Accessible	Read & Write
HSTAT	Host Status	Read Only	Read & Write
SLCON	Slave Control	Read & Write	Read & Write
SSTAT	Slave Status	Read Only	Read & Write
IEP	Interrupt Enable & Priority	Read & Write	Read & Write
MODE	Mode Register	Read & Write	Read & Write
IWPR	Input FIFO Write Pointer	Read Only	Read & Write
IRPR	Input FIFO Read Pointer	Read Only	Read & Write
OWPR	Output FIFO Write Pointer	Read Only	Read & Write
ORPR	Output FIFO Read Pointer	Read Only	Read & Write
CBP	Channel Boundary Pointer	Read Only	Read & Write
IMIN	Immediate Command In	Read Only	Read & Write
IMONT	Immediate Command Out	Read & Write	Read & Write
FIN	FIFO IN	Read Only	Read Only
CIN	COMMAND IN	Read Only	Read Only
FOUT	FIFO OUT	Read & Write	Read & Write
COUT	COMMAND OUT	Read & Write	Read & Write
ITHR	Input FIFO Threshold	Read Only	Read & Write
OTHR	Other FIFO Threshold	Read Only	Read & Write

APPLICATION NOTE

AP-283

September 1986

4

Flexibility in Frame Size with the 8044

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APPLICATIONS ENGINEER

Order Number: 292019-001

FLEXIBILITY IN FRAME SIZE WITH THE 8044

CONTENTS

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CONTENTS

1.0 INTRODUCTION

The 8044 is a serial communication microcontroller known as the RUPI (Remote Universal Peripheral Interface). It merges the popular 8051 8-bit microcontroller with an intelligent, high performance HDLC/SDLC serial communication controller called the Serial Interface Unit (SIU). The chip provides all features of the microcontroller and supports the Synchronous Data Link Control (SDLC) communications protocol.

There are two methods of operation relating to frame size:

1) Normal operation (limited frame size)
2) Expanded operation (unlimited frame size)

In Normal operation the internal 192 byte RAM is used as the receive and transmit buffer. In this operation, the chip supports data rates up to 2.4 Mbps externally clocked and 375 Kbps self-clocked. For frame sizes greater than 192 bytes, Expanded operation is required. In Expanded operation the external RAM, in conjunction with the internal RAM, is used as the transmit and receive buffer. In this operation, the chip supports data rates up to 500 Kbps externally clocked and 375 Kbps self-clocked. In both cases, the SIU handles many of the data link functions in hardware, and the chip can be configured in either Auto or Flexible mode.

The discussion that follows describes the operation of the chip and the behavior of the serial interface unit. Both Normal and Expanded operations will be further explained with extra emphasis on Expanded operation and its supporting software. Two examples of SDLC communication systems will also be covered, where the chip is used in Expanded operation. The discussion assumes that the reader is familiar with the 8044 data sheet and the SDLC communications protocol.

1.1 Normal Operation

In Normal operation the on-chip CPU and the SIU operate in parallel. The SIU handles the serial communication task while the CPU processes the contents of the on-chip transmit and receiver buffer, services interrupt routines, or performs the local real time processing tasks.

The 192 bytes of on-chip RAM serves as the interface buffer between the CPU and the SIU, used by both as a receive and transmit buffer. Some of the internal RAM space is used as general purpose registers (e.g. R0–R7). The remaining bytes may be divided into at least two sections: one section for the transmit buffer and the other section for the receive buffer. In some applications, the 192 byte internal RAM size imposes a limitation on the size of the information field of each frame and, consequently, achieves less than optimal information throughput.

Figure 1 illustrates the flow of data when internal RAM is used as the receive and transmit buffer. The on-chip CPU allocates a receive buffer in the internal RAM and enables the SIU. A receiving SDLC frame is processed by the SIU and the information bytes of the frame, if any, are stored in the internal RAM. Then, the SIU informs the CPU of the received bytes (Serial Channel interrupt). For transmission, the CPU loads the transmitting bytes into the internal RAM and enables the SIU. The SIU transmits the information bytes in SDLC format.

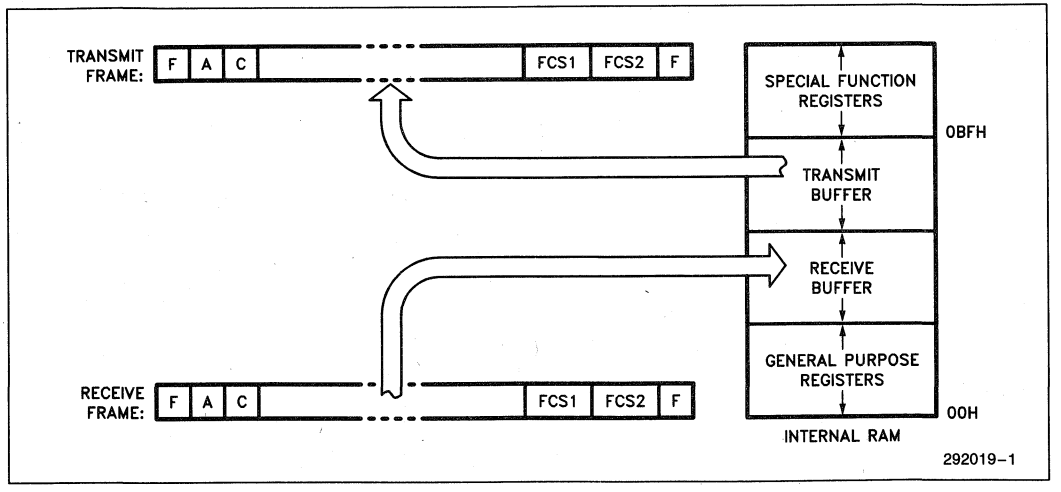

Figure 1. Transmission/Reception Data Flow Using Internal RAM

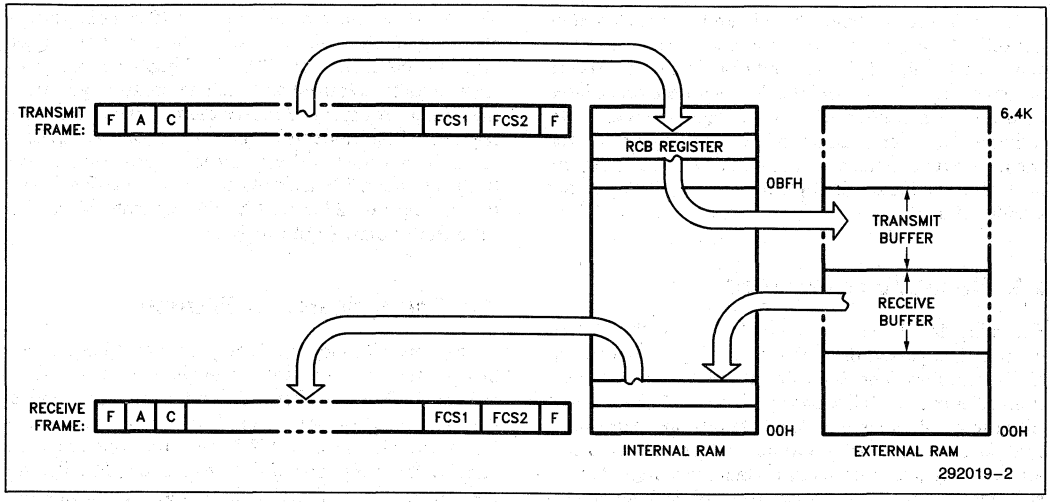

Figure 2. Transmission/Reception Data Flow Using External RAM

1.2 Expanded Operation

In Expanded operation the on-chip CPU monitors the state of the SIU, and moves data from/to external buffer to/from the internal RAM and registers while reception/transmission is taking place. If the CPU must service an interrupt during transmission or reception of a frame or transmit from internal RAM, the chip can shift to Normal operation.

There is a special function register called SIUST, the contents of which dictate the operation of the SIU. Also, at data rates lower than 2.4 Mbps, one section of the SIU, in fixed intervals during transmission and reception, is in the "standby" mode and performs no function. The above two characteristics make it possible to program the CPU to move data to/from external RAM and to force the SIU to repeat or skip some desired hardware tasks while transmission or reception is taking place. With these modifications, external RAM can be utilized as a transmit and receive buffer instead of the internal RAM.

Figure 2 graphically shows the flow of data when external RAM is used. For reception, the receiving bytes are loaded into the Receive Control Byte (RCB) register. Then, the data in RCB is moved to external RAM and the SIU is forced to load the next byte into the RCB register - The chip believes it is receiving a control byte continuously. For transmission, Information bytes (I-bytes) are loaded into a location in the internal RAM and the chip is forced to transmit the contents of this location repeatedly.

Discussion of expanded operation is continued in sections 4 and 5. First, however, sections 2 and 3 describe features of the 8044 which are necessary to further explain expanded operation.

2.0 THE SERIAL INTERFACE UNIT

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2.1 Hardware Description

The Serial Interface Unit (SIU) of the RUPI, shown in Figure 3, is divided functionally into a Bit Processor (BIP) and a Byte Processor (BYP), each sharing some common timing and control logic. The bit processor is the interface between the SIU bus and the serial port pins. It performs all functions necessary to transmit/receive a byte of data to/from the serial data line (shifting, NRZI coding, zero insertion/deletion, etc.). The byte processor manipulates bytes of data to perform message formatting, transmitting, and receiving functions. For example, moving bytes from/to the special function registers to/from the bit processor.

The byte processor is controlled by a Finite-State Machine (FSM). For every receiving/transmitting byte, the byte processor executes one state. It then jumps to the next state or repeats the same state. These states will be explained in section 3. The status of the FSM is kept in an 8-bit register called SIUST (SIU State Counter). This register is used to manipulate the behavior of the byte processor.

As the name implies, the bit processor processes data one bit at a time. The speed of the bit processor is a function of the serial channel data rate. When one byte of data is processed by the bit processor, a byte bounda-

ry is reached. Each time a byte boundary is detected in the serial data stream, a burst of clock cycles (16 CPU states) is generated for the byte processor to execute one state of the state machine. When all the procedures in the state are executed, a wait signal is asserted to terminate the burst, and the byte processor waits for the next byte boundary (standby mode). The lower the data rate, the longer the byte processor will stay in the standby mode.

2.2 Reception of Frames

Incoming data is NRZI decoded by the on-chip decoder. It is then passed through the zero insertion/deletion (ZID) circuitry. The ZID not only performs zero insertion/deletion, but also detects flags and Go Aheads (GA) in the data stream. The data bits are then loaded into the shift register (SR) which performs serial to parallel conversion. When 8 bits of data are collected in the shift register, the bit processor triggers the byte processor to process the byte, and it proceeds to load the next block of data into the shift register. The serial data is also shifted, through SR, to a 16-bit register called "FCS GEN/CHK" for CRC checking. The byte processor takes the received address and control bytes from the SR shift register and moves them to the appropriate registers. If the contents of the shift register is expected to be an information byte, the byte processor moves them through a 3-byte FIFO to the internal RAM at a starting location addressed by the contents of the Receive Buffer Start (RBS) register.

2.3 Transmission of Frames

In the transmit mode, the byte processor relinquishes a byte to the bit processor by moving it to a register called RB (RAM buffer). The bit processor converts the data to serial form through the shift register, performs zero bit insertion, NRZI encoding, and sends the data to the serial port for transmission. Finally, the contents of the FCS GEN/CHK and the closing flag are routed to the serial port for transmission.

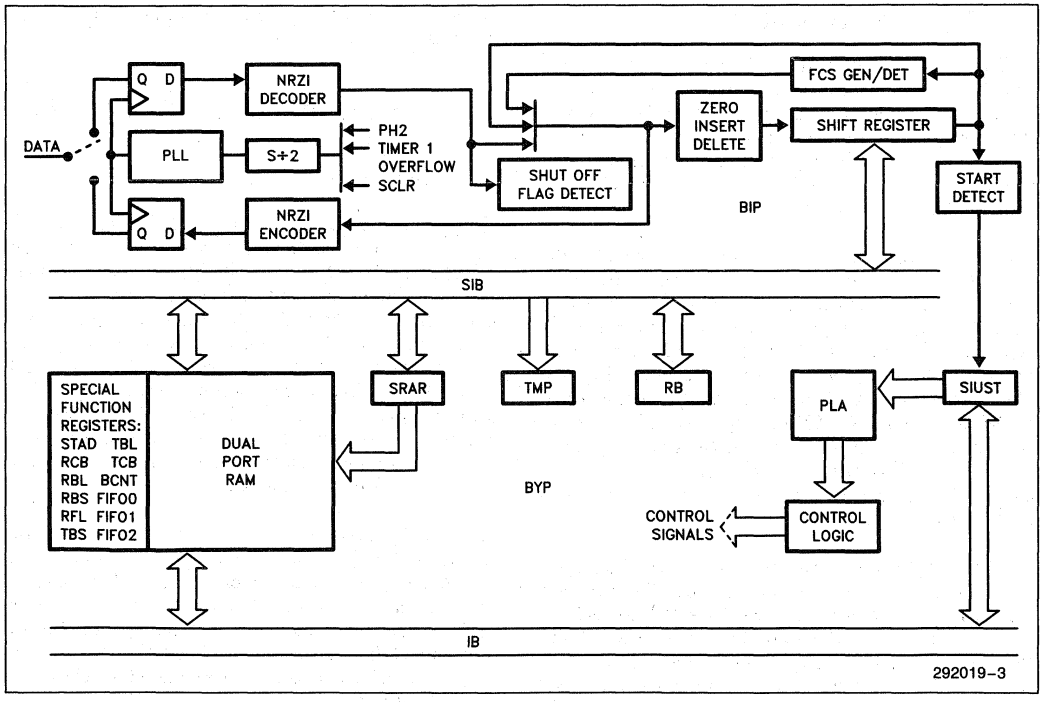


Figure 3. SIU Block Diagram

3.0 TRANSMIT AND RECEIVE STATES

The simplified receive and transmit state diagrams are shown in Figures 4 and 5, respectively. The numbers on the left of each state represent the contents of the SIUST register when the byte processor is in the standby mode, and the instructions on the right of each state represent the "state procedures" of that state. When the byte processor executes these procedures the least three significant bits of the SIUST register are being incremented while the other bits remain unchanged. The byte processor will jump from one state to another without going into the standby mode when a conditional jump procedure executed by the byte processor is true.

3.1 Receive State Sequence

When an opening flag (7EH) is detected by the bit processor, the byte processor is triggered to execute the procedures of the FLAG state. In the FLAG state, the byte processor loads the contents of the RBS register into the Special RAM (SRAR) register. SRAR is the pointer to the internal RAM. The byte processor decrements the contents of the Receive Buffer Length (RBL) register and loads them into the DMA Count (DCNT) register. The FCS GEN/CHK circuit is turned on to monitor the serial data stream for Frame Check Sequence functions as per SDLC specifications.

Assuming there is an address field in the frame, contents of the SIUST register will then be changed to 08H, causing the byte processor to jump to the ADDRESS state and wait (standby) for the next byte boundary. As soon as the bit processor moves the address byte into the SR shift register, a byte boundary is achieved and the byte processor is triggered to execute the procedures in the ADDRESS state.

In the ADDRESS state the received station address is compared to the contents of the STAD register. If there is no match, or the address is not the broadcast address (FFH), reception will be aborted (SIUST = 01H). Otherwise, the byte processor jumps to the CONTROL state (SIUST = 10H) and goes into standby mode.

The byte processor jumps to the CONTROL state if there exists a control field in the receiving frame. In this state the control byte is moved to the RCB register by the byte processor. Note that the only action taken in this state is that a received byte, processed by the bit processor, is moved to RCB. There is no other hardware task performed, and DCNT and SRAR are not affected in this state.

The next two states, PUSH-1 and PUSH-2, will be executed if Frame check sequence (NFCS = 0) option is selected. In these two states the first and second bytes of the information field are pushed into the 3-byte FIFO (FIFO0, FIFO1, FIFO2) and the Receive Field Length register (RFL) is set to zero. The 3-byte FIFO is used as a pipeline to move received bytes into the internal RAM. The FIFO prevents transfer of CRC bytes and the closing flag to the receive buffer (i.e., when the ending flag is received, the contents of FIFO are FLAG, FCS1, and FCS0.) The three byte FIFO is collapsed to one byte in No FCS mode.

In the DMA-LOOP state the byte processor pushes a byte from SR to FIFO0, moves the contents of FIFO2 to the internal RAM addressed by the contents of SRAR, increments the SRAR and RFL registers, and decrements the DCNT register. If more information bytes are expected, the byte processor repeats this state on the next byte boundaries until DMA Buffer End occurs. The DMA Buffer End occurs if SRAR reaches 0BFH (192 decimal), DCNT reaches zero, or the RBP bit of the STS register is set.

The BOV-LOOP state, the last state, is executed if there is a buffer overrun. Buffer overrun occurs when the number of information bytes received is larger than the length of the receive buffer (RFL > RBL). This state is executed until the closing flag is received.

At the end of reception, if the FCS option is used, the closing flag and the FCS bytes will remain in the 3-byte FIFO. The contents of the RCB register are used to update the NSNR (Receive/Send Count) register. The SIU updates the STS register and sets the serial interrupt.

3.2 Transmit State Sequence

Setting the RTS bit puts the SIU in the transmit mode. When the CTS pin goes active, the byte processor goes into START-XMIT state. In this state the opening flag is moved into the RAM Buffer (RB) register. The byte processor jumps to the next state and goes into the standby mode.

If the Pre-Frame Sync (PFS) option is selected, the PFS1 and PFS2 states will be executed to transmit the two Pre-Frame Sync bytes (00H or 55H). In these two states the contents of the Pre-Frame Sync generator are sent to the serial port while the Zero Insertion Circuit (ZID) is turned off. ZID is turned back on automatically on the next byte boundary.

If the PFS option is not chosen, the byte processor jumps to the FLAG state. In this state, the byte processor moves the contents of TBS into the SRAR register, decrements TBL and moves the contents into the DCNT register. The byte processor turns off the ZID and turns on FCS GEN/CHK. The contents of FCS GEN/CHK are not transmitted unless the NFCS bit is

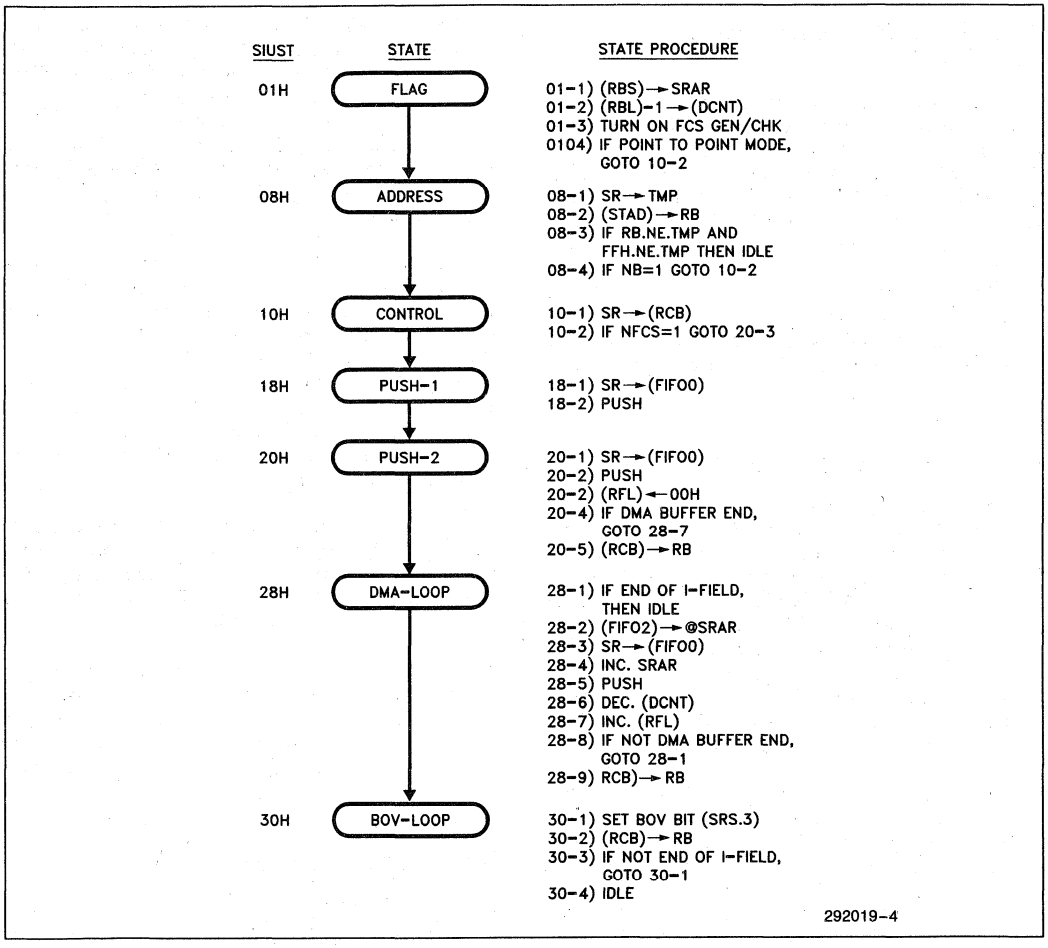


Figure 4. Receive State Diagram

set. If a frame with the address field is chosen, it moves the contents of the STAD register into the RB register for transmission. At the same time, the opening flag is being transmitted by the bit processor.

In the ADDRESS (SIUST = A0H) and CONTROL (SIUST = A8H) states, TCB and the first information byte are loaded into the RB register for transmission, respectively. Note that in the CONTROL state, none of the registers (e.g. DCNT, SRAR) are incremented, and ZID and FCS GEN/CHK are not turned on or off.

The procedures in the DMA-LOOP state are similar to the procedures of the DMA-LOOP in the receive state diagram. The SRAR register pointer to the internal RAM is incremented, and the DCNT register is decremented. The contents of DCNT reach zero when all the information bytes from the transmit buffer are transmitted. A byte from RAM is moved to the RB register for transmission. This state is executed on the following byte boundaries until all the information bytes are transmitted.

The FCS1 and the FCS2 states are executed to transmit the Frame Check Sequence bytes generated by the FCS generator, and the END-FLAG state is executed to transmit the closing flag.

The XMIT-ACTION and the ABORT-ACTION states are executed by the byte processor to synchronize the SIU with the CPU clock. The XMIT-ACTION or the ABORT-ACTION state is repeated until the byte processor status is updated. At the end, the STS and the TMOD registers are updated.

The two ABORT-SEQUENCE states (SIUST = E0H and SIUST = E8H) are executed only if transmission is aborted by the CPU (RTS or TBF bit of the STS register is cleared) or by the serial data link (CTS signal goes inactive or shut-off occurs in loop mode.)

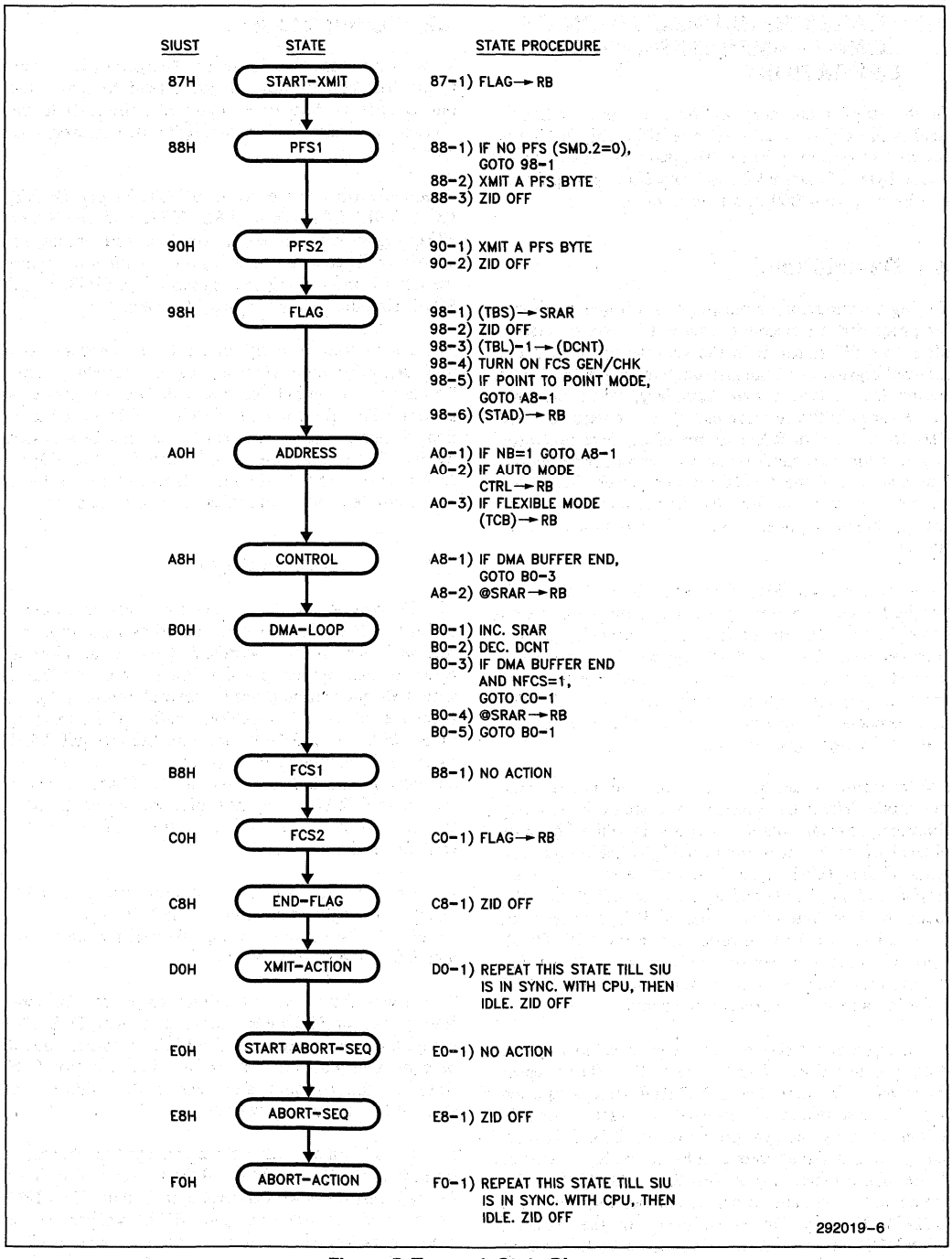


Figure 5. Transmit State Diagram

4.0 TRANSMISSION/RECEPTION OF LONG FRAMES (EXPANDED OPERATION)

In this application note, a frame whose information field is more than 192 bytes (size of on-chip RAM) is referred to as a long frame. The 8044 can access up to 64000 bytes of external RAM. Therefore, a long frame can have up to 64000 information bytes.

4.1 Description

During transmission or reception of a frame, while the bit processor is processing a byte, the byte processor, after 16 CPU states, is in the standby mode, and the internal registers and the internal bus are not used. The period between each byte boundary, when the byte processor is in the standby mode, can be used to move data from external RAM to one of the byte processor registers for transmission and vice versa for reception. The contents of the SIUST register, which dictate the state of the byte processor, can be monitored to recognize the beginning of each SDLC field and the consecutive byte boundaries.

By writing into the SIUST register, the byte processor can be forced to repeat or skip a specific state. As an example, the SIU can be forced to repeatedly put the received bytes into the RCB register. This is accomplished by writing E7H into the SIUST register when the byte processor goes into the standby mode. The byte processor, therefore, executes the CONTROL state at the next byte boundary.

For transmission, the byte processor is put in the transmit mode. When transmission of a frame is initiated, the user program calls a subroutine in which the state of the byte processor is monitored by checking the contents of the SIUST register. When the byte processor reaches a desired state and goes into standby, the CPU loads the first byte of the internal RAM buffer with data and moves the byte processor to the CONTROL state. The routine is repeated for every byte. At the end, the program returns from the subroutine, and the SIU finishes its task (see application examples).

For reception, a software routine is executed to move data to external RAM and to force the SIU to repeat the CONTROL state. The CONTROL state is repeated because, as shown in the receive state diagram, the only action taken by the byte processor, in the CONTROL state, is to move the contents of SR to the RCB register. None of the registers (e.g. SRAR and DCNT) are incremented. A similar comment justifies the use of the CONTROL state for transmission. In the transmit CONTROL state, contents of a location in the on-chip RAM addressed by TBS is moved to RB for transmission.

4.2 SIU Registers

To write into the SIUST register, the data must be complemented. For example, if you intend to write 18H into the SIUST register, you should write E7H to the register. The data read from SIUST is, however, true data (i.e. 18H).

Read and write accesses to the SIUST, STAD, DCNT, RCB, RBL, RFL, TCB, TBL, TBS, and the 3-byte FIFO registers are done on even and odd phases, respectively. Therefore, there is no bus contention when the CPU is monitoring the registers (e.g. SIUST), and SIU is simultaneously writing into them.

There is no need to change or reset the contents of any SIU register while transmitting or receiving long frames, unless the byte processor is forced to repeat a state in which the contents of these registers are modified. Note that the SRAR register can not be accessed by the CPU; therefore, avoid repeating the DMA-LOOP states. If SRAR increments to 192, the SIU will be interrupted and communication will be aborted.

4.3 Other Possibilities

The internal RAM, in conjunction with an external buffer (RAM or FIFOs), can be used as a transmit and receive buffer. In other words, Expanded and Normal operation can be used together. For example, if a frame with 300 Information bytes is received and only 255 of them are moved to an external buffer, the remaining bytes (45 bytes) will be loaded into the internal RAM by the SIU (assuming RBL is set to 45 or more). The contents of RFL indicate the number of bytes stored in the internal RAM. For transmission, the contents of the external buffer can be transmitted followed by the contents of the internal buffer.

If the internal RAM is not used, contents of the RBL register can be 0 and contents of the TBL register must be set to 1. The contents of the TBS register can be any location in the internal RAM.

The transmission and reception procedures for long frames with no FCS are similar to those with FCS. The exception is the contents of the SIUST register should be compared with different values since the two FCS states of the transmit and receive flow charts are skipped by the byte processor.

If a frame format with no control byte is chosen, a location in the RAM addressed by TBS should be used for transmission as with control byte format. The FIFO can be used for reception. The STAD register can be used for transmission if no zero insertion is required.

If the RUPI is used in Auto mode (see Section 5), it will still respond to RR, RNR, REJ, and Unnumbered Poll (UP) SDLC commands with RR or RNR automatically, without using any transmit routine. For example, if the on-chip CPU is busy performing some real time operations, the SIU can transmit an information frame from the internal buffer or transmit a supervisory frame without the help of CPU (Normal operation).

Maximum data rate using this feature is limited primarily by the number of instructions needed to be executed during the standby mode.

Transmission or reception of a frame can be timed out so that the CPU will not hang up in the transmit or receive procedures if a frame is aborted. Or, if the data rate allows enough time (standby time is long enough), the CPU can monitor the SIUST register for idle mode (SIUST = 01H).

It is also possible to transmit multiple opening or closing flags by forcing the byte processor to repeat the END-FLAG state.

4.4 Maximum Data Rate in Expanded Operation

Assuming there is no zero-insertion/deletion, the bit processor requires eight serial clock periods to process one block of data. The byte processor, running on the CPU clock, processes one byte of data in 16 CPU states (one state of the state diagrams). Each CPU state is two oscillator periods. At an oscillator frequency of 12 MHz, the CPU clock is 6 MHz, and 16 CPU states is 2.7 μs. At a 3 Mbit rate with no zero-insertion/deletion, there is exactly enough time to execute one state per byte (16 states at 6 MHz = 8 bits at 3M baud). In other words, the standby time is zero.

Figure 6 demonstrates portions of the timing relationship between the byte processor and the bit processor. In each state, the actions taken by the processors, plus the contents of the SIUST register, are shown. When the byte processor is running, the contents of SIUST are unknown. However, when it is in the standby mode, its contents are determinable.

The maximum data rate for transmitting and receiving long frames depends on the number of instructions needed to be executed during standby, and is propor-

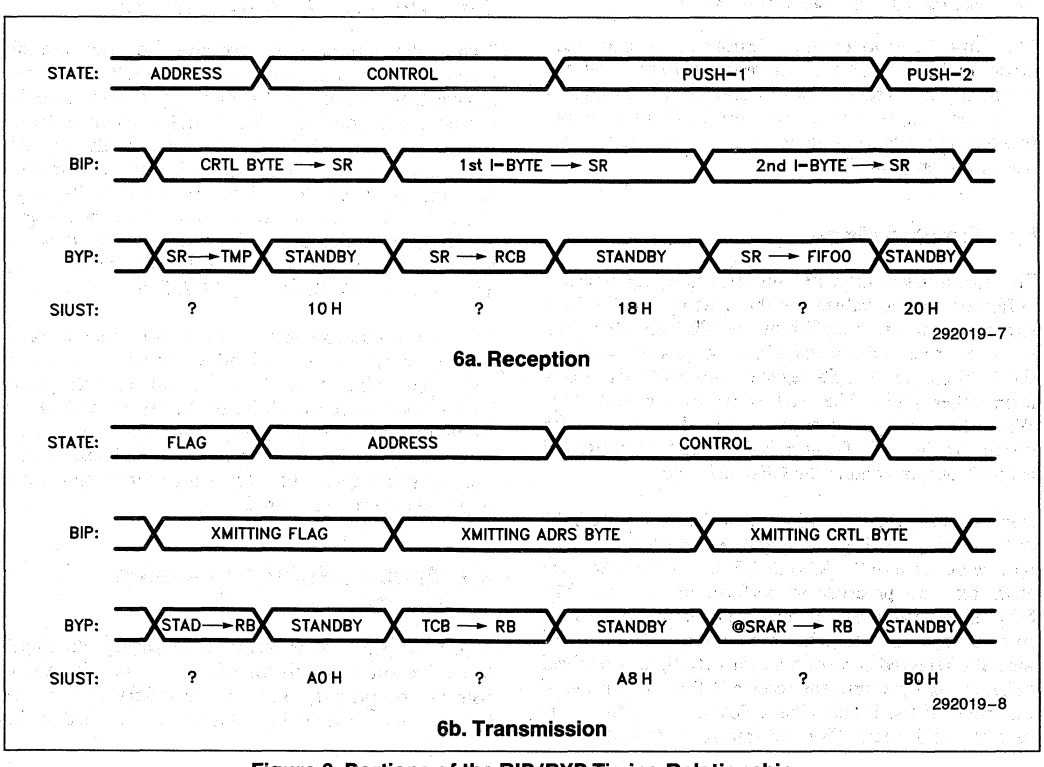


Figure 6. Portions of the BIP/BYP Timing Relationship

tional to the oscillator frequency. The time the byte processor is in the standby mode, waiting for the bit processor to deliver a processed byte, is at least equal to eight serial clock periods minus 16 CPU states. If an inserted zero is in the block of data, the bit processor will process the byte in nine serial clock periods.

The equation for theoretical maximum data rate is given as:

$$(2TCLCL) \times (16 \text{ states}) + (\#\text{ of instruction cycles}) \times (12TCLCL) = (8TDCY) \quad \text{Equation (1)}$$

Where: TCLCL is the oscillator period.
TDCY is the serial clock period.

At an oscillator frequency of 12 MHz and baud rate of 375 Kbps, about 18 instruction cycles can be executed when the byte processor is in the standby mode. At a 9600 baud rate, there is time to execute about 830 instruction cycles—plenty of time to service a long interrupt routine or perform bit-manipulation or arithmetic operations on the data while transmission or reception is taking place.

5.0 MODES OF OPERATION

The 8044 has two modes: Flexible mode and Auto mode. In Auto mode, the chip responds to many SDLC commands and keeps track of frame sequence numbering automatically without on-chip CPU intervention. In Flexible mode, communication tasks are under control of the on-chip CPU.

5.1 Flexible Mode

For transmission, the CPU allocates space for transmit buffer by storing values for the starting location and size of the transmit buffer in the TBS and the TBL registers. It loads the buffer with data, sets the TBF and the RTS bits in the STS register, and proceeds to perform other tasks. The SIU activates the RTS line. When the CTS signal goes active, the SIU transmits the frame. At the end of transmission, the SIU clears the RTS bit and interrupts the CPU (SI set).

For reception, the CPU allocates space for receive buffer by loading the beginning address and length of the receive buffer into the RBS and RBL registers, sets the RBE bit, and proceeds to perform other tasks. The SIU, upon detection of an opening flag, checks the next received byte. If it matches the station address, it will load the received control byte into RCB, and received information bytes into the receive buffer. At the end of reception, if the Frame Check Sequence (FCS) is correct, the SIU clears RBE and interrupts the CPU.

5.2 Auto Mode

In the Auto mode, the 8044 can only be a secondary station operating in the SDLC "Normal Response Mode". The 8044 in Auto mode does not transmit messages unless it is polled by the primary.

For transmission of an information frame, the CPU allocates space for the transmit buffer, loads the buffer with data, and sets the TBF bit. The SIU will transmit the frame when it receives a valid poll-frame. A frame whose poll bit of the control byte is set, is a poll-frame. The poll bit causes the RTS bit to be set. If TBF were not set, the SIU would respond with Receive Not Ready (RNR) SDLC command if RBP = 1, or with Receive Ready (RR) SDLC command if RBP = 0. After transmission RTS is cleared, and the CPU is not interrupted.

For reception, the procedure is the same as that of Flexible mode. In addition, the SIU sets the RTS bit if the received frame is a poll-frame (causing an automatic response) and increments the NS and NR counts accordingly.

6.0 APPLICATION EXAMPLES

Two application examples are given to provide additional details about the procedures used to transmit and receive long frames. In the first application example, procedures to construct receive and transmit software routines for the point-to-point frame format are described. The point-to-point frame has the information field and the FCS field enclosed between two flags (see Figure 7). In the second example software code is generated for reception and transmission of the standard SDLC frame. The SDLC frame has the pattern: flag, address, control, information, FCS, flag.

The first example focuses on the construction of transmit and receive code which allow the chip to transmit and receive long frames. The second example shows how to make more use of the 8044 features, such as the on-chip phase locked loop for clock recovery and automatic responses in the Auto mode to demonstrate the capability of the 8044 to achieve high throughput when Expanded operation is used.

6.1 Point-to-Point Application Example

A point-to-point communication system was developed to receive and transmit long frames. The system consists of one primary and one secondary station. Although multiple secondary stations can be used in this

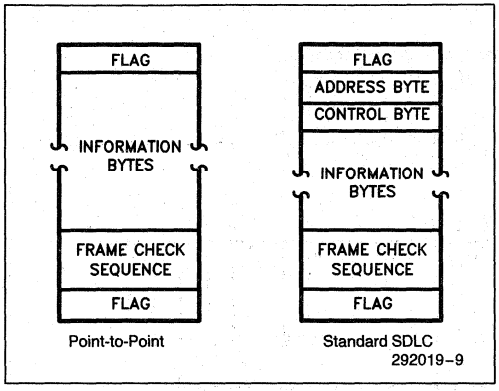


Figure 7. Point-to-Point and Standard SDLC Frame Formats

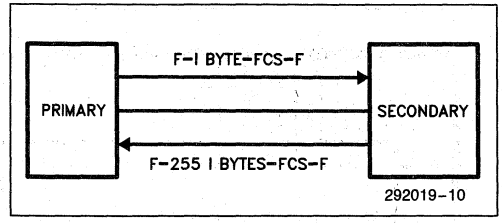


Figure 8. Secondary Responses to Primary Station Commands

system, one secondary is chosen to simplify the primary station's software and focus on the long frame software code. Both the primary and the secondary stations are in Flexible mode and the external clock option is used for the serial channel. The maximum data rate is 500 Kbps. The FCS bytes are generated and checked automatically by both stations.

6.1.1 POLLING SEQUENCE

The polling sequence, shown in Figure 8, takes place continuously between the primary and the secondary stations. The primary transmits a frame with one information byte to the secondary. The information byte is used by the secondary as an address byte. The secondary checks the received byte, and if the address matches, the secondary responds with a long frame. In this example, the information field of the frame is chosen to be 255 bytes long. Since there is only one secondary station, the address always matches. Upon successful reception of the long frame, the primary transmits another frame to the secondary station.

6.1.2 HARDWARE

The schematic of the secondary station is given in Figure 9. The circuit of the primary station is identical to the secondary station with the exception of pin 11 (DATA) being connected to pin 14 (T0). In the primary station, the 8044 is interrupted when activity is detected on the communication line by the on-chip timer (in counter mode). This is explained more later. The serial clock to both stations is supplied by a pulse generator. The output of the pulse generator (not shown in the diagram) is connected to pin 15 of the 8044s. Since the two stations are located near each other (less than 4 feet), line drivers are not used.

The central processor of each station is the 8044. The data link program is stored in a 2Kx8 EPROM (2732A), and a 2Kx8 static RAM (AM9128) is used as the external transmit and receive buffer. The RTS pin is connected to the CTS pin. For simplicity, the stations are assumed to be in the SDLC Normal Respond Mode after Hardware reset.

6.1.3 PRIMARY STATION SOFTWARE

The assembly code for the primary station software is listed in Appendix A. The primary software consists of the main routine, the SIU interrupt routine, and the receive interrupt routine. The receive interrupt routine is executed when a long frame is being received.

In the flow charts that follow, all actions taken by the SIU appear in squares, and actions taken by the on-chip CPU appear in spheres.

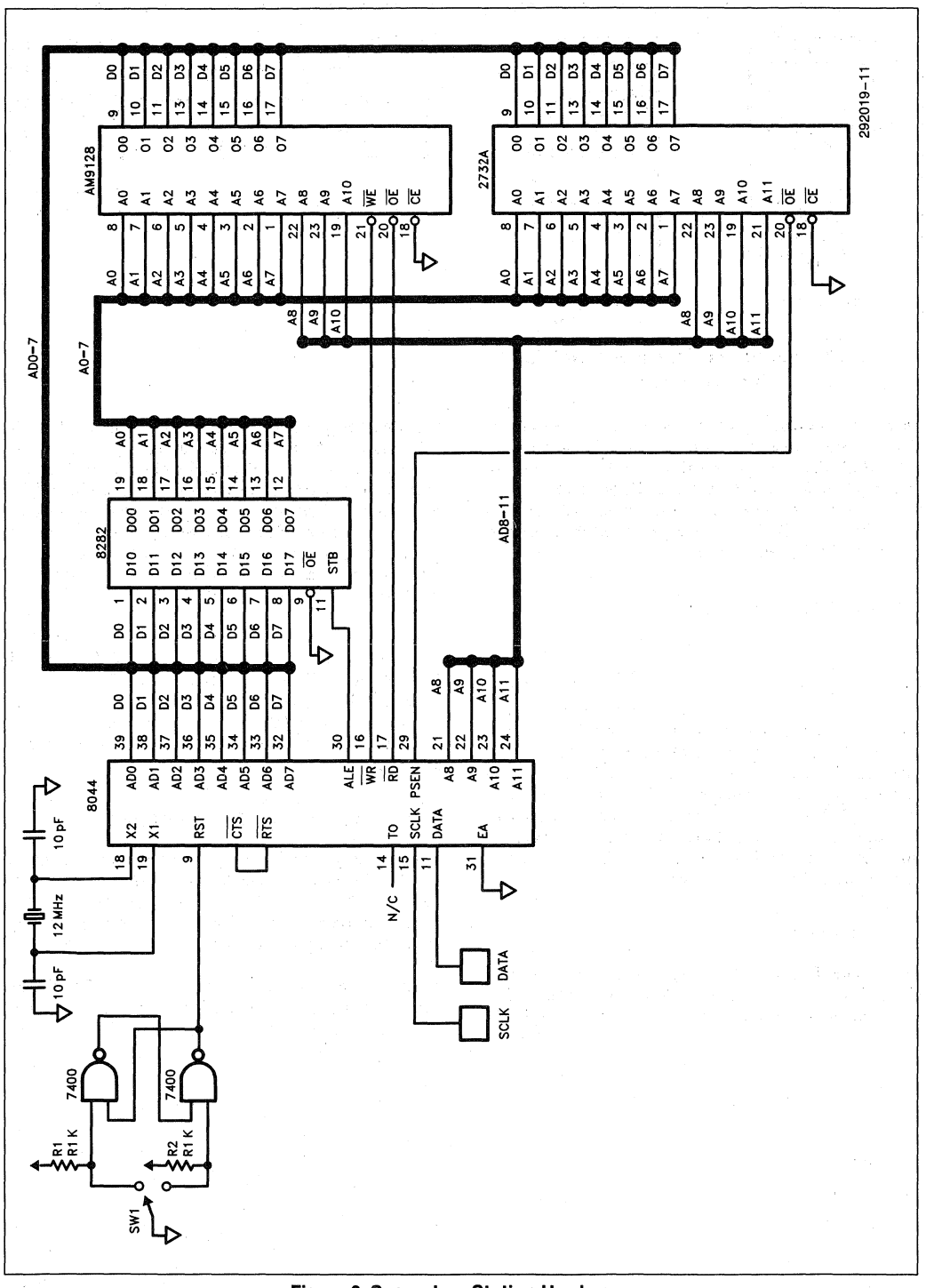


Figure 9. Secondary Station Hardware

Main Routine

First, the chip is initialized (see Figure 10). It is put in Flexible mode, externally clocked, and "Flag-Information Field-FCS-Flag" frame format. Pre-Frame Sync option (PFS = 1) and automatic Frame Check Sequence generation/detection (NFCS = 0) are selected. The on-chip transmit buffer starts at location 20H and the transmit buffer length is set to 1. This one byte buffer contains the address of the secondary station. There is no on-chip receive buffer since the long frame being received is moved to the external buffer. The RTS, TBF, and RBE bits are set simultaneously. Setting the RTS and TBF bits causes the SIU to transmit the contents of the transmit buffer.

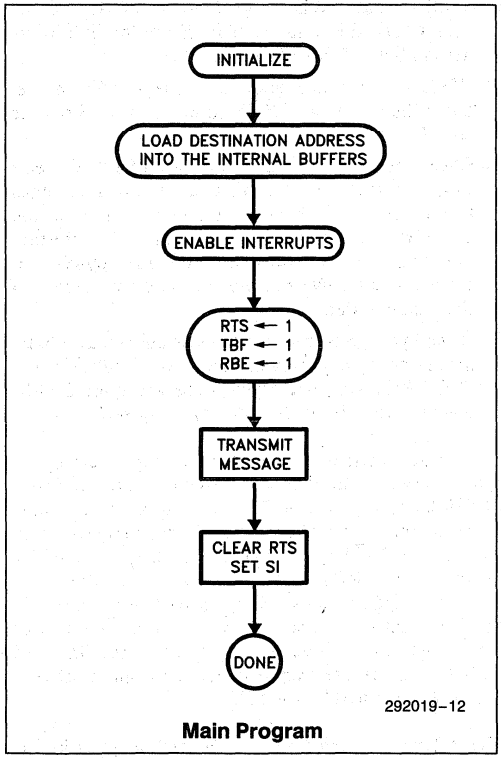


Figure 10. Primary Station Flow Charts

SIU Interrupt Routine

After transmission of the frame, the SIU interrupts the on-chip CPU (SI is set). In the SIU interrupt service routine, counter 0 is initialized and turned on (see Figure 11). The user program returns to perform other tasks. After reception of the long frame, the SIU interrupt routine is executed again. This time, RTS, TBF, and RBE are set for another round of information exchange between the two stations.

SIU never interrupts while reception or transmission is taking place. The SIU registers are updated and the SI is set (serial interrupt) after the closing flag has been received or transmitted. An SIU interrupt never occurs if the receive interrupt routine or the transmit subroutine is being executed.

Setting the RBE bit of the STS register puts the RUPI in the receive mode. However, the jump to the receive interrupt routine occurs only when a frame appears on the serial port. Incoming frames can be detected using the Pre-Frame Sync. option and one of the CPU timers in counter mode. The counter external pin (T0) is connected to the data line (pin 11 is tied to pin 14). Setting the PFS (Pre-Frame Sync.) bit will guarantee 16 transitions before the opening flag of a flame.

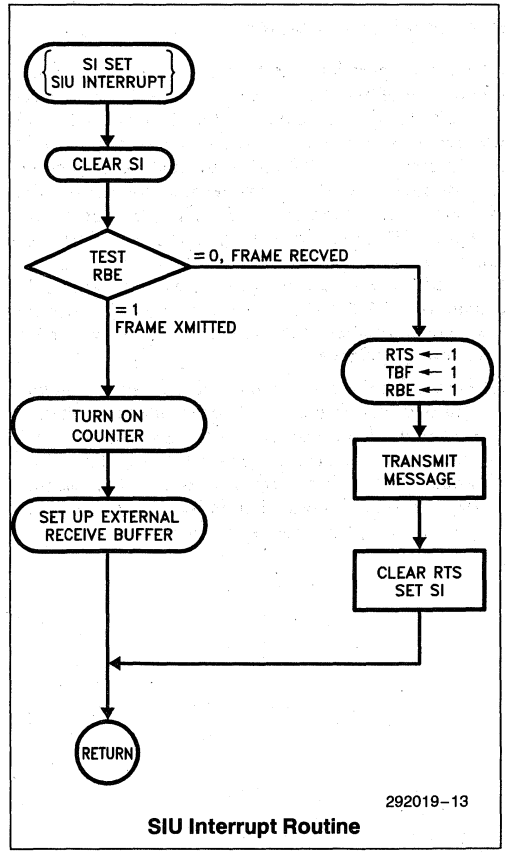


Figure 11. Primary Station Flow Charts

The counter registers are initialized such that the counter interrupt occurs before the opening flag of a frame. When the PFS transitions appear on the data line, the counter overflows and interrupts the CPU. The CPU program jumps to the timer interrupt service routine and executes the receive routine. In the receive routine, the received frame is processed, and the information bytes are moved to the external RAM. Note that the maximum count rate of the 8051 counter is $1/24$ of the oscillator frequency. At 12 MHz, the data rate is limited to 500 Kbps.

Another method to detect a frame on the data line and cause an interrupt is to use an external "Flag-Detect" circuit to interrupt the CPU. The "Flag Detect" circuit can be an 8-bit shift register plus some TTL chips. If this option is used, the RUPI must operate in externally clocked mode because the clock is needed to shift the incoming data into the shift register. With this option, the maximum data rate is not limited by the maximum count rate of the 8051 counter.

Receive Interrupt Routine

In Normal operation, the byte processor executes the procedures of the FLAG state, jumps to the CONTROL state without going into the standby mode, and executes 10–2 procedure of the state (see Figure 4). It then jumps to the PUSH-1 state and goes into the standby mode. At the following byte boundaries, the byte processor executes the PUSH-1, PUSH-2, and DMA-LOOP states, respectively. The receive interrupt routine as shown in the flow chart of Figure 12 and described below forces the byte processor to repeatedly execute the CONTROL state before the PUSH-1 state is executed. The following is the step by step procedure to receive long frames:

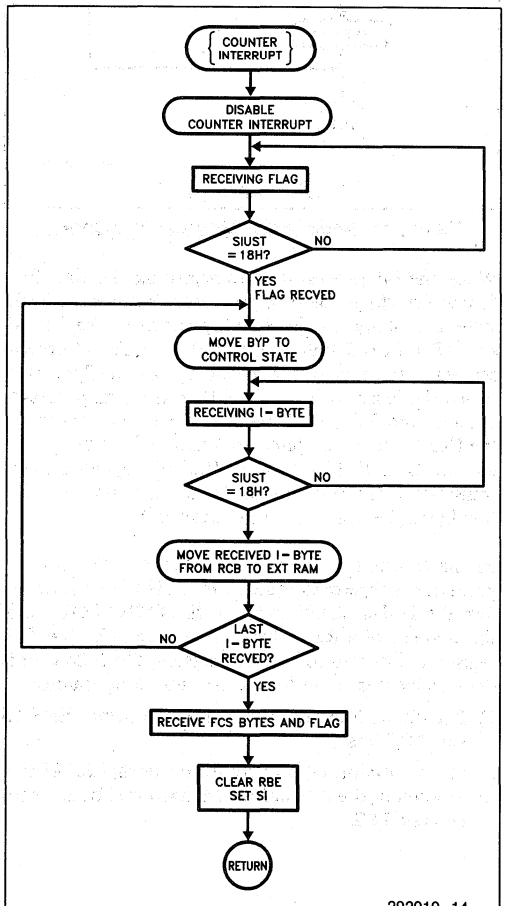
1) Turn off the CPU counter and save all the important registers. Jump to the receive interrupt routine, execution of the instructions to save registers, and initialization of the receive buffer pointer take place while the Pre-Frame Sync bytes and the opening flag are being received. This is about three data byte periods (48 CPU cycles at 500 Kbps).
2) Monitor the SIUST register for standby in the PUSH-1 state (SIUST = 18H). When the SIUST contents are 18H, the byte processor is waiting for the first information byte. The bit processor has already recognized the flag and is processing the first information byte.
3) In the standby mode, move the byte processor into the CONTROL state by writing "EFH" (complement of 10H) into the SIUST register. When the next byte boundary occurs, the bit processor has processed and moved a byte of data into the SR register. The byte processor moves the contents of SR into the RCB register, jumps to the PUSH-1 state (SIUST = 18H), and waits.
4) Monitor the SIUST register for standby in the PUSH-1 state. When the contents of SIUST becomes 18H, the contents of RCB are the first information byte of the information field.
5) While the byte processor is in the standby mode, move the contents of RCB to an external RAM or an I/O port.
6) Check for the end of the information field. The end can be detected by knowing the number of bytes transmitted, or by having a unique character at the end of information field. The length of the information field can be loaded into the first byte(s) received. The receive routine can load this byte into the loop counter.
7) If the byte received is not the last information byte, move the byte processor back to standby in the CONTROL state and repeat steps 4 through 6. Otherwise, return from the interrupt routine.

Upon returning from the receive interrupt routine, the byte processor automatically executes the PUSH-1, PUSH-2, and DMA-LOOP before it stops. This causes the remaining information bytes (if any) to be stored in the internal RAM at the starting location specified by the contents of RBS register. At the end of the cycle, the closing flag and the CRC bytes are left in the FIFO. The RFL register will be incremented by the number of bytes stored in the internal RAM. Then, the STS and NSNR registers are updated, and an appropriate response is generated by the SIU.

The software to perform the above task is given in Table 1. In this example, the number of instruction cycles executed during standby is 12 cycles.

Table 1. Codes for Long Frame Reception

```
Receive Codes                                                    Cycles
                    •       •
                    •       •
                    •       •
        REC:        CLR     TR0
                    MOV     A,#18H
        WAIT1:      CJNE    A,SIUST,WAIT1
        NEXTI:      MOV     SIUST,#0EFH ..........................2
                    MOV     A,#18H ...............................1
        WAIT2:      CJNE    A,SIUST,WAIT2 ........................2
                    MOV     A,RCB ................................1
                    MOVX    @DPTR,A ..............................2
                    INC     DPTR .................................2
                    DJNZ    R5,NEXTI .............................2
                    RETI
        END                                                        12 Cycles
```



Receive Interrupt Routine

Figure 12. Primary Station Flow Charts

6.1.4 SECONDARY STATION SOFTWARE

The assembly code for the secondary station software is given in Appendix A. The secondary station contains the transmit subroutine which is called for transmission of long frames.

4

Main Routine

As shown in the secondary station flow chart (Figure 13), the external transmit buffer (external RAM) is loaded with the information data (FFH, FEH, FDH, . . .) at starting location 200H. The internal transmit buffer (on chip RAM) starts at location 20H (TBS = 20H), and the transmit buffer length (TBL) is set to 1. The on-chip CPU, in the transmit subroutine, moves the information bytes from the external RAM to this one byte buffer for transmission. The receive buffer starts at location 10H and the receiver buffer length is 1. This buffer is used to buffer the frame transmitted by the primary. The received byte is used as an address byte.

The Secondary is configured like the Primary station. It is put in Flexible mode, externally clocked, Point-to-point frame format. The PFS bit is set to transmit two bytes before the first flag of a frame. The RBE bit is set to put the chip in receive mode. Upon reception of a valid frame, the SIU loads the received information byte into the on-chip receive buffer and interrupts the CPU.

SIU Interrupt Routine

In the serial interrupt routine, the RBE bit is checked (see Figure 14). Since RBE is clear, a frame has been received. The received Information byte is compared with the contents of the Station Address (STAD) register.

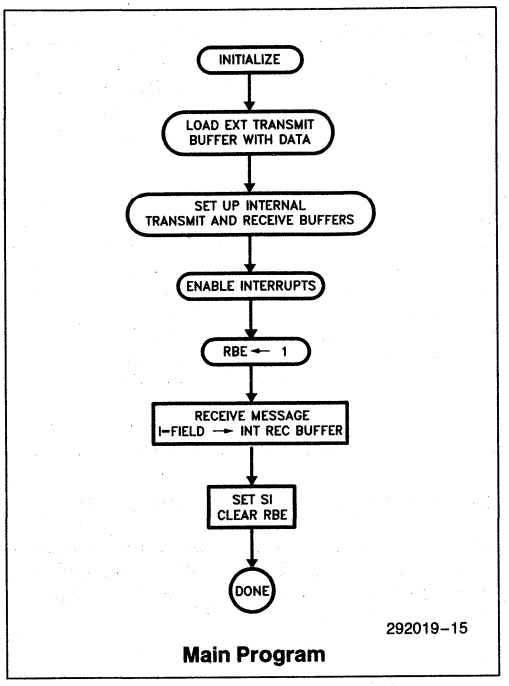


Figure 13. Secondary Station Flow Charts

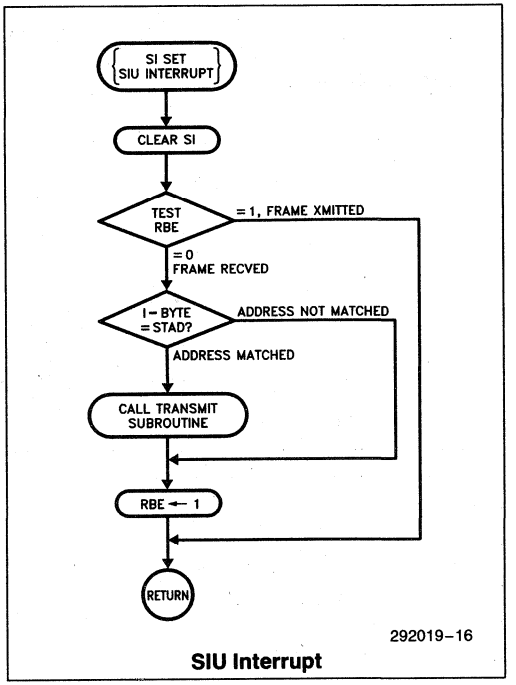


Figure 14. Secondary Station Flow Charts

If they match, the secondary will call the transmit subroutine to transmit the long frame. Upon returning from the transmit subroutine, the RBE bit is set, and program returns from the SIU interrupt. After transmission of the closing flag, SIU interrupt occurs again. In the interrupt routine, the RBE is checked. Since the RBE is set, the program returns from the SIU interrupt routine and waits until another long frame is received.

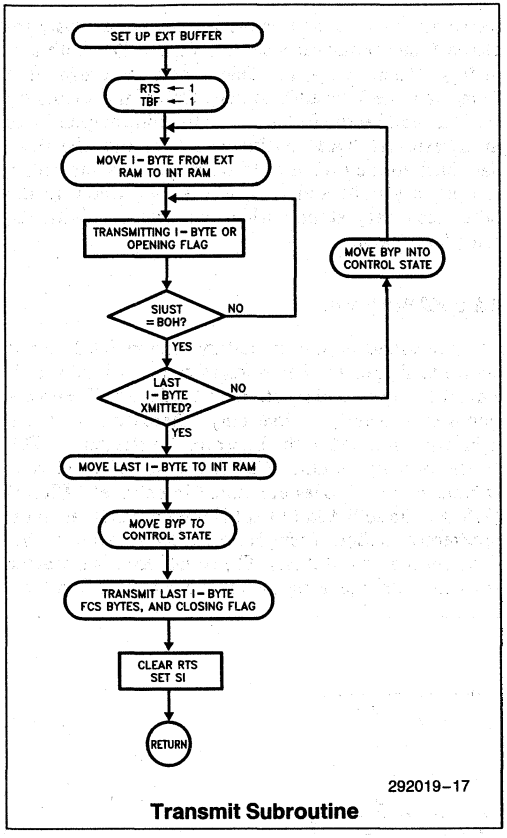
If the secondary were in Auto mode, the chip must be ready to execute the transmit routine upon reception of a poll-frame; otherwise, the chip automatically transmits the contents of the internal transmit buffer if the TBF bit is set, or transmits a supervisory command (RR or RNR) if TBF is clear.

Transmit Subroutine

In Normal operation the byte processor executes the START-TRANSMIT state and jumps to the PFS1 state. While the bit processor is transmitting some unwanted bits, the byte processor executes the PFS1 state and jumps to the standby mode in the PFS2 state. While the bit processor is transmitting the first Pre-Frame Sync byte, the byte processor executes the PFS2 state and jumps to the standby mode in the FLAG state. The FLAG state is executed when the bit processor begins to transmit the second Pre-Frame Sync byte. When the flag is being transmitted, the byte processor executes the 98-1, 98-2, 98-3, and 98-4 procedures of the FLAG state, and jumps to execute the A8-1 procedure of the CONTROL state. When the opening flag is transmitted, the contents of RB are the first information byte. (See transmit State diagram.)

In the transmit subroutine (see Figure 15), the byte processor is forced to repeat the CONTROL state before the DMA-LOOP state. In the CONTROL state, the contents of a RAM location addressed by the TBS register are moved to the RB register. The following is the step by step procedure to transmit long frames:

1) Put the chip in transmit mode by setting the RTS and TBF bits.
2) Move an information byte from external RAM to a location in the internal RAM addressed by the contents of TBS.



Transmit Subroutine

Figure 15. Secondary Station Flow Charts

3) Monitor the SIUST register for the standby mode in the DMA-LOOP state (SIUST = B0H). When SIUST is B0H, the opening flag has been transmitted, and the first information byte is being transmitted by the bit processor.
4) If there are more information bytes, move the byte processor back to the CONTROL state, and repeat steps 2 through 4. Otherwise, continue.
5) Move byte processor to the Standby mode in the CONTROL state (SIUST = A8H) and return from the subroutine.

The byte processor automatically executes the remaining states to send the FCS bytes and the closing flag. After the completion of transmission, SIU updates the STS and NSNR registers and interrupts the CPU.

If the contents of the TBL register were more than 1, the SIU transmits (TBL)−1 additional bytes from the internal RAM at starting address (TBS)+1 because it executes the DMA-LOOP state (TBL)−1 additional times. The byte processor should not be programmed to skip the DMA-LOOP state, because the transmission of FCS bytes is enabled in this state.

The maximum baud rate that can be used with these codes is calculated by adding the number of instruction cycles executed, during the standby mode, between each byte boundaries (see Table 2).

Using Equation 1, the maximum data rate, based on the transmit software, is 509 Kbps; However, the maximum count rate of the counter limits the data rate to 500 Kbps.

Table 2. Codes for Long Frame Transmission

```
Transmit Codes                                              Cycles
                    •       •
                    •       •
                    •       •
        TRAN:       MOV     DPTR,#200H
                    MOV     R5,#0FFH
                    SETB    TBF
                    SETB    RTS
        LOOP:       MOVX    A,@DPTR
                    MOV     @R1,A
                    MOV     A,#0B0H
        WAIT1:      CJNE    A,SIUST,WAIT1 ..................2
                    INC     DPTR ...........................2
                    MOVX    A,@DPTR ........................2
                    MOV     @R1,A ..........................1
                    DJNZ    R5,NEXTI .......................2
                    MOV     SIUST,#57H
                    RET
        NEXTI:      MOV     SIUST,#57H .....................2
                    MOV     A,#0B0H ........................1
                    JMP     WAIT1 ..........................1
        END
                                                           13 Cycles
```

6.2 Multidrop Application

Performance of long frame in addition to the features of the 8044 are described using a simple multidrop communication system in which three RUPIs, one as a master and the other two as secondary stations, transmit and receive long frames alternately (see Figure 16). All stations perform automatic zero bit insertion/deletion, NRZI decoding/encoding, Frame Check Sequence (FCS) generation/detection, and on-chip clock recovery at a data rate of 375 Kbps.

The primary and the secondary station's software code is given in Appendix B. These programs, for simplicity, assume only reception of information and supervisory frames. It is also assumed that the frames are received and transmitted in order. All stations use very similar transmit and receive routines. This code is written for standard SDLC frames (see Figure 7).

6.2.1 POLLING SEQUENCE

The primary station, in Flexible mode, transmits a long frame (for this example, 255 I-bytes), polls one of the secondary stations, and acknowledges a previously received frame simultaneously (see Figure 17). Both secondary stations, in Auto mode, detect the transmitted frame and check its address byte. One of the secondary stations receives the frame, stores the Information bytes in an external RAM buffer, and transmits the same data back to the primary. After reception of the frame, the primary polls and transmits a long frame to the other secondary station which will respond with the same long frame.

6.2.2 HARDWARE

The schematic of the secondary station hardware is shown in Figure 18. The primary station's hardware is similar to the secondary station's hardware. The exception is in secondary stations only, where the RTS signal is inverted and tied to the interrupt 0 input pin (INT0). In the primary station, RTS is tied to CTS. At each station, software codes are stored in external EPROM (2732A). Static RAM (2Kx8) is used as external transmit/receive buffer. There is no hardware handshaking done between the stations. The serial clock is extracted from the data line using the on-chip phase locked loop.

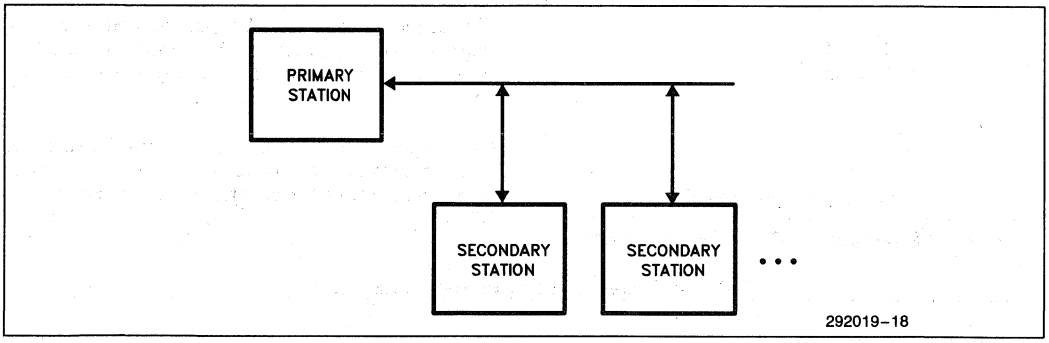


Figure 16. SDLC Multidrop Application Example

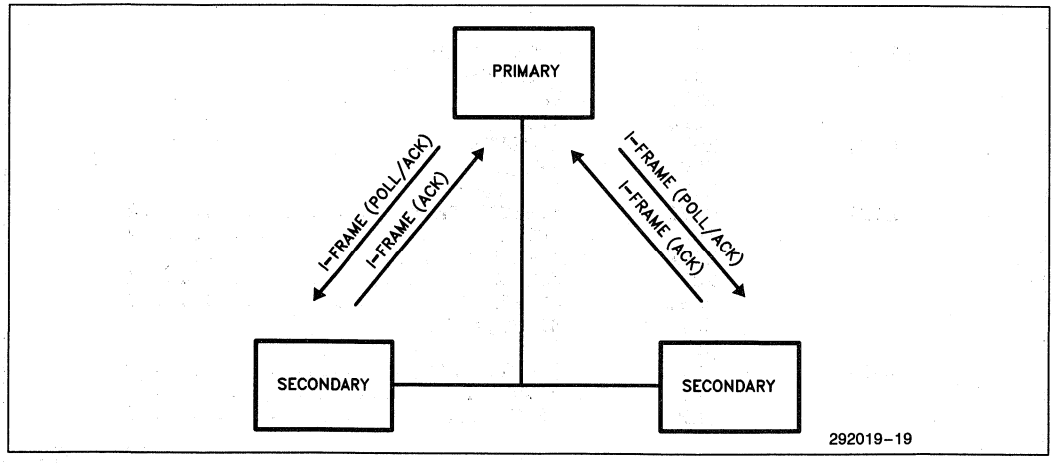


Figure 17. Polling Sequence Between the Primary and Secondary Stations

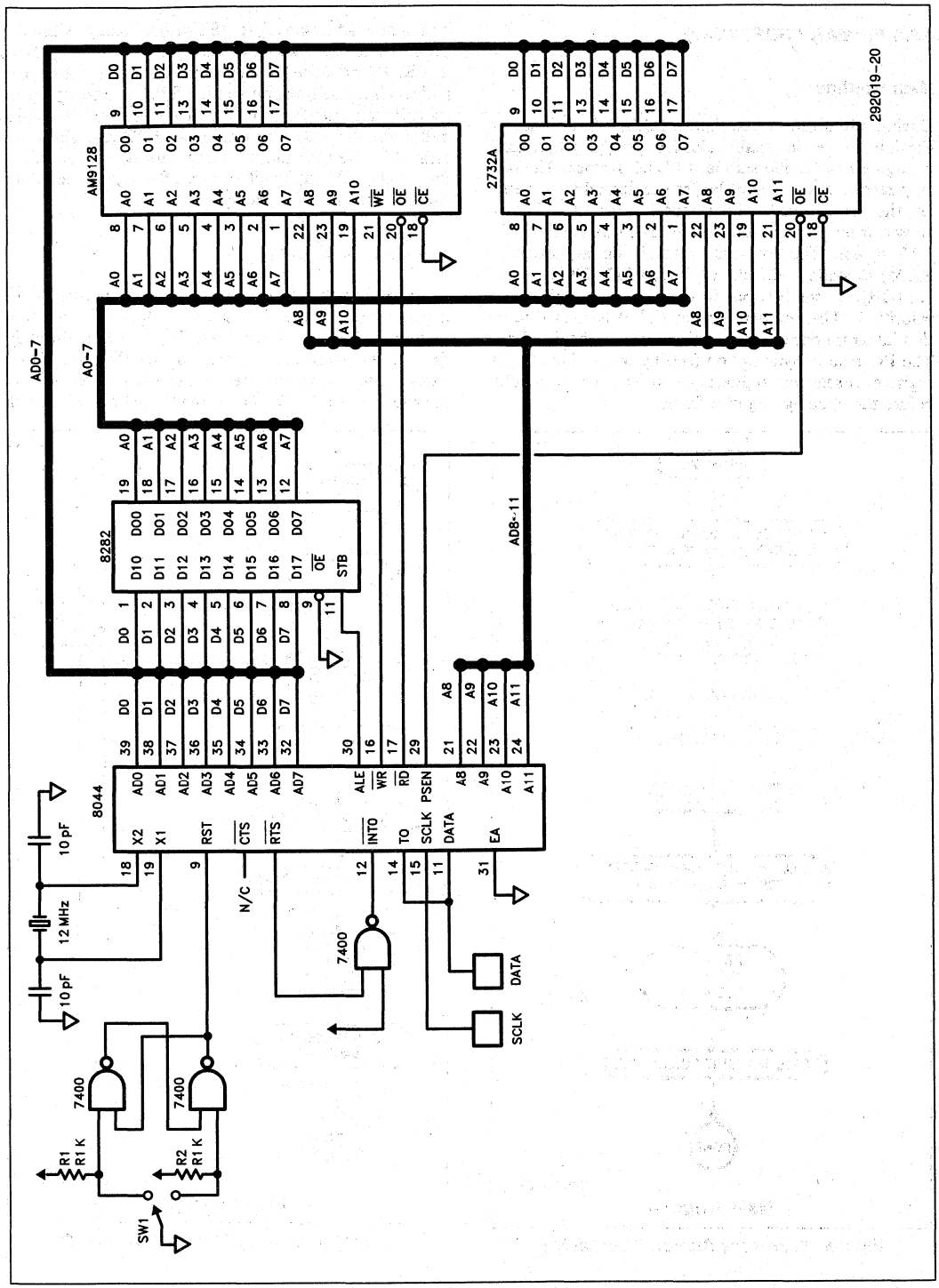


Figure 18. Secondary Station Hardware

6.2.3 PRIMARY SOFTWARE

Main Routine

During initialization (see Figure 19), the 8044 is set to Flexible mode, internally clocked at 375 Kbps, and configured to handle standard SDLC frames. The on-chip receive and transmit buffer starting addresses and lengths are selected. The external transmit buffer is chosen from physical location 200H to location 2FFH (255 bytes). The external transmit buffer (external RAM) is loaded with data (FFH, FEH, FDH, FCH, . . . 00H). Timer 0 is put in counter mode and set to priority 1. The counter register (TL0) is loaded such that interrupt occurs after 8 transitions on the data line. The Pre-Frame Sync option (setting bit 2 of the SMD register) is selected to guarantee at least 16 transitions before the opening flag of a frame.

The station address register (STAD) is loaded with address of one of the secondary stations. The RTS, TBF, and RBE bits of the STS register are simultaneously set and a call to the transmit routine follows. The transmit routine transmits the contents of the external transmit buffer. At the end of transmission, RTS and TBF are cleared by the SIU, and SIU interrupt occurs. In Flexible mode, SIU interrupt occurs after every transmission or reception of a frame.

SIU Interrupt Routine

In the SIU interrupt service routine (see Figure 20), SI is cleared and the RBE bit is checked. If RBE is set, a long frame has been transmitted. The first time through the SIU interrupt service routine, the RBE test indicates a long frame has been transmitted to one of the secondary stations. Therefore, the Counter is initialized

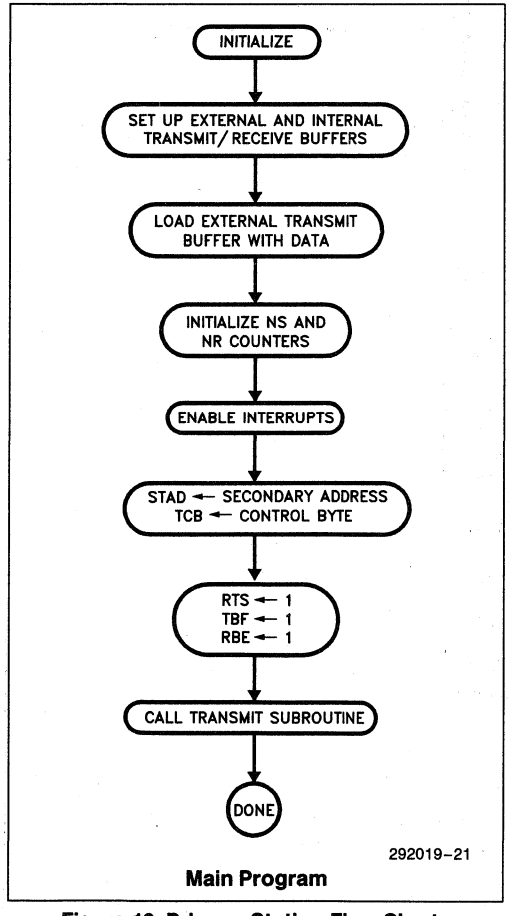


Figure 19. Primary Station Flow Charts

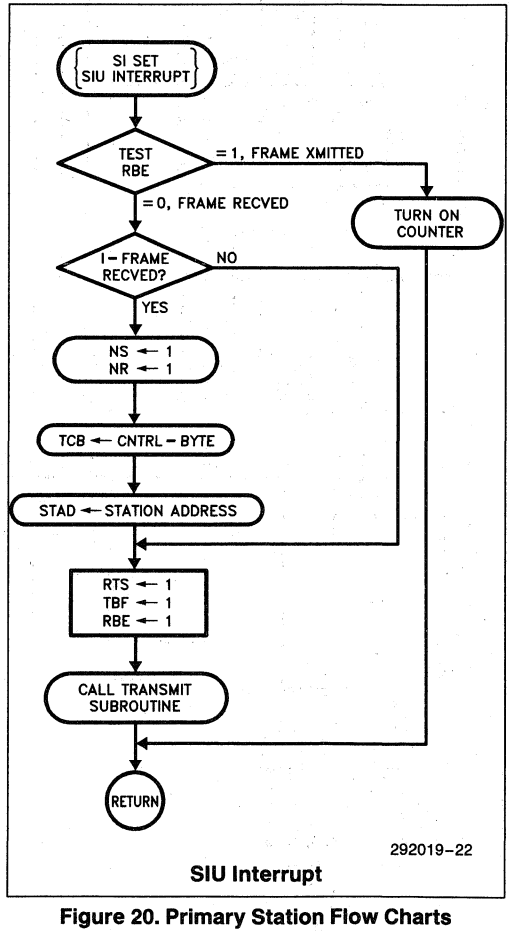


Figure 20. Primary Station Flow Charts

and turned on. The program returns from the interrupt routine before a frame appears on the communication channel.

When a frame appears on the communication line, counter interrupt occurs and the receive routine is executed to move the incoming bytes into the external RAM. After reception of the frame and return from the receive routine, SIU interrupt occurs again.

In the SIU interrupt routine, RBE is checked. Since the RBE bit is clear, a frame has been received. Therefore, the appropriate NS and NR counters are incremented and loaded into the TCB register (two pairs of internal RAM bytes keep track of NS and NR counts for the two secondary stations). Transmission of a frame to the next secondary station is enabled by setting the RTS and the TBF bits. The chip is also put in receive mode (RBE set), and a call to transmit routine is made. After transmission, SIU interrupt occurs again, and the process continues.

6.2.4 SECONDARY SOFTWARE

Main Routine

Both secondary stations have identical software (Appendix B). The only differences are the station addresses. Contents of the STAD register are 55H for one station and 44H for the other.

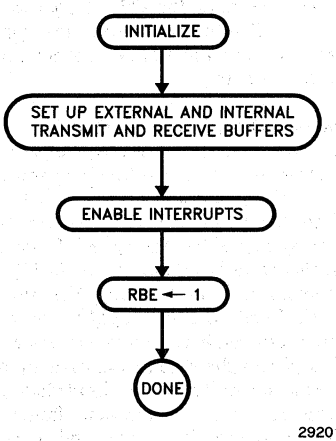


Figure 21. Secondary Station Flow Charts

During initialization, the chip is set to Auto mode, standard SDLC frame, and internally clocked at 375 Kbps (see Figure 21). Internal buffer registers: RBS, RBL, TBS, and TBL are initialized. The RBE bit is set and the counter 0 is turned on.

The secondary is configured to transmit an Information frame every time it is polled. The RTS pin is inverted and tied to INT1 pin. External interrupt 1 is enabled and set to interrupt on low to high transition of the RTS signal. This will cause an interrupt (EX1 set) after a frame is transmitted. In the interrupt routine the CTS pin is cleared to prevent any automatic response from the secondary. If the CTS pin were not disabled, the secondary station would respond with a supervisory frame (RNR) since the TBF is set to zero by the SIU due to the acknowledge. In the SIU interrupt routine, the CTS pin is cleared after the TBF bit is set. If this option is not used, the primary should acknowledge the previously received frame and poll for the next frame in two separate transmissions.

SIU Interrupt Routine

When a frame is received, counter 0 interrupt occurs and the receive routine is executed (see Figure 22). If the incoming frame is addressed to the station, the information bytes are stored in external RAM; Otherwise, the program returns from the receive routine to perform other tasks. At the end of the frame, SIU interrupt occurs. In Auto mode, SIU interrupt occurs whenever an Information frame or a supervisory frame is received. Transmission will not cause an interrupt. In the SIU interrupt service routine, the AM bit of the STS is checked.

If AM bit is set, the interrupt is due to a frame whose address did not match with the address of the station. In this case, NFCS, AM, and the BOV bits are cleared, the RBE bit is set, the counter 0 is initialized and turned on, and program returns from the interrupt routine.

If AM bit is not set, a valid frame has been received and stored in the external RAM. TBF bit is set, CTS pin is activated, counter 0 is disabled and a call to transmit routine is made which transmits the contents of external transmit buffer. This frame also acknowledges the reception of the previously received frame (NS and NR are automatically incremented). Upon return from the transmit routine RBE is set and counter 0 is turned on, thereby putting the chip in the receive mode for another round of data exchange with the primary.

Note that, if the second station is in receive mode, and the counter is enabled and turned on, the CPU will be interrupted each time a frame is on the communication channel. If the frame is not addressed to the secondary station, the chip enters the receive routine, executes only a few lines of code (address comparison) and returns to perform other tasks. This interrupt will not occupy the CPU for more than two data byte periods (43 microseconds at 375 Kbps). At the end of the frame, the BOV bit is set by the SIU, and the SIU interrupt occurs. In the SIU interrupt service routine,

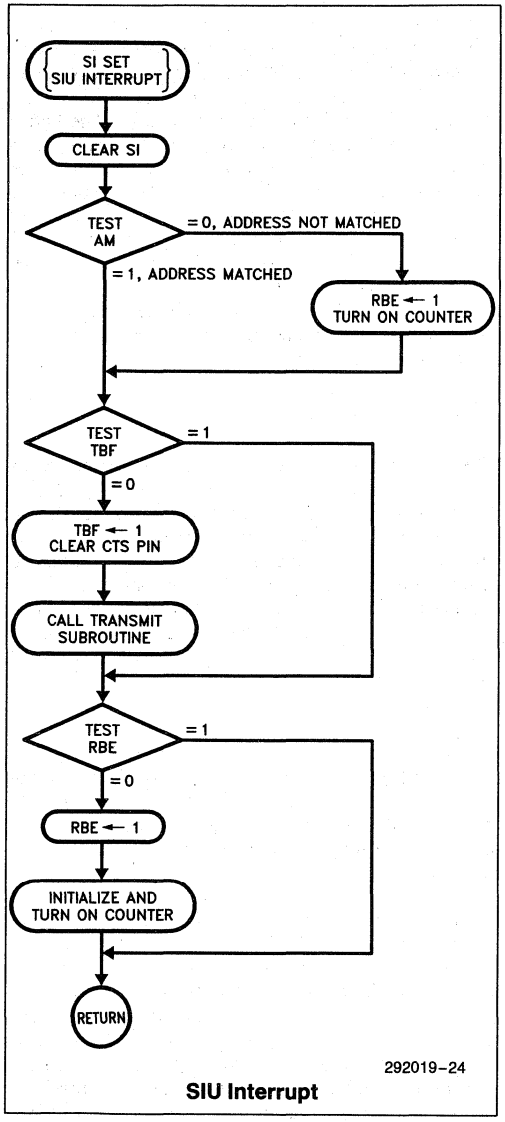


Figure 22. Secondary Station Flow Charts

the RBE bit is set and the counter is turned on which put the chip back in the receive mode.

6.2.5 RECEIVE INTERRUPT ROUTINE

Assembly code for the receive interrupt routine can be found in both primary and secondary software (Appendix B). The receive interrupt routine of the primary station is very similar to that of the primary station in example 1. In the following two sections the receive and transmit routine of the secondary stations are discussed.

In the receive interrupt service routine (see Figure 23), counter 0 is turned off, important registers are saved, receive buffer starting address and receive buffer length of the external RAM are set (do not confuse the external RAM settings with that of the internal RAM buffer.)

After reception of an opening flag, the byte processor jumps to the ADDRESS state and waits until the bit processor processes and moves the receiving address byte to SR. Then, the byte processor is triggered to execute the state. In the secondary stations, the CPU monitors the SIUST register for the ADDRESS state (SIUST = 08H). When the ADDRESS state is reached, the byte processor is moved to the next state (CONTROL state), and the ADDRESS state is skipped. Therefore, when the address byte is moved to SR, the byte processor executes the CONTROL state rather than the ADDRESS state and then jumps to the PUSH-1 state. The execution of the CONTROL state causes the contents of SR (the received address byte) to be loaded into the RCB register.

The CPU checks the contents of RCB with the contents of the STAD (Station Address) register. If they match, the receive routine continues to store the received Information bytes in the external RAM buffer; Otherwise, the byte processor is moved to the very last state (BOV-LOOP), and the program returns from the routine to perform other tasks. The byte processor executes the BOV-LOOP state in each byte boundary until the closing flag of the frame is reached. It then sets the BOV bit and interrupts the CPU (serial interrupt SI set). In the serial interrupt routine the counter 0 is turned back on, and the station is reset back to the receive mode (RBE set).

In Normal operation, in the ADDRESS state, the received address byte is automatically compared with the station address. If they match, the byte processor executes the remaining states; otherwise, the byte processor goes into the idle mode (SIUST = 01H) and waits for the opening flag of the next frame. In the expanded operation, this state is skipped to avoid idle mode. If the byte processor went into the idle mode, clocks which run the byte processor would be turned off, and the byte processor can not be moved to any other states by the CPU. When the byte processor is in idle mode, counter 0 can not be turned on immediately because counter interrupt occurs on the same frame, and program returns to the receive routine and stays there.

If the address byte matches the station address, the byte processor is moved to the CONTROL state again. This time, after execution of the CONTROL state the contents of RCB are the received control byte.

CPU investigates the type of received frame by checking the received control byte. If the receiving frame is not an information frame (i.e. Supervisory frame), execution of receive routine will be terminated to free the

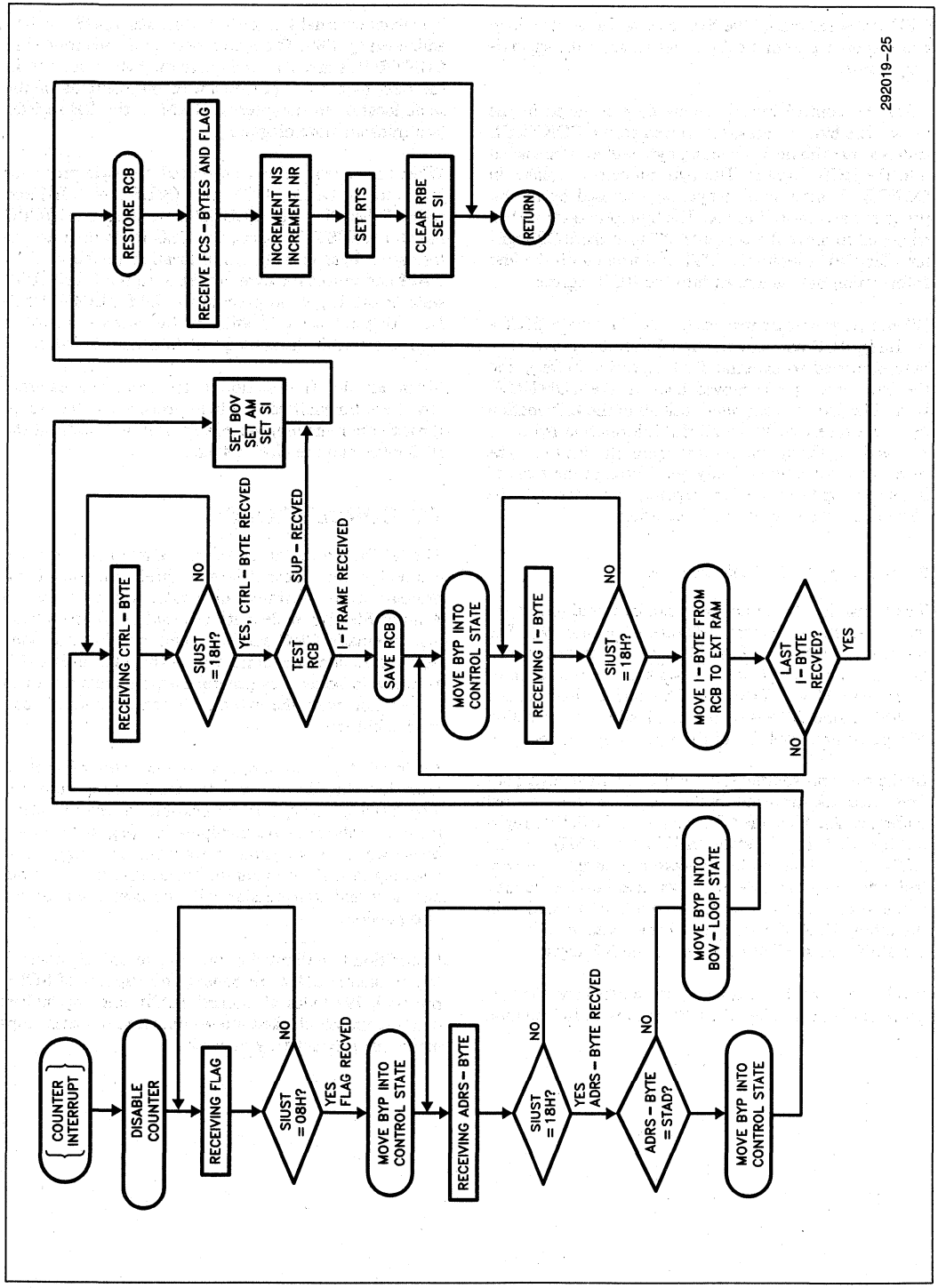


Figure 23. Receive Flow Chart (secondary station)

CPU. In Auto mode, the SIU checks the control byte and responds automatically in response to the supervisory frame.

After the control byte is received, it is saved in the stack. The byte processor is moved to the CONTROL state so that the next incoming byte will also be loaded into the RCB register. The byte processor remains in CONTROL state until a byte is processed by the bit processor and moved to SR. The byte processor is then triggered to move the contents of SR to the RCB register. The CPU monitors SIUST and waits until the first Information byte is loaded into the RCB register.

When byte processor reaches the PUSH-1 state (SIUST = 18H), RCB contains the first Information byte. The byte is moved to external RAM (receive buffer), and the byte processor is moved back to the CONTROL state. The process continues until all of the Information bytes are received. When all the Information bytes are received, the program returns from the routine. The byte processor automatically goes through the remaining states, updates the STS register, and interrupts the CPU as it would in Normal operation.

6.2.6 TRANSMIT SUBROUTINE

The transmit subroutine codes can be found in the primary and the secondary software (Appendix B). The transmit subroutines of the Primary and secondary stations are identical. A call to transmit routine is made when the RTS and TBF bits of the STS register are set. In Auto mode, RTS is set automatically upon reception of a poll-frame (poll bit of the control byte is set).

In the transmit routine (see Figure 15), the starting address and the transmit buffer length of the external buffer are set. Then the CPU monitors the SIUST register for CONTROL state (SIUST = A8H). In the CONTROL state the bit processor transmits the control byte, while the byte processor goes into the standby mode after it has moved the contents of a location in the internal RAM addressed by the contents of Transmit Buffer Start (TBS) register to the RB register.

While the control byte is being transmitted and the byte processor is in standby, the CPU moves an Information byte from external RAM to the internal RAM location addressed by TBS. The byte processor is then moved to CONTROL state. This will cause the byte processor, in the next byte boundary, to move the contents of the same location in the internal RAM to the RB register (see transmit state diagram.)

When this byte is being transmitted, the byte processor jumps to the DMA-LOOP state (SIUST = B0H) and waits. When the DMA-LOOP state is reached (CPU monitors SIUST for B0H), the CPU loads the next Information byte into the same location in the internal RAM and moves the byte processor to the CONTROL state before it gets to execute the DMA-LOOP state. Note that the same location in the internal RAM is used to transmit the subsequent Information bytes.

When all the Information bytes from the external RAM are transmitted, the byte processor is free to go through the remaining states so that it will transmit the FCS bytes and the closing flag.

7.0 CONCLUSIONS

The RUPI, with addition of only a few bytes of code, can accept and transmit large frames with some compromise in the maximum data rate. It can be used in Auto or Flexible mode, with external or internal clocking, automatic CRC checking, and zero bit insertion/deletion. In addition, almost all of the internal RAM is available to be used as general purpose registers, or in conjunction with the external RAM as transmit and receive buffers.

All in all, this feature opens up new areas of applications for this device. Besides transmitting/receiving long frames, it may now be possible to perform arithmetic operations or bit manipulation (e.g. data scrambling) while transmission or reception is taking place, resulting in high throughput. Transmission of continuous flags and transmission with no zero insertion are also possible.

In addition to unlimited frame size, an on-chip controller, automatic SDLC responses, full support of SDLC protocol, 192 bytes of internal RAM, and the highest data rate in self clocked mode compared to other chips make this product very attractive.

APPENDIX A
LISTING OF SOFTWARE MODULES FOR APPLICATION EXAMPLE 1

```
$DEBUG NOMOD51
$INCLUDE (REG44.PDF)

;  ASSEMBLY CODE FOR  PRIMARY STATION (POINT TO POINT)
;  FLEXIBLE MODE; FCS OPTION

        ORG    00H                ; LOCATIONS 00 THRU 26H ARE USED
        SJMP   INIT               ; BY INTERRUPT SERVICE ROUTINES.
        ORG    0BH                ; VECTOR ADDRESS FOR TIMER0 INT.
        JMP    REC
        ORG    23H                ; VECTOR ADDRESS FOR SIU INT.
        SJMP   SIINT

;********************** INITIALIZATION **************************

        ORG    26H
INIT:   MOV    SMD,#00000110B     ; EXT CLOCK; PFS=NB=1
        MOV    TBS,#20H           ; INT TRANSMIT BUFFER START
        MOV    TBL,#01H           ; INT TRANSMIT BUFFER LENGTH
        MOV    20H,#55H           ; STATION ADDRESS
        MOV    TMOD,#00000111B    ; COUNTER FUNCTION; MODE 3
        MOV    IE,#10010010B      ; EA=1; SI=1; ET0=1
        MOV    STS,#11100000B     ; TRANSMIT A FRAME
DOT:    SJMP   DOT                ; WAIT FOR AN INTERRUPT

; SIU TRANSMITS THE DFS BYTES, THE OPENNING FLAG, THE CONTENTS
; OF LOCATION 20H, THE CALCULATED FCS-BYTES, AND THE CLOSING
; FLAG.  AT THE END OF TRANSMISSION, SIU INTERRUPT OCCURS.

;************* SERIAL CHANNEL INTERRUPT ROUTINE ****************

SIINT:  CLR    SI
        JNB    RBE,RECVED         ; TRANSMITTED A FRAME ?
        MOV    TL0,#0F8H          ; YES, INITIALIZE COUNTER REGISTER
        MOV    DPTR,#200H         ; EXT RAM RECEIVE BUFFER START
        MOV    R5,#0FFH           ; EXT RAM RECEIVE BUFFER LENGTH
        SETB   TR0                ; TURN ON COUNTER 0
        RETI                      ; RETURN                                  292019-28
; WHEN A FRAME APPEARS ON THE SERIAL CHANNEL, COUNTER (RECEIVE)
; INTERRUPT OCCURS. AFTER SERVICING THE INTERRUPT ROUTINE, SIU
; INTERRUPT OCCURS.

RECVED: MOV    STS,#11100000B     ; TRANSMIT A FRAME
        RETI                      ; RETURN


;***************** RECEIVE INTERRUPT ROUTINE ********************

REC:    CLR    TR0                ; DISABLE THE COUNTER 0 INTERRUPT
        MOV    A,#18H             ; PUSH-1 STATE
WAIT1:  CJNE   A,SIUST,WAIT1
NEXTI:  MOV    SIUST,#0EFH        ; MOVE BYP\TO CONTROL STATE
        MOV    A,#18H             ; PUSH-1 STATE
WAIT2:  CJNE   A,SIUST,WAIT2      ;
        MOV    A,RCB              ; MOVE RECEIVED BYTE INTO ACC.
        MOVX   @DPTR,A            ; MOVE DATA TO EXT. RAM
        INC    DPTR               ; INCREMENT POINTER TO EXT RAM
        DJNZ   R5,NEXTI           ; LAST BYTE RECEIVED?
        RETI                      ; YES, RETURN
END
                                                                          292019-29
```

4

```
$DEBUG NOMOD51
$INCLUDE (REG44.PDF)

;  ASSEMBLY CODE FOR SECONDARY STATION (POINT TO POINT)
;  FLEXIBLE MODE; FCS OPTION

       ORG   00H
       SJMP  INIT
       ORG   23H              ; VECTOR ADDRESS FOR SIU INT.
       SJMP  SIINT

;**************** LOAD TRANSMIT BUFFER WITH DATA *************

       ORG   26H
INIT:  MOV   DPTR,#200H       ; EXT RAM XMIT BUFFER START
       MOV   R3,#0FFH         ; EXT RAM XMIT BUFFER LENGHT
LDRAM: MOV   A,R3
       MOVX  @DPTR,A          ; LOAD EXT BUFFER WITH FFH,FEH,...
       INC   DPTR             ; INCREMENT POINTER
       DJNZ  R3,LDRAM

;******************INITIALIZATION ****************************

       MOV   SMD,#00000110B   ; EXT CLOCK; PFS=NB=1
       MOV   R1,#10H
       MOV   TBS,R1           ; INT RAM XMIT BUFFER START
       MOV   TBL,#01H         ; INT RAM XMIT BUFFER LENGTH
       MOV   RBS,#20H         ; INT RAM RECEIVE BUFFER START
       MOV   RBL,#01H         ; INT RAM RECEIVE BUFFER LENGTH
       MOV   STAD,#55H        ; STAD ADDRESS=55H
       MOV   TCON,#00H        ; RESET TCON REGISTER
       MOV   IE,#10010000B    ; ENABLE  SI INT. ;EA=1
       MOV   IP,#0FFH         ; ALL INTERRUPTS: PRIORITY 1
       MOV   STS,#01000000B   ; RBE=1, RECEIVE A FRAME.
DOT:   SJMP  DOT              ; WAIT FOR AN INTERRUPT

; SIU INTERRUPT OCCURS AT THE END OF A RECEIVED FRAME OR
; A TRANSMITTED FRAME.
;**************** SERIAL CHANNEL INTERRUPT ROUTINE ************

SIINT: CLR   SI
       JB    RBE,RETRN        ; RECEIVED A FRAME?
       MOV   A,STAD           ; YES
       CJNE  A,20H,NMACH      ; STATION ADDRESS MATCHED?
       ACALL TRAN             ; YES, CALL TRANSMIT SUBROUTINE

; TRANSMIT SUBROUTINE IS CALLED TO TRANSMIT A LONG FRAME.
; AFTER TRANSMISSION, SI IS SET.  SIU INTERRRUPT IS SERVICED
; AFTER THE CURRENT ROUTINE (SIINT) IS COMPLETED.

NMACH: SETB  RBE              ; RBE=1, RECEIVE A FRAME
RETRN: RETI                   ; RETURN

;************** TRANSMIT SUBROUTINE **************************

TRAN:  MOV    DPTR,#200H      ; EXT RAM RECEIVE BUFFER START
       MOV   R5,#0FFH         ; EXT RAM RECEIVE BUFFER LENGTH
       SETB  TBF              ; SET TRANSMIT BUFFER FULL
       SETB  RTS              ; ENABLE XMISSION OF AN I-FRAME
LOOP:  MOVX  A,@DPTR          ; MOVE THE 1ST I-BYTE INTO ACC.
       MOV   @R1,A            ; THEN, MOVE TO INT. RAM @ (TBS)
       MOV   A,#0B0H          ; DMA-LOOP STATE
WAIT1: CJNE  A,SIUST,WAIT1    ; WAIT FOR XMISSION OF AN I-FRAME
       INC   DPTR             ; INCREMENT POINTER TO EXT. RAM
       DJNZ  R5,NEXTI         ; ALL BYTES XMITTED?
       MOVX  A,@DPTR          ; YES, EXCEPT THE LAST BYTE.
       MOV   @R1,A            ; MOVE DATA INTO INT. RAM @ (TBS)
       MOV   SIUST,#57H       ; MOVE BYP TO CONTROL STATE
                              ; THE SIU TRANSMITS THE FCS-BYTES
                              ; AND THE CLOSING FLAG.
       RET                    ; RETURN
NEXTI: MOV   SIUST,#57H       ; MOVE BYP TO CONTROL STATE (A8H).
       JMP   LOOP             ; TRANSMIT THE NEXT BYTE
END
```

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APPENDIX B
LISTING OF SOFTWARE MODULES FOR APPLICATION EXAMPLE 2

```
$DEBUG NOMOD51
$INCLUDE (REG44.PDF)

; ASSEMBLY CODE FOR PRIMARY STATION (MULTIPOINT)
; FLEXIBLE MODE; FCS OPTION

        ORG   00H               ; LOCATIONS 00 THRU 26H ARE USED
        SJMP  INIT              ; BY INTERRUPT SERVICE ROUTINES.
        ORG   0BH               ; VECTOR ADDRESS FOR TIMER0 INT.
        JMP   REC
        ORG   23H               ; VECTOR ADDRESS FOR SIU INT.
        SJMP  SIINT

;**************** LOAD TRANSMIT BUFFER WITH DATA ************

       ORG   26H
INIT:  MOV   DPTR,#200H         ; EXT RAM XMIT BUFFER START
       MOV   R3,#0FFH           ; EXT RAM XMIT BUFFER LENGHT
LDRAM: MOV   A,R3
       MOVX  @DPTR,A            ; LOAD BUFFER WITH FFH,FEH,...00
       INC   DPTR               ; INCREMENT POINTER
       DJNZ  R3,LDRAM                                          292019-32
;********************* INITIALIZATION ***********************

        MOV   R0,#0BFH          ; PUT  ZEROS INTO INT. RAM
LOOP:   MOV   A,#00H            ; FROM BFH TO 40H.
        MOV   @R0,A             ; MOVE 0 INTO RAM ADDRESSD BY R0
        DEC   R0
        CJNE  R0,#40H,LOOP
;
        MOV   30H,#00H          ; NS COUNTER FOR STAD=55
        MOV   31H,#00H          ; NR COUNTER FOR STAD=55
        MOV   32H,#0FFH         ; NS COUNTER FOR STAD=44
        MOV   33H,#0FFH         ; NR COUNTER FOR STAD=44
        MOV   34H,#01H          ; PONITER TO SECONDARY STATIONS
        MOV   SMD,#11010100B    ; INT. CLKED @ 375K; NRZI=1; PFS=1
        MOV   RBS,#10H          ; INT. RAM RECEIVE BUFFER START=10H
        MOV   RBL,#00H          ; INT. RAM RECEIVE BUFFER LENGTH=0
        MOV   R1,#20H           ; INT. RAM XMIT BUFFER START=20H
        MOV   TBS,R1
        MOV   TBL,#01H          ; INT. RAM XMIT BUFFER LENGTH=1
        MOV   NSNR,#00H         ; NS=NR=0
        MOV   TMOD,#00000111B   ; COUNTER FUNCTION, MODE 3
        MOV   TCON,#00H
        MOV   IE,#10010010B     ; EA=1; SI=1; ET0=1
        MOV   IP,#00000010B     ; TIMER 0 INT. PRIORITY 1
        MOV   TCB,#00010000B    ; I-FRAME W/POLL
        MOV   STAD,#55H         ; ADDRESS BYTE=55H
        MOV   STS,#11100000B    ; RBE=TBF=RTS=1

; TRANSMIT A LONG FRAME WITH POLL BIT SET, WAIT FOR A
; RESPONSE.

        ACALL TRAN              ; CALL TRANSMIT ROUTINE
DOT:    SJMP  DOT               ; WAIT FOR AN INTERRUPT
                                                            292019-33
```

```
;************** SERIAL INTERRUPT ROUTINE **********************

SIINT:  CLR   SI                ; CLEAR SI
        JB    RBE,RETURN        ; RECEIVED A FRAME ?
        MOV   A,RCB             ; YES, LOAD ACC WITH REC CNTRL BYTE
        JB    ACC.0,GETI        ; IS IT AN I-FRAME ?
        MOV   A,#01H            ; YES
        CJNE  A,34H,SKIP
        MOV   A,30H             ; MOVE NS INTO ACC.
        INC   A                 ; INCREMENT NS
        ANL   A,#00000111B      ; MASK OUT THE LEAST 3 SIG. BITS
        MOV   30H,A             ; SAVE NS
        MOV   A,31H             ; MOVE NR INTO ACC.
        INC   A                 ; INCREMENT NR
        ANL   A,#00000111B      ; MASK OUT THE LEAST 3 SIG. BITS
        MOV   31H,A             ; SAVE NR
        RL    A                 ; SHIFT 4 BITS TO LEFT
        RL    A
        RL    A
        RL    A
        ORL   A,30H             ; MOVE NS COUNT TO ACC.
        RL    A                 ; SHIFT 1 BIT TO LEFT
        ORL   A,#00010000B      ; SET THE POLL BIT
        MOV   TCB,A             ; MOVE CONTROL BYTE INTO TCB REG.
                                ; TCB: NR2,NR1,NR0,1,NS2,NS1,NS0,0
        MOV   STAD,#55H
        MOV   34H,#00H
        JMP   GETI                                              292019-34
SKIP:   MOV   A,32H             ; MOVE NS INTO ACC.
        INC   A                 ; INCREMENT NS
        ANL   A,#00000111B      ; MASK OUT THE LEAST 3 SIG. BITS
        MOV   32H,A             ; SAVE NS
        MOV   A,33H             ; MOVE NR INTO ACC.
        INC   A                 ; INCREMENT NR
        ANL   A,#00000111B      ; MASK OUT THE LEAST 3 SIG. BITS
        MOV   33H,A             ; SAVE NR
        RL    A                 ; SHIFT 4 BITS TO LEFT
        RL    A
        RL    A
        RL    A
        ORL   A,33H             ; MOVE NS COUNT TO ACC.
        RL    A                 ; SHIFT 1 BIT TO LEFT
        ORL   A,#00010000B      ; SET THE POLL BIT
        MOV   TCB,A             ; MOVE CONTROL BYTE INTO TCB
                                ; TCB: NR2,NR1,NR0,1,NS2,NS1,NS0,0
        MOV   STAD,#44H
        MOV   34H,#01H
GETI:   MOV   STS,#11100000B    ; ENABLE TRANSMISSION
        ACALL TRAN              ; CALL TRANSMIT ROUTINE
        RETI
RETURN: CLR   EA                ; DISABLE ALL INTERRUPTS
        MOV   TL0,#0FBH         ; INTERRUPT AFTER 8 COUNTS
        SETB  TR0               ; TURN ON COUNTER 0
        SETB  EA
        RETI                                                    292019-35
;************** RECEIVE INTERRUPT ROUTINE *********************

REC:    CLR   TR0               ; TURN OFF COUNTER 0
        MOV   DPTR,#400H        ; EXT. RAM RECEIVE BUFFER START
        MOV   R5,#0FFH          ; EXT. RAM RECEIVE BUFFER LENGTH
        MOV   A,#18H            ; PUSH-1 STATE
WAIT1:  CJNE  A,SIUST,WAIT1     ; WAIT FOR THE CONTROL BYTE
        PUSH  RCB               ; SAVE RECEIVE CONTROL BYTE
NEXTI:  MOV   SIUST,#0EFH       ; PUSH "BYP" INTO CONTROL STATE(10H).
        MOV   A,#18H            ; PUSH-1 STATE
WAIT2:  CJNE  A,SIUST,WAIT2     ; WAIT FOR AN I-BYTE
        MOV   A,RCB             ; MOVE RECEIVED I-BYTE INTO ACC.
        MOVX  @DPTR,A           ; MOVE DATA TO EXT. RAM
        INC   DPTR              ; INCREMENT PTR TO EXTERNAL RAM
        DJNZ  R5,NEXTI          ; IS IT THE LAST I-BYTE?
        POP   RCB               ; YES, RESTORE THE CONTENTS OF RCB
        RETI                    ; RETURN

;***************** TRANSMIT SUBROUTINE **********************

TRAN:   MOV   DPTR,#200H        ; EXT. RAM TRANSMIT BUFFER START
        MOV   R5,#0FFH          ; EXT. RAM TRANSMIT BUFFER LENGTH
        MOV   A,#0A8H           ; CONTROL STATE
WAIT:   CJNE  A,SIUST,WAIT      ; WAIT  FOR CTRL BYTE XMISSION
        MOVX  A,@DPTR           ; MOVE DATA FROM EXT. RAM TO ACC.
        MOV   @R1,A             ; MOVE DATA INTO INT. RAM @ (TBS)
        INC   DPTR              ; INCREMENT POINTER
        DJNZ  R5,NXTI           ; IS IT THE LAST I-BYTE ?
        MOV   SIUST,#57H        ; NO. XMIT THE LAST I-BYTE
        RET                     ; RETURN.
NXTI:   MOV   SIUST,#57H        ; KEEP "BYP" IN CONTROL STATE(A8H).
        MOV   A,#0B0H           ; DMA-LOOP STATE
        JMP   WAIT              ; TRANSMIT THE NEXT BYTE
END
                                                                292019-36
```

```
$DEBUG NOMOD51
$INCLUDE (REG44.PDF)

; ASSEMBLY CODE FOR SECONDARY STATIONS (MULTIPOINT)
; AUTO MODE; FCS OPTION

        ORG   00H
        SJMP  INIT
        ORG   0BH               ; VECTOR ADDRESS FOR TIMER0 INT.
        JMP   REC
        ORG   13H               ; VECTOR ADDRESS FOR EXT. INT. 1
        JMP   XINT1
        ORG   23H               ; VECTOR ADDRESS FOR SIU INTERRUPT
        JMP   SIINT


;******************INITIALIZATION ***************************

        ORG   26H
INIT:   MOV   SMD,#11010100B  ; INT. CLKED @ 375K;NRZI=1;PFS=1
        MOV   STAD,#55H         ; STATION ADDRESS; STAD=44H FOR THE
                                ; OTHER STATION
        MOV   RBS,#10H          ; INT. RAM RECEIVE BUFFER START
        MOV   RBL,#00H          ; INT. RAM RECEIVE BUFFER LENGTH
        MOV   R1,#20H
        MOV   TBS,R1            ; INT. RAM XMIT BUFFER START
        MOV   TBL,#01H          ; INT. RAM XMIT BUFFER LENGTH
        MOV   NSNR,#00H         ; NS=NR=0
        MOV   TCON,#00000100B ; EXT. INT.: EDGE TRIGGERED
        MOV   IE,#00010110B     ; SI=1; ET0=1; EX0=1
        MOV   IP,#00000010B     ; TIMER 0: PRIORITY 1
        MOV   TMOD,#0000011B    ; COUNTER FUNCTION: MODE 3
        MOV   STS,#01000010B    ; RECEIVE I-FRAME.
        MOV   TL0,#0F8H         ; SET COUNTER TO OVERFLOW
                                ; AFTER 8 COUNTS
        SETB  TR0               ; TURN ON COUNTER
        SETB  EA                ; ENABLE ALL INTERRUPTS
DOT:    SJMP  DOT               ; WAIT FOR AN INTERRUPT.
; CPU IS INTERRUPTED  AT THE END OF RECEPTION (SI SET), AND AT*
; THE END OF LONG-FRAME TRANSMISSION (EX0 SET).              *

;***************EXTERNAL INTERRUPT ***************************

XINT1:  SETB  P1.7              ; DISABLE CTS PIN
        RETI                    ; RETURN.

;*************** SERIAL INTERRUPT ROUTINE ********************

SIINT:  CLR   SI
        JB    AM,HOP            ; ADDRESS MATCHED?
        CLR   EA                ; DISABLE ALL INTERRUPTS
        MOV   STS,#01000010B    ; RBE=1; NB=1
        MOV   TL0,#0F8H
        SETB  TR0               ; TURN ON COUNTER 0
        SETB  EA                ; ENABLE ALL INTERRUPTS
        RETI                    ; RETURN.
;
HOP:    JB    TBF,GETI          ; A FRAME TRANSMITTED?
        SETB  TBF               ; ENABLE TRANSMISSION OF I-FRAME
        CLR   P1.7              ; ENABLE CTS PIN
        ACALL TRAN              ; CALL TRANSMIT ROUTINE
GETI:   JB    RBE,RETURN        ; A FRAME RECEIVED?
        CLR   EA                ; DISABLE ALL INTERRUPTS
        SETB  RBE               ; PUT RUPI IN RECEIVE MODE
        MOV   TL0,#0F8H         ;
        SETB  TR0               ; TURN ON COUNTER 0
        SETB  EA                ; ENABLE ALL INTERRUPTS
RETURN: RETI                    ; RETURN.
;***************** TRANSMIT SUBROUTINE **********************

TRAN:   MOV   DPTR,#200H        ; EXT. RAM TRANSMIT BUFFER START
        MOV   R5,#0FFH          ; EXT. RAM TRANSMIT BUFFER LENGTH
        MOV   A,#0A8H           ; CONTROL STATE
WAIT:   CJNE  A,SIUST,WAIT      ; WAIT  FOR CONTROL BYTE TRANSMISSION
        MOVX  A,@DPTR           ; MOVE DATA FROM EXT. RAM TO ACC.
        MOV   @R1,A             ; MOVE DATA INTO INT. RAM AT @TBS
        INC   DPTR              ; INCREMENT POINTER
        DJNZ  R5,NXTI           ; IS IT THE LAST I-BYTE ?
        MOV   SIUST,#57H        ; XMIT THE LAST I-BYTE
        RET                     ; RETURN.
NXTI:   MOV   SIUST,#57H        ; KEEP "BYP" IN CONTROL STATE
        MOV   A,#0B0H           ; DMA-LOOP STATE
        JMP   WAIT              ; TRANSMIT THE NEXT BYTE
```

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```
;**********RECEIVE INTERRUPT ROUTINE**************************

REC:    CLR   TR0              ; TURN OFF COUNTER 0
        MOV   DPTR,#200H       ; EXT. RAM RECEIVE BUFFER START
        MOV   R5,#0FFH         ; EXT. RAM RECEIVE BUFFER LENGTH
        MOV   A,#08H           ; ADDRESS STATE
HOLD:   CJNE  A,SIUST,HOLD     ; WAIT FOR ADDRESS BYTE
        MOV   SIUST,#0EFH      ; MOVE "BYP" INTO CONTROL STATE
                               ; SKIP THE ADDRESS STATE
        MOV   A,#18H           ; PUSH-1 STATE
WAIT1:  CJNE  A,SIUST,WAIT1    ; WAIT FOR THE ADDRESS BYTE
        MOV   A,RCB            ; MOVE THE RECEIVED ADDRESS BYTE TO ACC.
        CJNE  A,STAD,WAIT2     ; ADDRESS MATCHED?
        SJMP  WAIT3            ; YES.
WAIT2:  MOV   RCB,#00010000B   ; MOVE INFO. CONTROL BYTE TO RCB
        MOV   SIUST,#0CFH      ; MOVE "BYP" INTO BOV-LOOP STATE
        RETI                   ; RETURN
;
WAIT3:  MOV   SIUST,#0EFH      ; MOVE "BYP" INTO CONTROL STATE
        MOV   A,#18H           ; PUSH-1 STATE
WAIT4:  CJNE  A,SIUST,WAIT4    ; WAIT FOR THE CONTROL BYTE
        MOV   A,RCB            ; MOVE RECEIVE CONTROL BYTE INTO ACC.
        JB    ACC.0,RTRN       ; IF NOT AN I-FRAME RETURN
        PUSH  RCB              ; SAVE RECEIVE CONTROL BYTE
NEXTI:  MOV   SIUST,#0EFH      ; PUSH "BYP" INTO CONTROL STATE(10H).
        MOV   A,#18H           ; PUSH-1 STATE
WAIT5:  CJNE  A,SIUST,WAIT5    ; WAIT FOR AN I-BYTE
        MOV   A,RCB            ; MOVE RECEIVED I-BYTE INTO ACC.
        MOVX  @DPTR,A          ; MOVE DATA TO EXT. RAM
        INC   DPTR             ; INCREMENT PTR TO EXTERNAL RAM
        DJNZ  R5,NEXTI         ; IS IT THE LAST I-BYTE?
        POP   RCB              ; YES. RESTORE THE CONTENTS OF RCB
RTRN:   RETI                   ; RETURN
END
```

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80186/188 Application Notes 5

intel®

APPLICATION NOTE

AP-258

February 1986

High Speed Numerics with the 80186/80188 and 8087

5

STEVE FARRER
APPLICATIONS ENGINEER

Order Number: 231590-001

HIGH SPEED NUMERICS WITH THE 80186/80188 AND 8087

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1.0 INTRODUCTION

From their introduction in 1982, the highly integrated 16-bit 80186 and its 8-bit external bus version, the 80188, have been ideal processor choices for high-performance, low-cost embedded control applications. The integrated peripheral functions and enhanced 8086 CPU of the 80186 and 80188 allow for an easy upgrade of older generation control applications to achieve higher performance while lowering the overall system cost through reduced board space, and a simplified production flow.

More and more controller applications need even higher performance in numerics, yet still require the low-cost and small form factor of the 80186 and 80188. The 8087 Numerics Data Coprocessor satisfies this need as an optional add-on component.

The 8087 Numeric Data Coprocessor is interfaced to the 80186 and 80188 through the 82188 IBC (Integrated Bus Controller). The IBC provides a highly integrated interface solution which replaces the 8288 used in 8086–8087 systems. The IBC incorporates all the necessary bus control for the 8087 while also providing the necessary logic to support the interface between the 80186/8 and the 8087.

This application note discusses the design considerations associated with using the 8087 Numeric Data Coprocessor with the 80186 and 80188. Sections two, three, and four contain an overview of the integrated circuits involved in the numerics configuration. Section five discusses the interfacing aspects between the 80186/8 and the 8087, including the role of the 82188 Integrated Bus Controller and the operation of the integrated peripherals on the 80186/8 with the 8087. Section six compares the advantages of using an 8087 Numeric Data Coprocessor over software routines written for the host processor as well as the advantage of using an 80186/8 numerics system over an 8086/8088 numerics system.

Except where noted, all future references to the 80186 will apply equally to the 80188.

2.0 OVERVIEW OF THE 80186

The 80186 and 80188 are highly integrated microprocessors which effectively combine up to 20 of the most common system components onto a single chip. The 80186 and 80188 processors are designed to provide both higher performance and a more highly integated solution to the total system.

Higher integration results from integrating system peripherals onto the microprocessor. The peripherals consist of a clock generator, an interrupt controller, a DMA controller, a counter/timer unit, a programmable wait state generator, programmable chip selects, and a bus controller. (See Figure 1.)

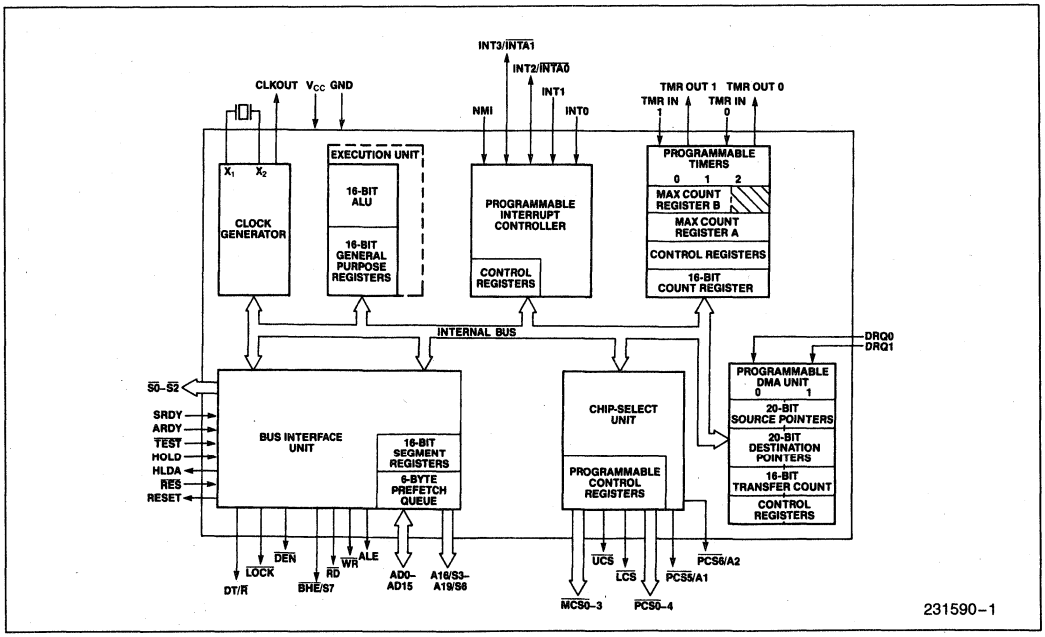


Figure 1. 80186/8 Block Diagram

Higher performance results from enhancements to both general and specific areas of the 8086 CPU, including faster effective address calculation, improvement in the execution speed of many instructions, and the inclusion of new instructions which are designed to produce optimum 80186 code.

The 80186 and 80188 are completely object code compatible with the 8086 and 8088. They have the same basic register set, memory organization, and addressing modes. The differences between the 80186 and 80188 are the same as the differences between the 8086 and 8088: the 80186 has a 16-bit architecture and 16-bit bus interface; the 80188 has a 16-bit internal architecture and an 8-bit data bus interface. The instruction execution times of the two processors differ accordingly: for each non-immediate 16-bit data read/write instruction, 4 additional clock cycles are required by the 80188.

3.0 NUMERICS OVERVIEW

3.1 The Benefits of Numeric Coprocessing

The 8086/8 and 80186/8 are general purpose microprocessors, designed for a very wide range of applications. Typically, these applications need fast, efficient data movement and general purpose control instructions. Arithmetic on data values tends to be simple in these applications. The 8086/8 and 80186/8 fulfill these needs in a low cost, effective manner.

However, some applications require extremely fast and complex math functions which are not provided by a general purpose processor. Such functions as square root, sine, cosine, and logarithms are not directly available in a general purpose processor. Software routines required to implement these functions tend to be slow and not very accurate. Integer data types and their arithmetic operations (i.e., add, subtract, multiply and divide) which are directly available on general purpose processors, still may not meet the needs for accuracy, speed and ease of use.

Providing fast, accurate, complex math can be quite complicated, requiring large areas of silicon on integrated circuits. A general data processor does not provide these features due to the extra cost burden that less complex general applications must take on. For such features, a special numeric data processor is required — one which is easy to use and has a high level of support in hardware and software.

3.2 Introduction to the 8087

The 8087 is a numeric data coprocessor which is capable of performing complex mathematical functions while the host processor (i.e. the main CPU) performs more general tasks. It supports the necessary data types and operations and allows use of all the current hardware and software support for the 8086/8 and 80186/8 microprocessors. The fact that the 8087 is a coprocessor means it is capable of operating in parallel with the host CPU, which greatly improves the processing power of the system.

The 8087 can increase the performance of floating-point calculations by 50 to 100 times, providing the performance and precision required for small business and graphics applications as well as scientific data processing.

The 8087 numeric coprocessor adds 68 floating-point instructions and eight 80-bit floating-point registers to the basic 8086 programming architecture. All the numeric instructions and data types of the 8087 are used by the programmer in the same manner as the general data types and instructions of the host.

The numeric data formats and arithmetic operations provided by the 8087 support the proposed IEEE Microprocessor Floating Point Standard. All of the proposed IEEE floating point standard algorithms, exception detection, exception handling, infinity arithmetic and rounding controls are implemented. The IEEE standard makes it easier to use floating point and helps to avoid common problems that are inherent to floating point.

3.3 Escape Instructions

The coprocessing capabilities of the 8087 are achieved by monitoring the local bus of the host processor. Certain instructions within the 8086 assembly language known as ESCAPE instructions are defined to be coprocessor instructions and, as such, are treated differently.

The coprocessor monitors program execution of the host processor to detect the occurrence of an ESCAPE instruction. The fetching of instructions is monitored via the data bus and bus cycle status S2–S0, while the execution of instructions is monitored via the queue status lines QS0 and QS1.

All ESCAPE instructions start with the high-order 5-bits of the instruction opcode being 11011. They have two basic forms, the memory reference form and the non-memory reference form. The non-memory form, shown in Figure 2A, initiates some activity in the coprocessor using the nine available bits of the ESCAPE instruction to indicate which function to perform.

Memory reference forms of the ESCAPE instruction, shown in Figure 2B, allow the host to point out a memory operand to the coprocessor using any host memory

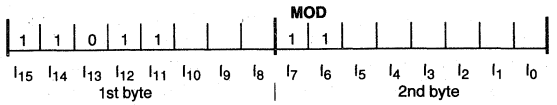


Figure 2A. Non-Memory Reference ESCAPE Instructions

addressing mode. Six bits are available in the memory reference form to identify what to do with the memory operand.

Memory reference forms of ESCAPE instructions are identified by bits 7 and 6 of the byte following the ESCAPE opcode. These two bits are the MOD field of the 8086/8 or 80186/8 effective address calculation byte. Together with the R/M field (bits 2 through 0), they determine the addressing mode and how many subsequent bytes remain in the instruction.

3.4 Host Response to Escape Instructions

The host performs one of two possible actions when encountering an ESCAPE instruction: do nothing (operation is internal to 8087) or calculate an effective address and read a word value beginning at that address (required for all LOADS and STORES). The host ignores the value of the word read and hence the cycle is referred to as a "Dummy Read Cycle." ESCAPE instructions do not change any registers in the host other than advancing the IP. If there is no coprocessor or the coprocessor ignores the ESCAPE instruction, the ESCAPE instruction is effectively a NOP to the host. Other than calculating a memory address and reading a word of memory, the host makes no other assumptions regarding coprocessor activity.

The memory reference ESCAPE instructions have two purposes: to identify a memory operand and, for certain instructions, to transfer a word from memory to the coprocessor.

3.5 Coprocessor Response to Escape Instructions

The 8087 performs basically three types of functions when encountering an ESCAPE instruction: LOAD (read from memory), STORE (write to memory), and EXECUTE (perform one of the internal 8087 math functions).

When the host executes a memory reference ESCAPE instruction intended to cause a read operation by the 8087, the host always reads the low-order word of any 8087 memory operand. The 8087 will save the address and data read. To read any subsequent words of the operand, the 8087 must become a local bus master.

When the 8087 has the local bus, it increments the 20-bit physical address it saved to address the remaining words of the operand.

When the ESCAPE instruction is intended to cause a write operation by the 8087, the 8087 will save the address but ignore the data read. Eventually, it will get control of the local bus and perform successive writes incrementing the 20-bit address after each word until the entire numeric variable has been written.

ESCAPE instructions intended to cause the execution of a coprocessor calculation do not require any bus activity. Numeric calculations work off of an internal register stack which has been initialized using a LOAD operation. The calculation takes place using one or two of the stack positions specified by the ESCAPE instruction. The result of the operation is also placed in one of the stack positions specified by the ESCAPE instruction. The result may then be returned to memory using a STORE instruction, thus allowing the host processor to access it.

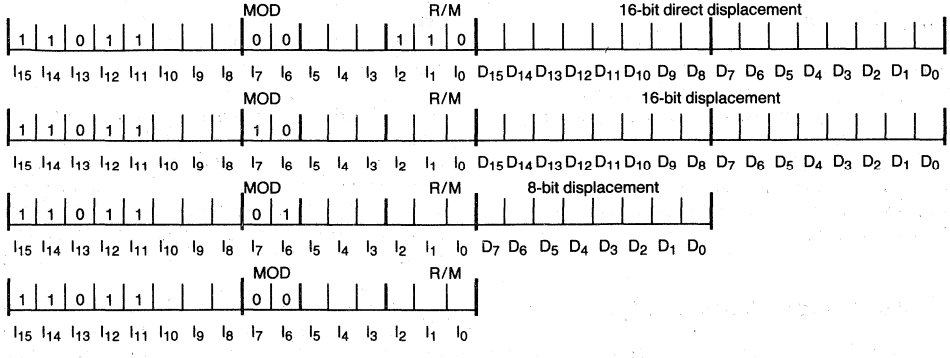


Figure 2B. Memory Reference ESCAPE Instruction Forms

4.0 OVERVIEW OF THE 82188 INTEGRATED BUS CONTROLLER

4.1 Introduction

The 82188 Integrated Bus Controller (IBC) is a highly integrated version of the 8288 Bus Controller. The IBC provides command and control timing signals for bus control and all of the necessary logic to interface the 80186 to the 8087.

4.2 Bus Control Signals

The bus command and control signals consist of $\overline{RD}$, $\overline{WR}$, $\overline{DEN}$, DT/$\overline{R}$, and ALE. The timings and levels are driven following the latching of valid signals on the status lines S0–S2. When S0–S2 change state from passive to active, the IBC begins cycling through a state machine which drives the corresponding control and command lines for the bus cycle. As with the 8288, an address enable input ($\overline{AEN}$) is present to allow tri-stating when other bus masters supply their own bus control signals.

4.3 Bus Arbitration

The IBC also has the ability to convert bus arbitration protocols of $\overline{RQ}/\overline{GT}$ to HOLD-HLDA. This allows the 82586 Local Area Network (LAN) Coprocessor, the 82730 Text Coprocessor, and other coprocessors using the HOLD-HLDA protocol to be interfaced to the 8086/8 as well as allowing the 80186/8 to be interfaced to the 8087. In addition to converting arbitration protocols, the IBC makes it possible to arbitrate between two bus masters using HOLD-HLDA with a third using $\overline{RQ}/\overline{GT}$.

4.4 Interface Logic

In addition to all the bus control and arbitration features, the IBC provides logic to connect the queue status to the 8087, a chip-select for the 8087, and the necessary READY synchronization required between the 8087 and the 80186/8.

5.0 DESIGNING THE SYSTEM

5.1 Circuit Schematics of the 80186/8–82888–8087 System

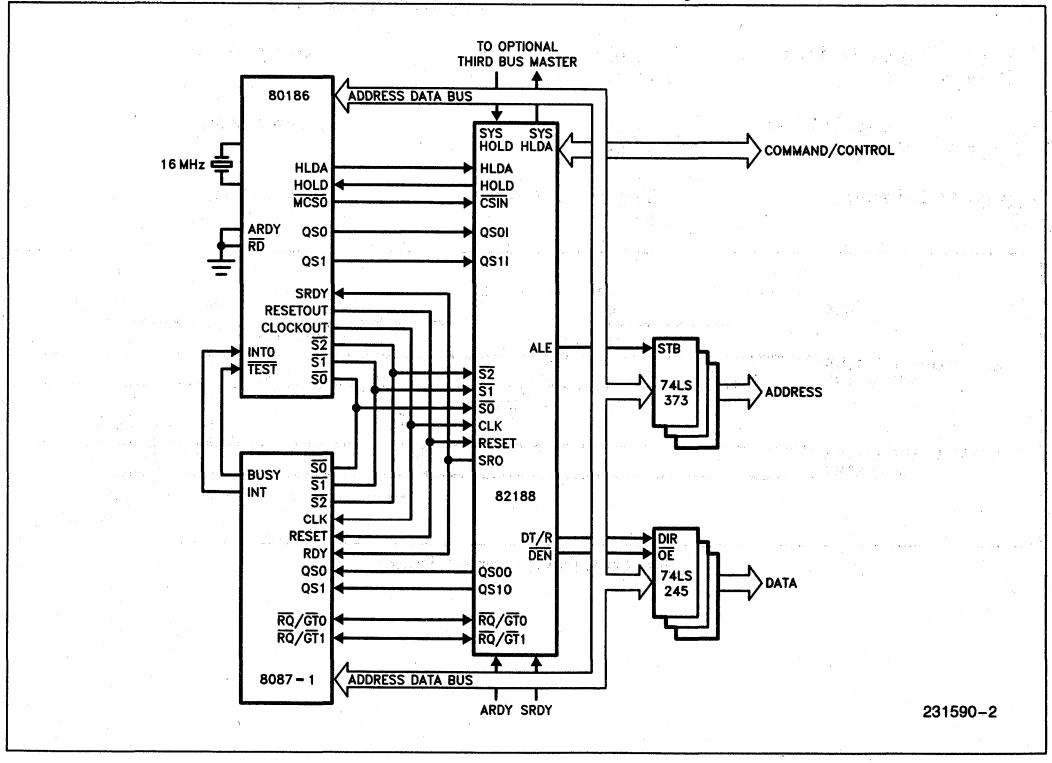


Figure 3. 80186/8–82188–8087 Circuit Diagram

5.2 Queue Status

The 8087 tracks the instruction execution of the 80186 by keeping an internal instruction queue which is identical to the processor's instruction queue. Each time the processor performs an instruction fetch, the 8087 latches the instruction into its own queue in parallel with the processor. Each time the processor removes the first byte of an instruction from the queue, the 8087 removes the byte at the top of the 8087 queue and checks to see if the byte is an ESCAPE prefix. If it is, the 8087 decodes the following bytes in parallel with the processor to determine which numeric instruction the bytes represent. If the first byte of the instruction is not an ESCAPE prefix, the 8087 discards it along with the subsequent bytes of the non-numeric instruction as the 80186 removes them from the queue for execution.

The 8087 operates its internal instruction queue by monitoring the two queue status lines from the CPU. This status information is made available by the CPU by placing it into queue status mode. This requires strapping the $\overline{RD}$ pin on the 80186 to ground. When $\overline{RD}$ is tied to ground, ALE and $\overline{WR}$ become QS0 (Queue Status #0) and QS1 (Queue Status #1) respectively.

Table 1. Queue Status Decoding

QS1	QS0	Queue Operation
0	0	No queue operation
0	1	First byte from queue
1	0	Subsequent byte from queue
1	1	Reserved

Each time the 80186 begins decoding a new instruction, the queue status lines indicate "first byte of instruction taken from the queue". This signals the 8087 to check for an ESCAPE prefix. As the remaining bytes of the instruction are removed, the queue status indicates "subsequent byte removed from queue". The 8087 uses this status to either continue decoding subsequent bytes, if the first byte was an ESCAPE prefix, or to discard the subsequent bytes if the first byte was not an ESCAPE prefix.

The QS0(ALE) and QS1($\overline{WR}$) pins of the 80186 are fed directly to the 82188 where they are latched and delayed by one-half-clock. The delayed queue status from the 82188 is then presented directly to the 8087.

The waveforms of the queue status signals are shown in Figure 4. The critical timings are the setup time into the 82188 from the 80186 and the setup and hold time into the 8087 from the 82188. The calculations for an 8 MHz system are as follows:

$.5T_{CLCL} - T_{CHQSV}$ (186 max)
$.5(125\text{ ns}) - 35$ $\geq T_{QIVCL}$ (82188 min)
≥ 15 ns ;setup to 82188

$T_{CLCL} - T_{CLQOV}$ (82188 max)
$(125\text{ ns}) - 50$ $\geq T_{QVCL}$
≥ 10 ns ;setup to 8087

T_{CLQOV} (82188 min)
5 $\geq T_{CLQX}$ (8087 min)
≥ 5 ns ;hold to 8087

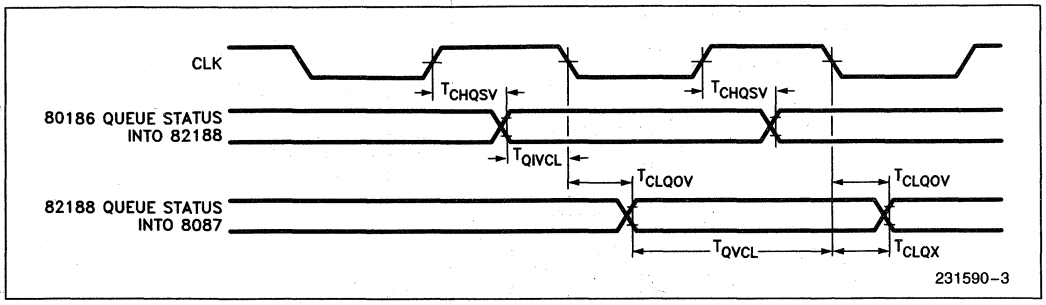


Figure 4. Queue Status Timing

5.3 Bus Control Signals

When the 80186 is in Queue Status mode, another component must generate the ALE, $\overline{RD}$, and $\overline{WR}$ signals. The 82188 provides these signals by monitoring the CPU bus cycle status ($\overline{S0}$–$\overline{S2}$). Also provided are $\overline{DEN}$ and DT/$\overline{R}$ which may be used for extra drive capability on the control bus. With the exception of ALE, all control signals on the 82188 are almost identical to their corresponding 80186 control signals. This section discusses the differences between the 80186 and the 82188 control signals for the purpose of upgrading an 80186 design to an 80186–8087 design. For original 80186–8087 designs, there is no need to compare control signal timings of the 82188 with the 80186.

5.3.1 ALE

The ALE (Address Latch Enable) signal goes active one clock phase earlier on the 80186 than on the 82188. Timing of the ALE signal on the 82188 is closer to that of the 8086 and 8288 bus controller because the bus cycle status is used to generate the ALE pulse. ALE on the 80186 goes active before the bus cycle status lines are valid.

The inactive edge of ALE occurs in the same clock phase for both the 80186 and the 82188. The setup and hold times of the 80186 address relative to the 82188 ALE signal are shown in Figure 5 and are calculated for an 8 MHz system as follows:

Setup Time

For 80186 = T_{AVCH} (186 min) + T_{CHLL} (82188 min)
= 10 + 0 = 10 ns.

For 8087 = 0.5 (T_{CLCL}) − T_{CLAV} (8087 max) + T_{CHLL} (82188 min)
= 0.5 (125) − 55 + 0 = 7.5

Hold Time

= 0.5 (T_{CLCL}) − T_{CHLL} (82188 max) + T_{CLAZ} (186 min)
= 0.5 (125) − 30 + 10 = 42.5 ns.

NOTE:
The hold time calculation is the same for both the 80186 and 8087.

These timings provide adequate setup and hold times for a 74LS373 address latch.

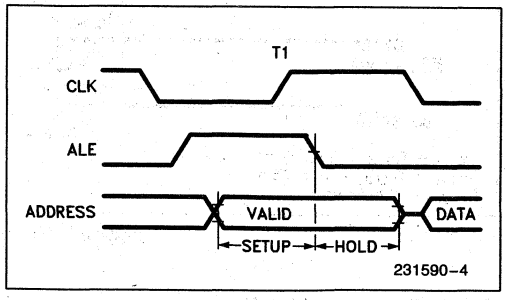
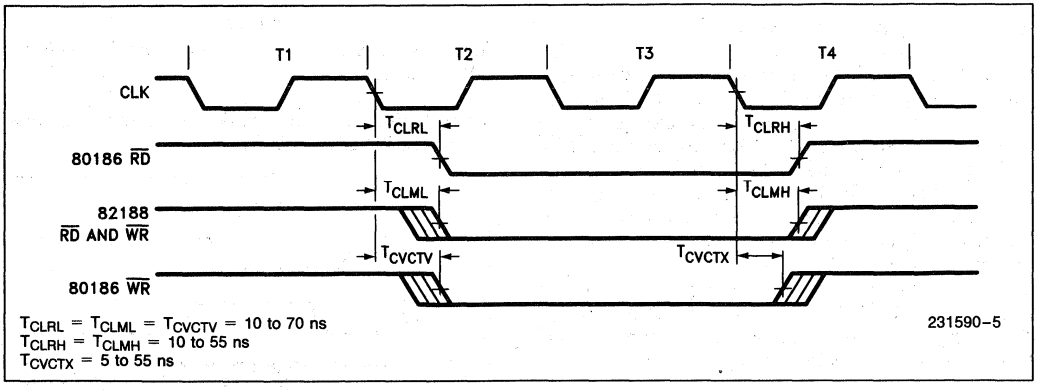


Figure 5. Address Latch Timings

5



$T_{CLRL} = T_{CLML} = T_{CVCTV}$ = 10 to 70 ns
$T_{CLRH} = T_{CLMH}$ = 10 to 55 ns
T_{CVCTX} = 5 to 55 ns

Figure 6. Read and Write Timings

5.3.2 Read and Write

The read and write signals of the 82188 have identical timings to those of the 80186 with one exception: the 82188 $\overline{WR}$ inactive edge may not go inactive quite as early as the 80186. This spec is, in fact, a tighter spec than the 80186 $\overline{WR}$ timing and should make designs easier. The timings for $\overline{RD}$ and $\overline{WR}$ are shown in Figure 6 for both the 80186 and the 82188.

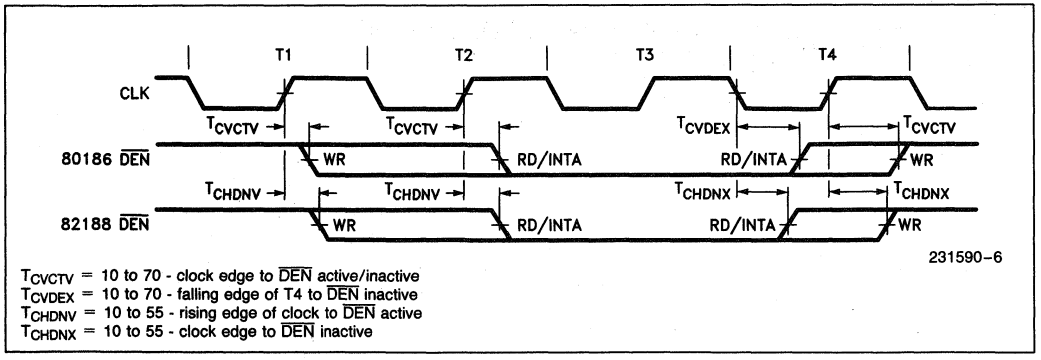
5.3.3 $\overline{DEN}$

The $\overline{DEN}$ signal on the 82188 is identical to the $\overline{DEN}$ signal on the 80186 but with a tighter timing specification. This makes designs easier with the 82188 and makes upgrades from 80186 bus control to 82188 bus control more straightforward. The timings for $\overline{DEN}$ on both the 80186 and 82188 are shown in Figure 7.

5.3.4 DT/$\overline{R}$

The operation of the DT/$\overline{R}$ signal varies somewhat between the 80186 and the 82188. The 80186 DT/$\overline{R}$ signal will remain in an active high state for all write cycles and will default to a high state when the system bus is idle (i.e., no bus activity). The 80186 DT/$\overline{R}$ goes low only for read cycles and does so only for the duration of the bus cycle. At the end of the read cycle, assuming the following cycle is a non-read, the DT/$\overline{R}$ signal will default back to a high state. Back-to-back read cycles will result in the DT/$\overline{R}$ signal remaining low until the end of the last read cycle.

The DT/$\overline{R}$ signal on the 82188 operates differently by making transitions only at the start of a bus cycle. The 82188 DT/$\overline{R}$ signal has no default state and therefore will remain in whichever state the previous bus cycle required. The 82188 DT/$\overline{R}$ signal will only change states when the current bus cycle requires a state different from the previous bus cycle.



T_{CVCTV} = 10 to 70 - clock edge to $\overline{DEN}$ active/inactive
T_{CVDEX} = 10 to 70 - falling edge of T4 to $\overline{DEN}$ inactive
T_{CHDNV} = 10 to 55 - rising edge of clock to $\overline{DEN}$ active
T_{CHDNX} = 10 to 55 - clock edge to $\overline{DEN}$ inactive

Figure 7. Data Control Timings

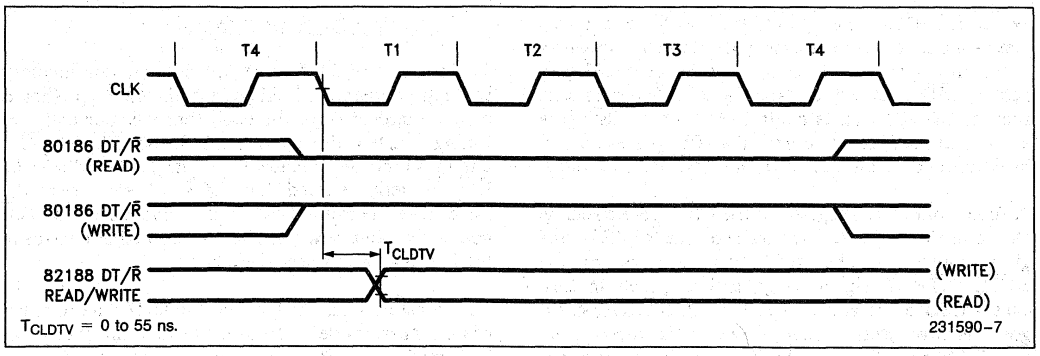


Figure 8. Data Transmit & Receive Timings

5.4 Chip Selects

5.4.1 INTRODUCTION

Chip-select circuitry is typically accomplished by using a discrete decoder to decode two or more of the upper address lines. When a valid address appears on the address bus, the decoder generates a valid chip-select. With this method, any bus master capable of placing an address on the system bus is able to generate a chip-select. An example of this is shown in Figure 9 where an 8086/8087 system uses a common decoder on the address bus. Note the decoder is able to operate regardless of which processor is in control of the bus.

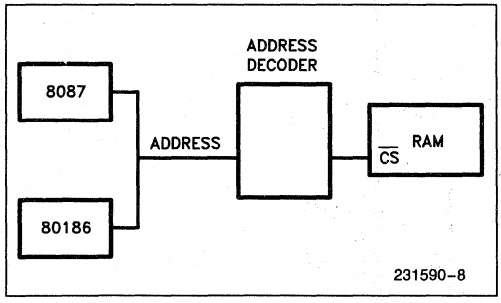


Figure 9. Typical 8086/8087 System

With high integration processors like the 80186 and 80188, the chip-select decoder is integrated onto the processor chip. The integrated chip-selects on the 80186 enable direct processor connection to the chip-enable pins on many memory devices, thus eliminating an external decoder. But because the integrated chip-selects decode the 80186's internal bus, an external bus master, such as the 8087, is unable to activate them. The 82188 IBC solves this problem by supplying a chip-select mechanism which may be activated by both the host processor and a second processor.

5.4.2 $\overline{CSI}$ AND $\overline{CSO}$ OF THE 82188

The $\overline{CSI}$ (chip select in) and $\overline{CSO}$ (chip select out) pins of the 82188 provide a way for a second bus master to select memory while also making use of the 80186 integrated chip-selects. The $\overline{CSI}$ pin of the 82188 connects directly to one of the 80186's chip-selects while $\overline{CSO}$ connects to the memory device designated for the chip-selects range. An example of this is shown in Figure 10.

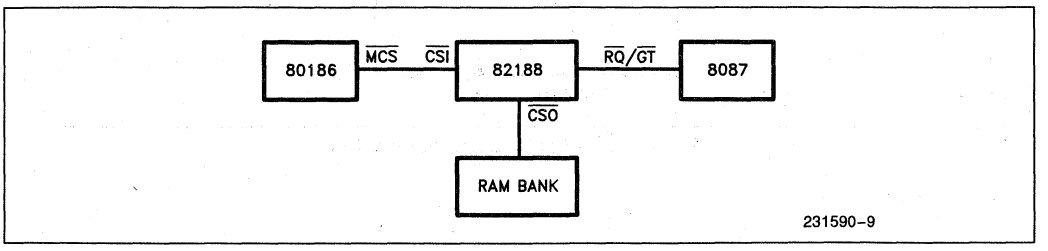


Figure 10. Typical 80186/82188/8087 System

When the 80186 has control of the bus, the circuit acts just as a buffer and the memory device gets selected as if the circuit had not been there. Whenever $\overline{CSI}$ goes active, $\overline{CSO}$ goes active. When a second bus master, such as the 8087, takes control of the bus, $\overline{CSO}$ goes active and remains active until the 8087 passes control back to the processor. At this time $\overline{CSO}$ is deactivated.

A functional block diagram of the $\overline{CSI}$–$\overline{CSO}$ circuit is shown in Figure 11. A grant pulse on the $\overline{RQ}/\overline{GT0}$ line gives control to the 8087 and also causes the $\overline{8087CONTROL}$ signal to go active, which in turn causes $\overline{CSO}$ to go active. The $\overline{8087CONTROL}$ signal goes inactive when either a release is received on $\overline{RQ}/\overline{GT0}$, indicating that the 8087 is relinquishing control to the main processor, or a grant is received on the $\overline{RQ}/\overline{GT1}$ line, indicating that the 8087 is relinquishing control to a third processor. Both actions signify that the 8087 is relinquishing the bus. If $\overline{CSO}$ goes inactive because a third processor took control of the bus, then $\overline{CSO}$ will go active again for the 8087 when a release pulse is transmitted on the $\overline{RQ}/\overline{GT1}$ line to the 8087. This release pulse occurs as a result of SYSHLDA going inactive from the third processor.

5.4.3 SYSTEM DESIGN EXAMPLE

To provide the 8087 access to data in low memory through an integrated chip-select, the $\overline{LCS}$ pin should be disconnected from the bank that it is currently selecting and fed directly into the 82188 $\overline{CSI}$. The $\overline{CSI}$ output should be connected to the banks which the $\overline{LCS}$ formerly selected. The $\overline{LCS}$ will still select the same banks because $\overline{CSO}$ goes active whenever $\overline{CSI}$ goes active. But now the 8087, when taking control of the bus, may also select these banks.

Care must be taken in locating the 8087 data area because it must reside in the area in which the chip-select is defined. If the 8087 generates an address outside of the $\overline{LCS}$ range, the $\overline{CSO}$ will still go active, but the address will erroneously select a part of the lower bank. Note also that this chip-select limits the size of the 8087 data area to the maximum size memory which can be selected with one chip-select. However, this does not place a limit on instruction code size or non-8087 data size. All 80186 and 8087 instructions are fetched by the processor and therefore do not require that the 8087 be

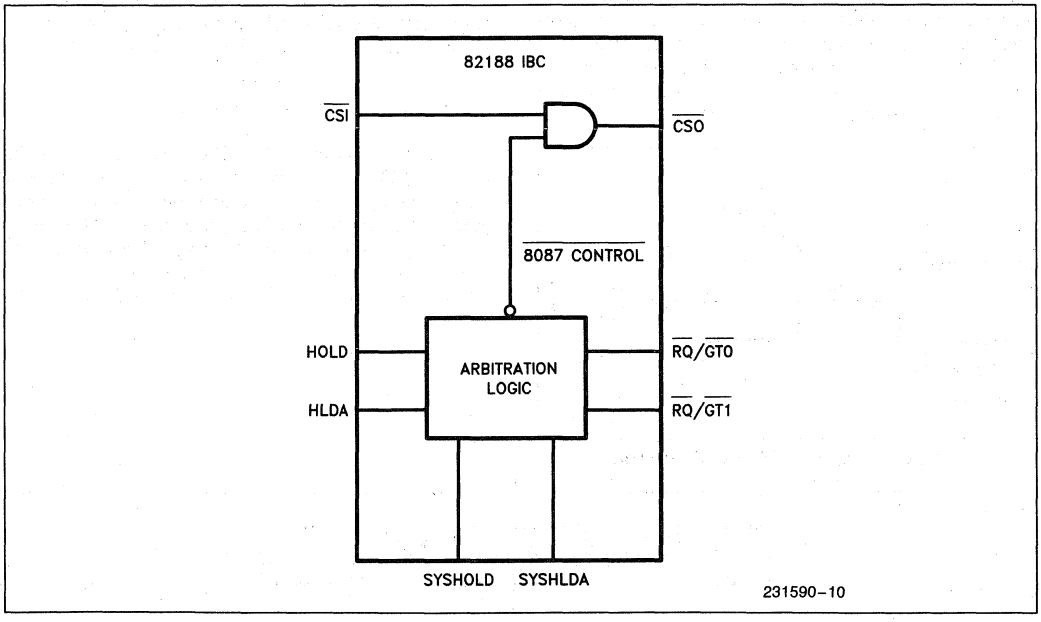


Figure 11. 82188 Chip Select Circuitry

able to address them. Likewise, non-8087 data is never accessed by the 8087 and therefore does not require an 8087 chip-select.

5.5 Wait State & Ready Logic

The 8087 must accurately track every instruction fetch the 80186 performs so that each op-code may be read from the system bus by the 8087 in parallel with the processor. This means that for instruction code areas, the 80186 cannot use internally generated wait states. All ready logic for these areas must be generated externally and sent into the 82188. The 82188 then presents a synchronous ready out (SRO) signal to both the 80186 and the 8087.

5.5.1 INTERNAL WAIT STATES WITH INSTRUCTION FETCHES

If internal wait states are used by the processor with the 8087 at zero wait states, then the 8087 will latch op-codes using a four clock bus cycle while the processor is using between five and seven clocks on each bus cycle. If the wait states are truly necessary to latch valid data from memory, then a four clock bus cycle will force the 8087 to latch invalid data. The invalid data may then be possibly interpreted to be an ESCAPE prefix when, in reality, it is not. The reverse may also hold true in that the 8087 may not recognize an ESCAPE prefix when it is fetched. These conditions could cause a system to hang (i.e., cease to operate), or operate with erroneous results.

If the memory is fast enough to allow latching of valid data within a four clock bus cycle, then the 80186 internal wait states will not cause the system to hang. Both processors will receive valid data during their respective bus cycles. The 8087 will finish its bus cycle earlier than the processor, but this is of no consequence to system operation. The 8087 will synchronize with the processor using the status lines S0–S2 at the start of the next instruction fetch.

5.5.2 INTERNAL WAIT STATES WITH DATA & I/O CYCLES

With the exception of "Dummy Read Cycles" and instruction fetches, all memory and I/O bus cycles executed by the host processor are ignored by the 8087. Coprocessor synchronization is not required for untracked bus cycles and, therefore, internally generated wait states do not affect system operation. All of the I/O space and any part of memory used strictly for data may use the internal wait state generator on the 80186.

Memory used for 8087 data is somewhat different. Here, as in the case of code segment areas, the system must rely on an external ready signal or else the memory must be fast enough to support zero wait state operation. Without an external ready signal, the 8087 will always perform a four clock bus cycle which, when used with slow memories, results in the latching of invalid data.

Internal wait states will not affect system operation for data cycles performed by the 8087. In this case the 8087 has control of the bus and the two processors operate independently.

One type of data cycle has not yet been considered. Each time a numerics variable is accessed, the host processor runs a "Dummy Read Cycle" in order to calculate the operand address for the 8087. The 8087 latches the address and then takes control of the bus to fetch any subsequent bytes which are necessary. If the 8087 variables are located at even addresses, then an internally generated wait state will not present any problems to the system. If any numeric variables are located at odd addresses, then the interface between the host and coprocessor becomes asynchronous causing erroneous results.

The erroneous results are due to the 80186 running two back-to-back bus cycles with wait states while the 8087 runs two back-to-back bus cycles without wait states. The start of the second bus cycle is completely uncoordinated between the two processors and the 8087 is unable to latch the correct address for subsequent transfers. For this reason, 8087 variables in a 80186 system must always lie on even boundaries when using the internal wait state generator to access them.

Numeric variables in an 80188 system must never be in a section of memory which uses the internal wait state generator. The 80188 will always perform consecutive bus cycles which would be equivalent to the 80186 performing an odd addressed "Dummy Read Cycle."

5.5.3 AUTOMATIC WAIT STATES AT RESET

The 80186 automatically inserts three wait states to the predefined upper memory chip select range upon power up and reset. This enables designers to use slow memories for system boot ROM if so desired. If slow ROM's are chosen, then no further programming is necessary. If fast ROM's are chosen, then the wait state logic may simply be reprogrammed to the appropriate number of wait states.

The automatic wait states have the possibility of presenting the same problem as described in section 5.5.1 if

the boot ROM needs one or more wait states. Under these conditions the 8087 would be forced to latch invalid opcodes and possibly mistake one for an ESCAPE instruction.

If the boot ROM requires wait states, then some sort of external ready logic is necessary. This allows both processors to run with the same number of wait states and insures that they always receive valid data.

If the boot ROM does not require wait states, then there is no need to design external ready logic for the upper chip select region. But if 8087 code is present in the upper memory chip select region, the situation described in section 3.4 regarding "Dummy Read Cycles" must be considered.

The 82188 solves this problem by inserting three wait states on the SRO line to the 8087 for the first 256 bus cycles. By doing this the 82188 inserts the same number of wait states to both processors keeping them synchronized. The initialization code for the 80186 must program the upper memory chip select to look at external ready and to insert zero wait states within these first 256 bus cycles. At the end of the 256 bus cycles, the 82188 stops inserting wait states and both processors run at zero wait states.

5.5.4 EXTERNAL READY SYNCHRONIZATION

The 80186 and 8087 sample READY on different clock edges. This implies that some sort of external synchronization is required to insure that both processors sample the same ready state. Without the synchronization, it would be possible for the external signal to change state between samples. The 80186 may sample ready high while the 8087 samples ready low. This would lead to the two processors running different length bus cycles and possibly cause the system to hang.

The 82188 provides ready synchronization through the ARDY and SRDY inputs. Once a valid transition is recorded, the 82188 presents the results on the SRO output and holds the output in that state until both processors have had a chance to sample the signal.

5.6 BUS ARBITRATION

In order for the 8087 to read and write numeric data to and from memory, it must have a means of taking control of the local bus. With the 8086/88 this is accomplished through a request-grant exchange protocol. The 80186, however, makes use of HOLD/HOLD ACKNOWLEDGE protocol to exchange control of the bus with another processor. The 82188 supplies the necessary conversion to interface $\overline{RQ/GT}$ to HOLD/HLDA signals. The $\overline{RQ/GT}$ signal of the 8087 connects directly to the 82188's $\overline{RQ/GT0}$ input while the 82188's HOLD and HLDA pins connect to the 80186's HOLD and HLDA pins.

When the 8087 requires control of the bus, the 8087 sends a request on the $\overline{RQ/GT0}$ line to the 82188. The 82188 responds by sending a HOLD request to the 80186. When HLDA is received back from the 80186, the 82188 sends a grant back to the 8087 on the same $\overline{RQ/GT0}$ line.

The 82188 also has provisions for adding a third busmaster to the system which uses HOLD/HLDA protocol. This is accomplished by using the 82188 SYSHOLD, SYSHLDA, and $\overline{RQ/GT1}$ signals. The third processor requests the bus by pulling the SYSHOLD line high. The 82188 will route (and translate if necessary) the requests to the current bus master. If the 8087 has control, the 82188 will request control via the $\overline{RQ/GT1}$ line which should be connected to the 8087's $\overline{RQ/GT1}$ line.

The 8087 will relinquish control by getting off the bus and sending a grant pulse on the $\overline{RQ/GT1}$ line. The 82188 responds by sending a SYSHLDA to the third processor. The third processor lowers SYSHOLD when it has finished on the bus. The 82188 routes this in the form of a release pulse on the $\overline{RQ/GT1}$ line to the 8087. The 8087 then continues bus activity where it left off. The maximum latency from SYSHOLD to SYSHLDA is equal to the 80186 latency + 8087 latency + 82188 latency.

5.7 SPEED REQUIREMENTS

One of the most important timing specs associated with the 80186-8087 interface is the speed at which the system should run. The 8087 was designed to operate with a 33% duty cycle clock whereas the 80186 and 80188 were designed to operate with a 50% duty cycle clock. In order to run both parts off the same clock, the 8087 must run at a slower speed than is typically implied by its dash number in the 8086/88 family.

To determine the speed at which an 8087 may run (with a 50% duty cycle clock), the minimum low and high times of the 8087 must be examined. The maximum of these two minimum specs becomes the half-period of the 50% duty cycle system clock. For example, the 8087-1 provides worst case spec compatibility with the 80186 at system clock-speeds of up to 8 MHz. The clock waveforms are shown in Figure 12 using 10 MHz timings.

The minimum clock low time spec (T_{CLCH}) of the 10 MHz 8087 is 53 ns. The clock low time of an 8 MHz 80186 is specified to be:

$$\frac{1}{2}(T_{CLCL}) - 7.5$$

Solving for T_{CLCL} of the 80186 using T_{CLCH} of the 8087 yields the following:

$$\frac{1}{2}(T_{CLCL}) - 7.5 = T_{CLCH}$$

$$(T_{CLCL}) = 2(T_{CLCH} + 7.5)$$

$$T_{CLCL} = 121 \text{ ns}$$

The calculation shows minimum cycle time of the 80186 to be 121 ns. This time translates into a maximum frequency of 8.26 MHz.

6.0 BENCHMARKS

6.1 Introduction

The following benchmarks compare the overall system performance of an 8086, 80188, and an 80186 in numeric applications. Results are shown for all three processors in systems with the 8087 coprocessor and in systems using an 8087 software emulator. Three FORTRAN benchmark programs are used to demonstrate the large increase in floating-point math performance provided by the 8087 and also the increase in performance due to the enhanced 80186 and 80188 host processors.

The 8086 results were measured on an Intellec® Series III Microcomputer Development System with an iSBC® 86/12 board and an iSBC 337 multimodule. Typically, one wait state for memory read cycles and two wait states for memory write cycles are experienced in this environment.

The 80186 and 80188 results were measured on a prototype board which allowed zero wait state operation at 8 MHz. The benchmarks measured using the 8087 showed little sensitivity to wait states. Instructions executed on the 8087 tend to be long in comparison to the amount of bus activity required and, therefore, are not affected much by wait states.

The benchmarks measured using the software emulator are much more bus intensive and average from 10 to 15 percent performance degradation for one wait state.

All execution times shown here represent 8 MHz operation. The 8086 results were measured at 5 MHz and extrapolated to achieve 8 MHz execution times.

6.2 Interest Rate Calculations

Routines were written in FORTRAN-86 to calculate the final value of a fund given the annual interest and the present value. It is assumed that the interest will be compounded daily, which requires the calculation of the yearly effective rate. This value, which is the equivalent annual interest if the interest were compounded daily, is determined by the following formula:

```
yer = (1 + (ir/np))**np - 1
```

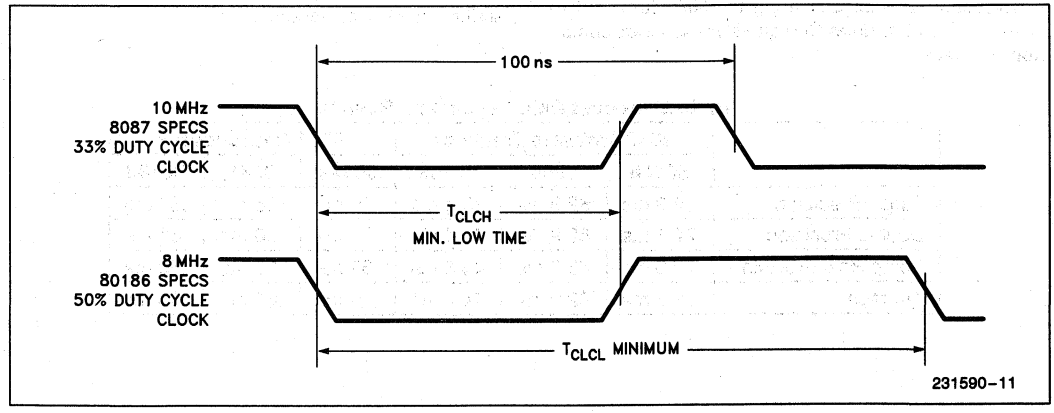


Figure 12. Clock Cycle Timing

where:

yer is the yearly effective rate
ir is the annual interest rate
np is the number of compounding periods per annum

Once the yer is determined, the final value of the fund is determined by the formula:

fv = (1 + yer) * pv

where:

pv is the present value
fv is the future value

Results are obtained using single-precision, double-precision, and temporary real precision operands when:

ir is set to 10% (0.1)
np is set to 365 (for daily compounding)
pv is set to $2,000,000

THE RESULTS:

	yer	Final Value
Single-Precision (32-bit)	10.514%	$2,210,287.50
Double-Precision (64-bit)	10.516%	$2,210,311.57
Temporary Real Precision	10.516%	$2,210,311.57

The difference between the final single-precision and double-precision values is $24.07; the difference in the final value between the double-precision and the temporary real precision is 0.000062 cents. Since the 8087 performs all internal calculations on 80-bit floating point numbers (temp real format), temporary real precision operations perform faster than single- or double-precision. No data conversions are required when loading or storing temporary real values in the 8087. Thus, for business applications, the double-precision computing of the 8087 is essential for accurate results, and the performance advantage of using the 8087 turns out to be as much as 100 times the equivalent software emulation program.

6.3 Matrix Multiply Benchmark Routine

A routine was written in FORTRAN-86 to compute the product of two matrices using a simple row/column inner-product method. Execution times were obtained for the multiplication of 32×32 matrices using double precision. The results of the benchmark are shown in Figure 14.

The results show the 8087 coprocessor systems performing from 23 to 31 times faster than the equivalent software emulation program. Both the 80188/87 and the 80186/87 systems outperform the 8086/87 system by 34 to 75 percent. This difference is mainly attributed to the fact that the matrix program largely consists of effective address calculations used in array accessing. The hardware effective address calculator of the 80186 and 80188 allow each array access to improve by as much as three times the 8086 effective address calculation.

6.4 Whetstone Benchmark Routine

The Whetstone benchmark program was developed by Harry Curnow for the Central Computer Agency of the British government. This benchmark has received high visibility in the scientific community as a measurement of main frame computer performance. It is a "synthetic" program. That is, it does not solve a real problem, but rather contains a mix of FORTRAN statements which reflect the frequency of such statements as measured in over 900 actual programs. The program computes a performance metric: "thousands of Whetstone instructions per second (KIPS)."

Simple variable and array addressing, fixed- and floating- point arithmetic, subroutine calls and parameter passing, and standard mathematical functions are performed in eleven separate modules or loops of a prescribed number of iterations.

Table 2. Interest Rate Benchmark Results

	8087 Software Emulator			8087 Coprocessor		
	80188	8086	80186	80188	8086	80186
Single Precision	70.3 ms	62.8 ms	43.4 ms	.70 ms	.66 ms	.61 ms
Double Precision	72.1 ms	62.9 ms	44.4 ms	.71 ms	.66 ms	.61 ms
Temp Real Precision	72.6 ms	63.0 ms	44.8 ms	.69 ms	.65 ms	.59 ms
Average	71.7 ms	62.9 ms	44.2 ms	.70 ms	.66 ms	.60 ms

The original coding of the Whetstone benchmark was written in Algol-60 and used single-precision values. It was rewritten in FORTRAN with single-precision values to exactly reflect the original intent. Another version was created using double-precision values. The results are shown in Table 3.

The results show the 8087 systems with the 80186 and 80188 outperforming the equivalent software emulation by 60 to 83 times. Additionally, the 80186 coupled with the 8087 outperformed the 8086/87 system by 22 percent.

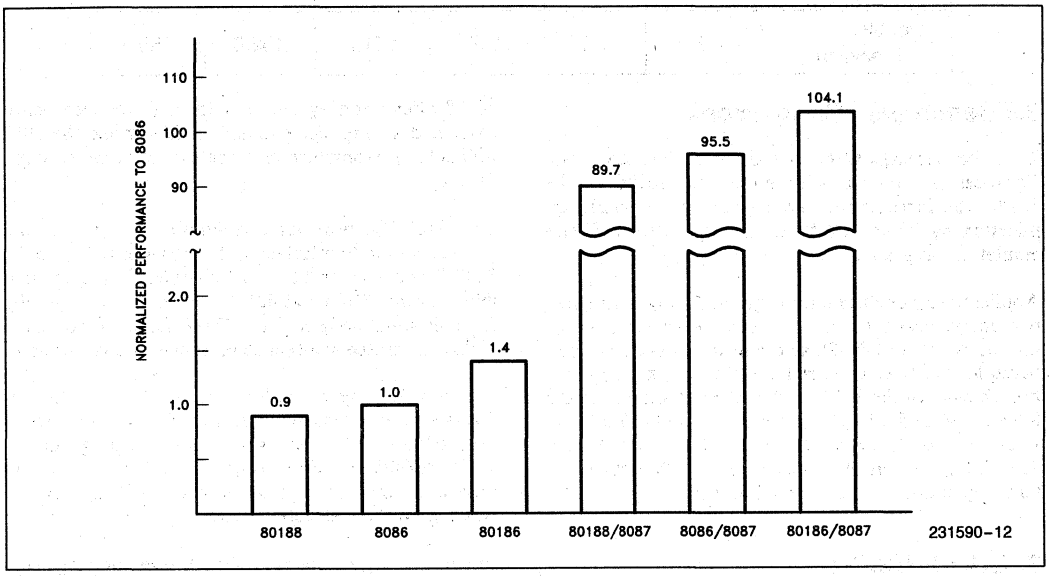


Figure 13. Interest Rate Benchmark Results

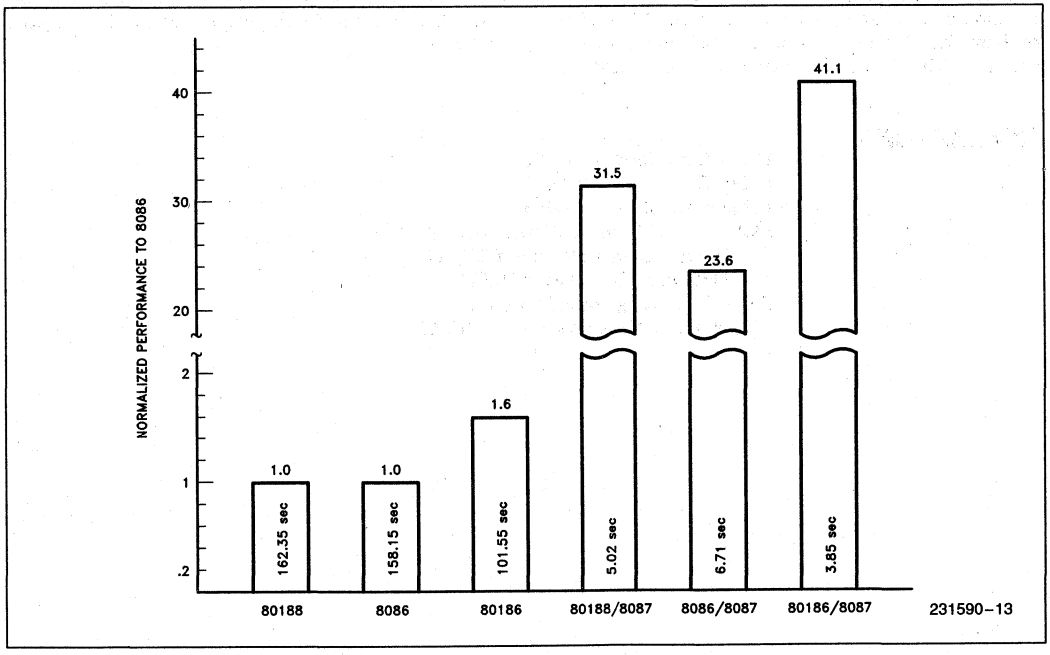


Figure 14. Double Precision Matrix Multiplication

Table 3. Whetstone Benchmark Results

Units = KIPS	8087 Software Emulator			8087 Coprocessor		
	80188	8086	80186	80188	8086	80186
Single Precision	2	2.3	3.3	165.8	178.0	197.6
Double Precision	2	2.2	3.2	151.7	152.0	185.2

6.5 Benchmark Conclusions

These benchmarks show that the 8087 Numeric Data Coprocessor, coupled with either the 80186 or the 80188, can increase the performance of a numeric application by 75 to 100 times the equivalent software emulation program.

Applications which require array accessing with effective address calculations will benefit even more by using the 80188 and 80186 as the host processor as compared to the 8086. The results of the matrix multiplication show both the 80188 and 80186 outperforming the 8086 by 34 and 75%, respectively, in an 8087 system. In general, an 80186/8087 system will offer a 10% to a 75% improvement over an equivalent 8086/8087 system, depending on the instruction mix.

7. CONCLUSION

For controller applications which require high performance in numerics and low system cost, the 16-bit 80186 or 8-bit 80188 coupled with the 8087 offers an ideal solution. The integrated features of the 80186 and 80188 offer a low system cost through reduced board space and a simplified production flow while the 8087 fulfills the performance requirements of numeric applications.

The 82188 IBC provides a straightforward, highly integrated solution to interfacing the 80188 or 80186 to the 8087. The bus control timings of the 82188 are compatible with the 80186 and 80188, allowing easy upgrades from existing designs. The 82188 features present a highly integrated solution to both new and old designs.

The coprocessing capabilities of the 8087 bring performance improvements of 75 to 100 times the equivalent 80186 or 80188 software emulation program and an 80186/8087 system will offer a 10% to a 75% improvement over an equivalent 8086/8087 system depending on the instruction mix.

In addition a growing base of high-level language support (FORTRAN, Pascal, C, Basic, PL/M, etc.) from Intel and numerous third-party software vendors facilitates the timely and efficient generation of application software.

REFERENCES:

82188 Data Sheet #231051
80186 Data Sheet #210451
80188 Data Sheet #210706
iAPX 86/88 80186/188 Users Manual
Programmers Reference #210911
Hardware Reference #210912
AP-113 "Getting Started with the
Numeric Data Processor #207865

intel®

APPLICATION NOTE

AP-286

October 1986

80186/188 Interface to Intel Microcontrollers

5

PARVIZ KHODADADI
APPLICATIONS ENGINEER

Order Number: 231784-001

80186/188 INTERFACE TO INTEL MICROCONTROLLERS

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1.0 INTRODUCTION

Systems which require I/O processing and serial data transmission are very software intensive. The communication task and I/O operations consume a lot of the system's intelligence and software. In many conventional systems the central processing unit carries the burden of all the communication and I/O operations in addition to its main routines, resulting in a slow and inefficient system.

In an ideal system, tasks are divided among processors to increase performance and achieve flexibility. One attractive solution is the combination of the Intel highly integrated 80186 microprocessor and the Intel 8-bit microcontrollers such as the 80C51, 8052, or 8044. In such a system, the 80186 provides the processing power and the 1 Mbyte memory addressability, while the controller provides the intelligence for the I/O operations and data communication tasks. The 80186 runs application programs, performs the high level communication tasks, and provides the human interface. The microcontroller performs 8-bit math and single bit boolean operations, the low level communication tasks, and I/O processing.

This application note describes an efficient method of interfacing the 16-bit 80186 high integration microprocessor to the 80C51, 8052, or the microcontroller-based 8044 serial communication controller. The interface hardware shown in Figure 1.1, is very simple and may be implemented with a programmable logic device or a gate-array. The 80186 and the microcontroller may run asynchronously and at different speeds. With this technique data transfers up to 200 Kbytes per second can be achieved between a 12 MHz microcontroller and an 8 MHz 80186.

The 8-bit 80188 high integration microprocessor can also be used with the same interface technique. The performance of the interface is the same since an 8-bit bus is used.

Interface to the 8044, 80C51, and the 8052 is identical because they have identical pinouts (some pins have alternate functions). As an example, the software procedures for the 8044/80186 interface, which is the building block for the application driver, is supplied in this Application Note.

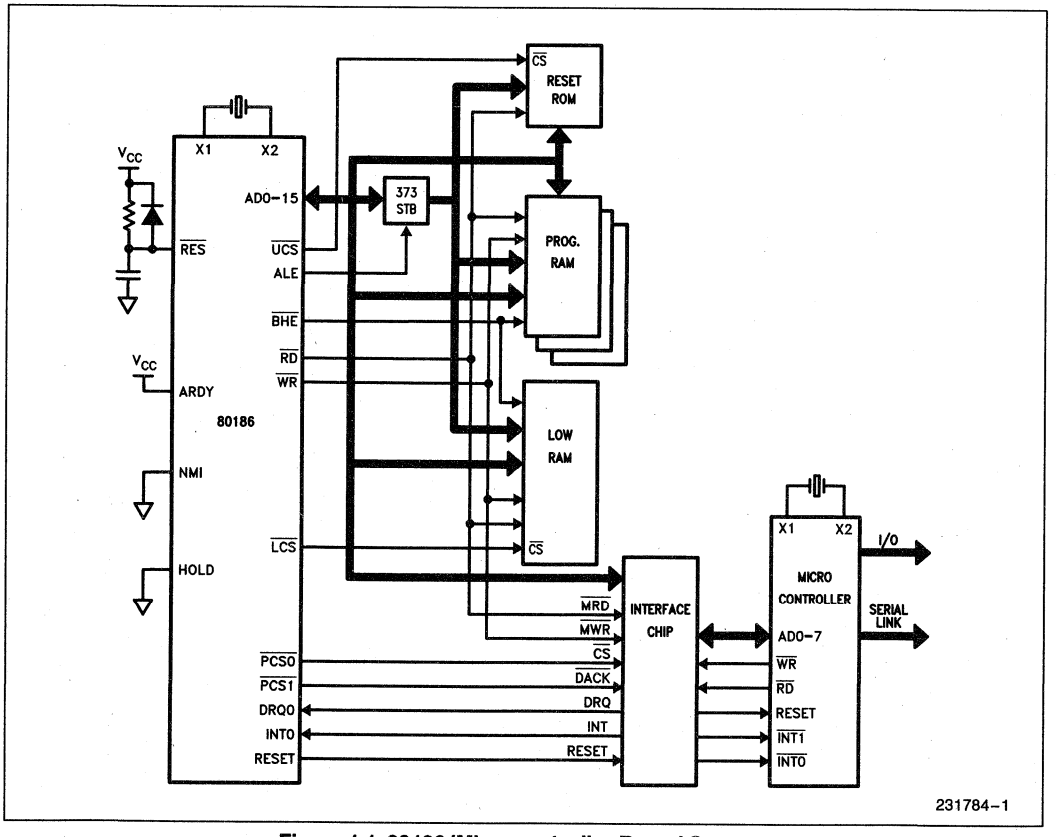

Figure 1.1. 80186/Microcontroller Based System

1.1 System Overview

The 80186 and the microcontrollers are processors. They each access memory and have address/data, read, and write signals. There are three common ways to interface multiple processors together:

1) First In First Out (FIFO)

2) Dual Port RAM (DPRAM)

3) Slave Port

The FIFO interface, compared to DPRAM, requires less TTL and is easier to interface; however, FIFOs are expensive. The DPRAM interface is also expensive and even more complex. When DPRAM is used, the address/data lines of each processor must be buffered, and hardware logic is needed to arbitrate access to DPRAM. The slave port interface given here is cheaper and easier than both FIFO and DPRAM alternatives.

The 80186 processor, when interfaced to this circuit, views the microcontroller as a peripheral chip with 8-bit data bus and no address lines (see Figure 1.1). It can read status and send commands to the microcontroller at any time. The microcontroller becomes a slave co-processor while keeping its processing power and serial communication capabilities.

The microcontrollers, with the interface hardware, have a high level command interface like many other data communication peripherals. For example, the 80186 can send the microcontroller commands such as Transmit or Configure. This means the designer does not have to write low level software to perform these tasks, and it offloads the 80186 to serve other functions in the application.

1.2 Application Examples:

The combination of the 80186 and a microcontroller basically provides all the functions that are needed in a system: a 16-bit CPU, 8-bit CPU, DMA controller, I/O ports, and a serial port. The 80C51 and the 8052 have an on-chip asynchronous channel, while the 8044 has an intelligent SDLC serial channel. In addition, many other functions such as timers, counters, and interrupt controllers are integrated in both the 80186 and the microcontrollers.

Applications of the system described above are in the area of robotics, data communication networks, or serial communication backplanes. A typical example is copiers. Different segments of the copy machine like the motor, paper feed, diagnostics, and error/warning displays are all controlled by microcontrollers. Each segment receives orders from and replies to the central processor which consists of the 80186 interfaced with a microcontroller.

Another common application is in the area of process controllers. An example is a central control unit for a multiple story building which controls the heating, cooling, and lighting of each room in each floor. In each room a microcontroller performs the above functions based on the orders received from the central processor. Depending on the throughput and type of the serial communication required, the 8044 or the 80C51 (8052) may be selected for the application.

2.0 OVERVIEW OF THE 80186, 80C51, 8052, AND 8044

This section briefly discusses the features of the microcontrollers and the 80186. For more information about these products please refer to the Intel Microcontroller and Microsystem components hand-books. Readers familiar with the above products may skip this section.

2.1 The 80186 Internal Architecture

The 80186 contains an enhanced version of Intel's popular 8086 CPU integrated with many other features common to most systems (Figure 2.1). The 16-bit CPU can access up to 1 Mbyte of memory and execute instructions faster than the 8086. With speed selection of 8, 10, and 12.5 MHz, this highly integrated product is the most popular 16-bit microprocessor for embedded control applications.

The on-chip DMA controller has two channels which can each be shared by multiple devices. Each channel is capable of transferring data up to 3.12 Mbytes per second (12.5 MHz speed). It offers the choice of byte or word transfer. It can be programmed to perform a burst transfer of a block of data, transfer data per specified time interval, or transfer data per external request.

The on-chip interrupt controller responds to both external interrupts and interrupts requested by the on-chip peripherals such as the timers and the DMA channels. It can be configured to generate interrupt vector addresses internally like the microcontrollers or externally like the popular 8259 interrupt controller. It can be configured to be a slave controller to an external interrupt controller (iRMX 86 mode) or be master for one or two 8259s which in turn may be masters for up to 8 more 8259s. When configured in master mode, each channel can support up to 64 external interrupts (128 total).

Three 16-bit timers are also integrated on the chip. Timer 0 and timer 1 can be configured to be 16-bit counters and count external events. If configured as timers, they can be started by software or by an external event. Timer 0 and 1 each contain a timer output pin. Transitions on these pins occur when the timers reach one of the two possible maximum counts. Timer

2 can be used as a prescaler for timer 0 and 1 or can be used to generate DMA requests to the on-chip DMA channel.

Finally, the integrated clock generator, the wait state generator, and the chip select logic reduce the external logic necessary to build a processing system.

2.2 The MCS-51 Internal Architecture

The 80C51BH, as shown in Figure 2.2, consists of an 8-bit CPU which can access up to 64 Kbytes of data memory (RAM) and 64 Kbytes of program memory (ROM). In addition, 4 Kbytes of ROM and 128 bytes of RAM are built onto the chip.

The on-chip interrupt controller supports five interrupts with two priority levels. There are two timers integrated in the 80C51. Timer 0 and 1 can be configured as 8-bit or 16-bit timers or event counters.

Finally the integrated full duplex asynchronous serial channel provides the human interface or communication capability with other microcontrollers. The UART supports data rates up to 500 kHz (with 15 MHz crystal) and can distinguish between address bytes and data bytes.

The 8052 has the same features as the 80C51 except it has 8 Kbytes of on-chip ROM and 256 bytes of on-chip RAM. In addition the 8052 has another timer which may be configured as the baud rate generator for the serial port.

2.3 The 8044 Internal Architecture

The 8044 has all the features of the 80C51. In addition the on-chip RAM size is increased to 192 bytes and an intelligent HDLC/SDLC serial channel (SIU) replaces the 80C51 serial port (see Figure 2.3). It supports data rates up to 2.4 Mbps when an external clock is used and 375 Kbps when the clock is extracted from the data line. The serial port can be used in half duplex point to point, multipoint, or one-way loop configurations.

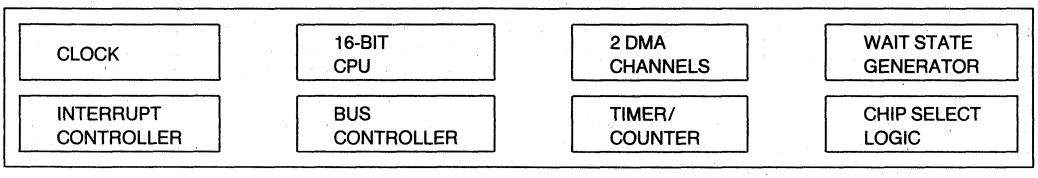

Figure 2.1. 80186 Block Diagram

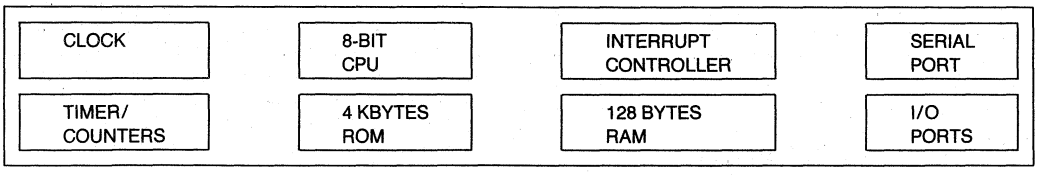

Figure 2.2. 80C51 Block Diagram

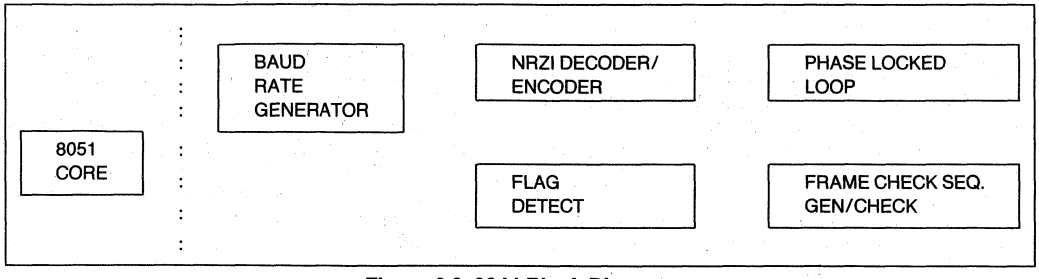

Figure 2.3. 8044 Block Diagram

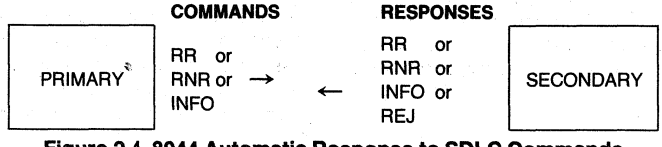

Figure 2.4. 8044 Automatic Response to SDLC Commands

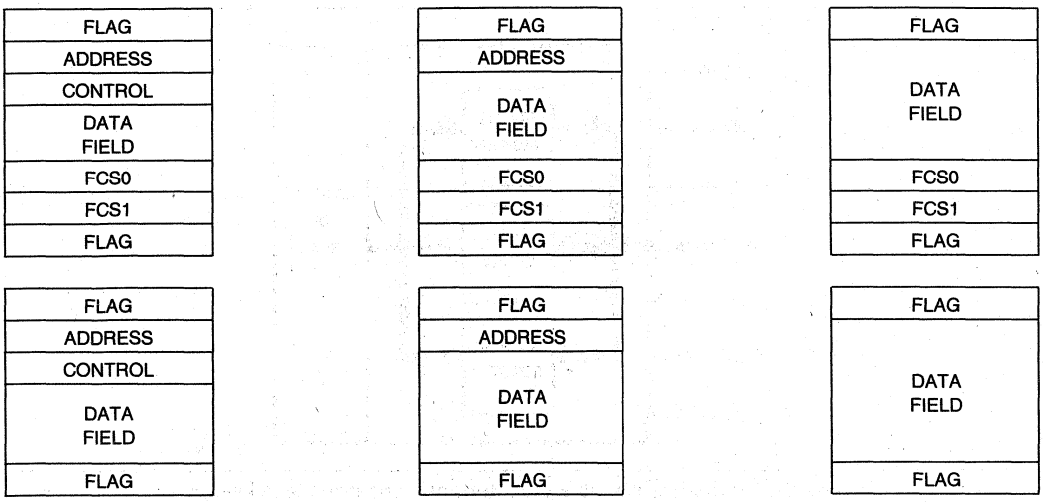

Figure 2.5. The 8044 Frame Formats

The SIU is called an intelligent channel because it responds to some SDLC commands automatically without the CPU intervention when it is set in auto mode. These automatic responses substantially reduce the communication software. Figure 2.4 gives the commands and the automatic responses.

The 8044 supports many types of frames including the standard SDLC format. Figure 2.5 shows the types of frames the 8044 can transmit and receive. If a format with an address byte is chosen, the 8044 performs address filtering during reception and transmits the contents of the station address register during transmission automatically. If a format with FCS bytes is chosen, the 8044 performs Cyclic Redundancy Check (CRC) during reception and calculates the FCS bytes during transmission of a frame in hardware. Two preamble bytes (PFS) may optionally be added to the frames. Formats that include the station address and the control byte are supported both in the auto and flexible modes.

3.0 80186/MICROCONTROLLER INTERACTION

The 80186 communicates with the microcontroller (8044, 80C51 or 8052) through the system's memory and the Command/Data and Status registers. The CPU creates a data structure in the memory, programs the DMA controller with the start address and byte count of the block, and issues a command to the microcontroller. A hypothetical block diagram of a microcontroller when used with the interface hardware is given in Figure 3.1.

Chip select and interrupt lines are used to communicate between the microcontroller and the host. The interrupt is used by the microcontroller to draw the 80186's attention. The Chip Select is used by the 80186 to draw the microcontroller's attention to a new command.

There are two kinds of transfers over the bus: Command/Status and data transfers. Command/Status transfers are always performed by the CPU. Data transfers are requested by the microcontroller and are typically performed by the DMA controller.

The CPU writes commands using CS and WR signals and interrupts the microcontroller. The microcontroller reads the command, decodes it and performs the necessary actions. The CPU reads the status register using CS and RD signals (see Figure 4.1).

To initiate a commnad like TRANSMIT or CONFIGURE, a write operation to the microcontroller is issued by the CPU. A read operation from the CPU gives the status of the microcontroller. Section 5 discusses details on these commands and the status.

Any parameters or data associated with the command are transferred between the system memory and the microcontroller using DMA. The 80186 prepares a data block in memory. Its first byte specifies the length of the rest of the block. The rest of the block is the information field. The CPU programs the DMA controller with the start address of the block, length of the block and other control information and then issues the command to the microcontroller.

When the microcontroller requires access to the memory for parameter or data transfer, it activates the 80186 DMA request line and uses the DMA controller to achieve the data transfer. Upon completion of an operation, the microcontroller interrupts the 80186. The CPU then reads results of the operation and status of the microcontroller.

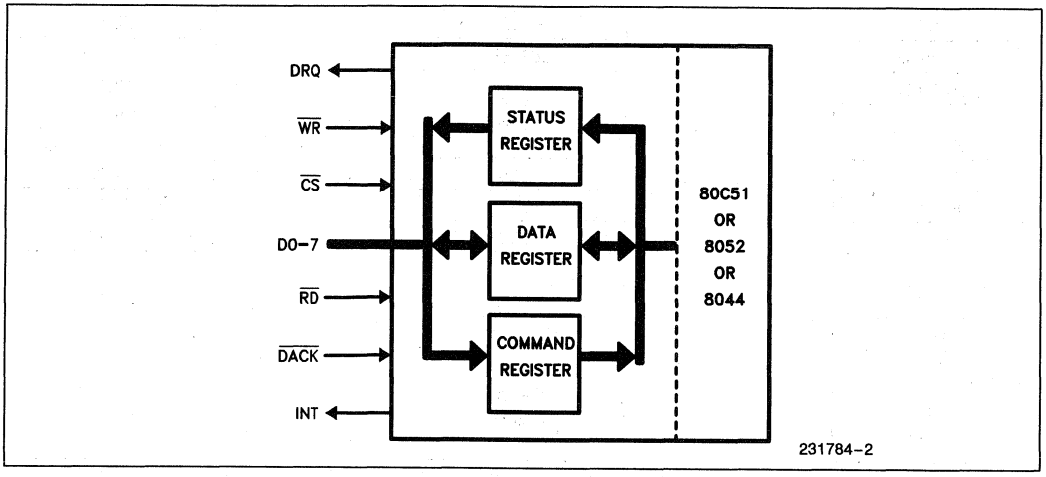

Figure 3.1. Microcontroller Plus the Interface Hardware Block Diagram

4.0 SYSTEM INTERFACE

There are two kinds of transfers over the bus: command/status and data transfers. The command/status transfers are always initiated and performed by the 80186. The data transfers are requested by the microcontroller using the DMA request (DRQ) line. In relatively slow systems the 80186 might also perform the data transfers. In that case, the request from the microcontroller will serve as an interrupt to the CPU. This mode of operation depends on the serial data rate.

The system interface performs command/status transfers, data/parameter transfers, and interrupts. This section describes the interface between the 80186 and a microcontroller shown in Figure 1.1. Section 6 describes the interface hardware.

4.1 Command/Status Transfers

The 80186 controls the microcontroller by writing into the command/data register and reading from the status register. The CPU writes a command by activating the chip select (PCS0), putting the command onto the data bus, and activating the WR signal. The command byte is latched into the command/data register, and the microcontroller is interrupted. In the interrupt service routine, the microcontroller reads the command byte from the command/data register, decodes the command byte, and activates the DRQ for data or parameter transfer if the decoded command requires such transfer.

At the end of parameter transfer the microcontroller updates the status register and interrupts the 80186.

4.2 Data/Parameter Transfer

Data/parameter transfers are controlled by a pair of REQUEST/ACKNOWLEDGE lines: DMA Request line (DRQ) and DMA Acknowledge line (DACK). Data and parameters are transferred via the Command/Data register to or from memory.

In order to request a transfer from memory, the microcontroller activates the DRQ pin. The DRQ signal goes active after a read operation by the microcontroller. In response, the 80186 DMA controller performs a byte transfer from the memory to the Command/Data register. Data is transferred on the bus and written into the Command/Data register on the rising edge of the 80186 WR signal ($\overline{MWR}$), which is activated by the DMA controller. Figure 4.2 shows the write timing.

In order to request a transfer to memory, the microcontroller activates the DRQ signal and outputs the data into the Command/Data latch. When the microcontroller WR signal goes active, DRQ is set. In response, the DMA performs the data transfer and resets the DRQ signal. Figure 4.3 shows the read timing.

4.3 Interrupt

The microcontroller reports on completion of an event by updating the status register and raising the interrupt signal assuming this signal is initially low. The interrupt is cleared by the command from the CPU where the INTERRUPT ACKNOWLEDGE bit is set (MD7). The INTA bit is the most significant bit of the command byte. Figure 4.4 and 4.5 show the interrupt timing. Note that it is the responsibility of the CPU to clear the interrupt in order to prevent a deadlock.

80186 Pin Name			Function
$\overline{CS}$	$\overline{RD}$	$\overline{WR}$	
1 0	X 1	X 1	No Transfer to/from Command/Status
0	0	0	Illegal
0	0	1	Read from Status Register
0	1	0	Write to Command/Data Register
$\overline{DACK}$	$\overline{RD}$	$\overline{WR}$	
1 0	X 1	X 1	No Transfer
0	0	0	Illegal
0	0	1	Data Read from DMA Channel
0	1	0	Data Write to DMA Channel

NOTE:
Only one of CS, DACK may be active at any time.

Figure 4.1. Data Bus Control Signals and Their Functions

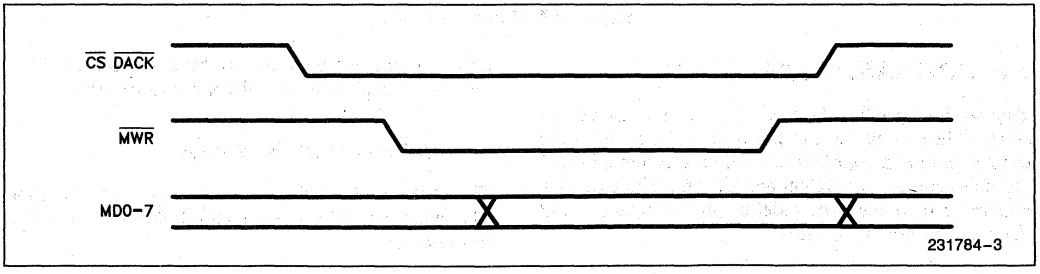

Figure 4.2. Write Timing

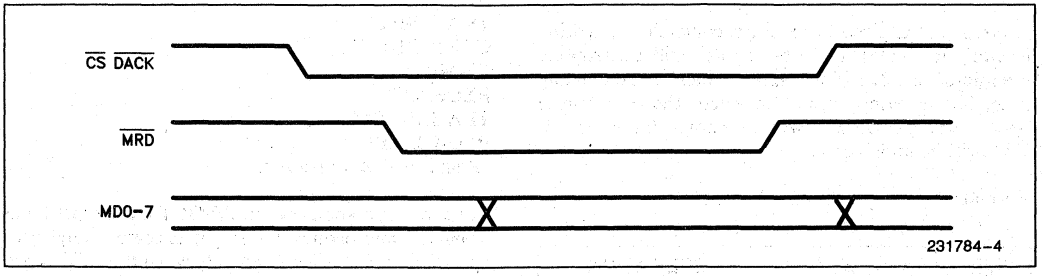

Figure 4.3. Read Timing

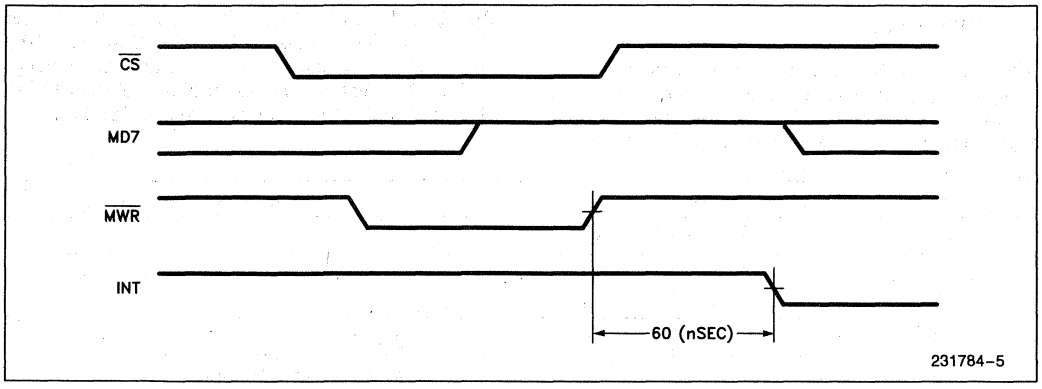

Figure 4.4. Interrupt Timing (Going Inactive)

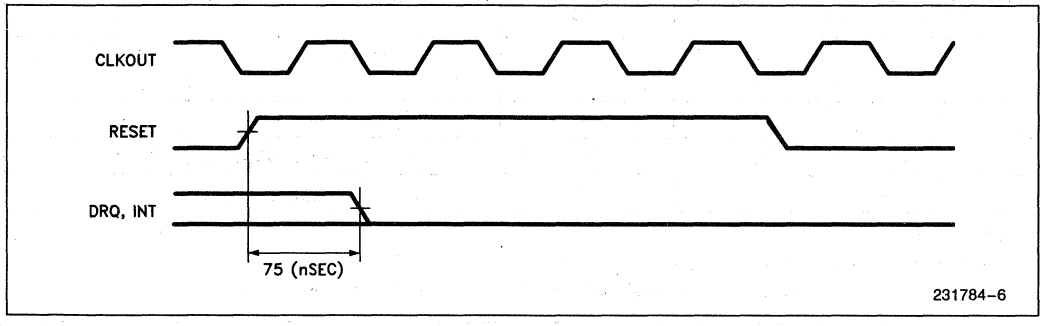

Figure 4.5. Reset Timing

5.0 COMMANDS AND STATUS

This section specifies the format of the commands and status. The commands and status given here are similar to most common coprocessors and data communication peripherals (e.g., the 82588 and 82586). The user may add more commands or redefine the formats for his/her own specific application.

5.1 Commands

A command is given to the microcontroller by writing it into the Command/Data register and interrupting the microcontroller. The command can be issued at any time; but in case it is not accepted, the operation is treated like a NOP and will be ignored (although the INT will be updated).

Format:

7	6	5	4	3	2	1	0
INTA	X	X	X	OPERATION			

5.1.1 ACKNOWLEDGING INTERRUPT (BIT 7)

The INTA bit, if set, causes the interrupt hardware signal and the interrupt bit to be cleared. This is the only way to clear the interrupt bit and reset the 80186 interrupt signal other than by a hardware reset.

5.1.2 OPERATIONS (BITS 0-3)

The OPERATION field initiates a specific operation. The microcontroller executes the following commands in software:

NOP
ABORT
TRANSMIT*
CONFIGURE*
DUMP*
RECEIVE*
TRA-DISABLE
REC-DISABLE
*Requires DMA operation.

The above operations except ABORT are executed only when the microcontroller is not executing any other operation. Abort is accepted only when the CPU is performing a DMA operation.

Operations that require parameter transfer (e.g., CONFIGURE and DUMP) or data transfer (e.g., TRANSMIT and RECEIVE) are called parametric operations. The remaining are called non-parametric operations.

An operation is initiated by writing into the command register. This causes the microcontroller to execute the command decode instructions. Some of the operations cause the microcontroller to read parameters from memory. The parameters are organized in a block that starts with an 8-bit byte count. The byte count specifies the length of the rest of the block. Before beginning the operation, the DMA pointer of the DMA channel must point to the byte count. There is no restriction on the memory structure of the parameter block as long as the microcontroller receives the next byte of the block for every DMA request it generates. Transferring the bytes is the job of the 80186 DMA controller.

The microcontroller requests the byte-count and determines the length of the parameter block. It then requests the parameters.

Upon completion of the operation, (when interrupt is low) the microcontroller updates the status, raises the interrupt signal, and goes idle.

NOP

This operation does not affect the microcontroller. It has no parameters and no results.

ABORT

This operation attempts to abort the completion of an operation under execution. It is valid for CONFIGURE, TRANSMIT, DUMP, and RECEIVE. It is ignored for any of the above if transfer of parameters has already been accomplished. The microcontroller, upon reception of the ABORT command, stops the DMA operation and issues an Execution-Aborted interrupt.

TRANSMIT

This operation transmits one message. A message may be transmitted as an SDLC frame by the 8044, or in ASYNC protocol by the 80C51 or the 8052 serial port.

Figure 5.1 shows the format of the Transmit block. A typical transmit operation parameter block includes the destination address and the control byte in the information field. As an example, see the 8044 transmit block in Figure 7.2.

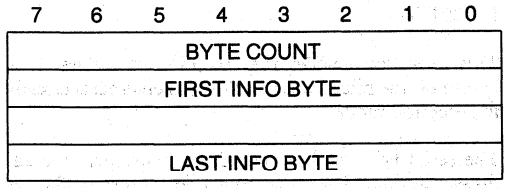

Figure 5.1. Format of Transmit Block

The transmit operation will either complete the execution or be aborted by a specific ABORT operation. A Transmit-Done or Execution-Aborted interrupt is issued upon completion of this operation.

CONFIGURE

This operation configures the microcontroller's internal registers. The length and the part of the configuration block that is modified are determined by the first two bytes of the command parameter (see Figure 5.2). The FIRST BYTE specifies the first register in the configure block that will be configured, and the BYTE COUNT specifies the number of registers that will be configured starting with the FIRST BYTE. For example, if the FIRST BYTE is 1 and the BYTE COUNT is the length of the configure block, then all of the registers are updated. If FIRST BYTE is 4 and BYTE COUNT is 2, then only the fourth register in the configure block is updated. Minimum byte count is 2.

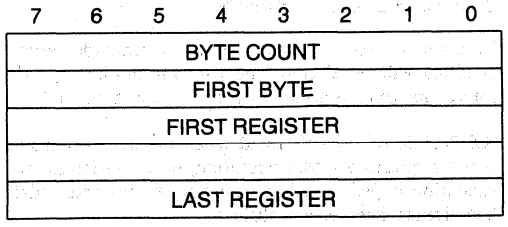

Figure 5.2. Format of Configure Block

A Configure-Done interrupt is issued when the operation is done unless ABORT was issued during the DMA operation.

DUMP

This operation causes dumping of a set of microcontroller internal registers to system memory. Figure 7.4 shows the format of the 8044 DUMP block.

The DUMP operation will either complete the execution or be aborted by a specific ABORT operation. A Dump-Done or Execution-Aborted interrupt is issued upon completion of this operation.

RECEIVE

This operation enables the reception of frames. It is ignored if the microcontroller's serial channel is already in reception mode.

The serial port receives only frames that pass the address filtering. The microcontroller transfers the received information and the byte count to the system memory using DMA. The completion of frame reception causes a Receive-Done event.

REC-DISABLE

This operation causes reception to be disabled. If transfer of data to the 80186 memory has already begun, then it is treated like the ABORT command. This operation has no parameters. REC-DISABLE is accepted only when the microcontroller's serial port is in receive mode.

TRA-DISABLE

This operation causes the transmission process to be aborted. If the microcontroller is fetching data from 80186 memory, then it is treated like the ABORT command. This operation has no parameters. It is accepted only when the serial port is in transmit mode.

5.1.3 ILLEGAL COMMANDS

Parametric and non-parametric commands except ABORT will be rejected (interrupt will not be set) if the microcontroller is already executing a command.

ABORT is rejected if issued when the microcontroller is not requesting DMA operation, or a non-Parametric execution is performed, or transfer of parameters/data has already been accomplished.

DMA operations shall not be aborted by any non-parametric or parametric command except by the ABORT command.

REC-DISABLE and TRA-DISABLE will not be accepted if the serial channel is idle.

5.2 Status

The microcontroller provides the information about the last operation that was executed, via the status register.

The microcontroller reports on these events by updating a status register and raising the INTERRUPT signal. Information from the status register is valid provided the interrupt signal is high or bit 0 of the status being read is set.

Format:

7	6	5	4 3 2	1	0
CTS*	RTS*	E	EVENT	DMA	INT

*8044 only

5.2.1 INTERRUPT (BIT 0)

The interrupt bit is set together with the hardware interrupt signal. Setting the INT bit indicates the occurrence of an event. This bit is cleared by any command whose INTA bit is set. Status is valid only when this bit is set.

5.2.2 DMA OPERATION (BIT 1)

The DMA bit, when set, indicates that a DMA operation is in progress. This bit is set if the commnad received by the microcontroller requires data or parameter transfer. If this bit is clear, DRQ will be inactive. The DMA bit, when cleared, indicates the completion of a DMA operation.

5.2.3 ERROR (BIT 5)

The E bit, if set, indicates that the event generated for the operation that was completed contains a warning, or the operation was not accepted.

5.2.4 REQUEST TO SEND (BIT 6)

The RTS bit, if clear, indicates that the serial channel is requesting a transmission.

5.2.5 CLEAR TO SEND (BIT 7)

The CTS bit indicates that, if the RTS bit is clear, the serial port is active and transmitting a frame.

5.2.6 EVENT (BITS 2-4)

The event field specifies why the microcontroller needs the attention of the 80186.

The following events may occur:

CONFIGURE-DONE
TRANSMIT-DONE
DUMP-DONE
RECEIVE-DONE
RECEPTION-DISABLED
TRANSMISSION-DISABLED
EXECUTION-ABORTED

CONFIGURE-DONE

This event indicates the completion of a CONFIGURE operation.

TRANSMIT-DONE

This event indicates the completion of the TRANSMIT operation.

If the E bit is set, it indicates that the transmit buffer was already full.

DUMP-DONE

This event indicates that the DUMP operation is completed.

RECEIVE-DONE

This event indicates that a frame has been received and stored in memory.

The format of the received message is indicated in Figure 5.3.

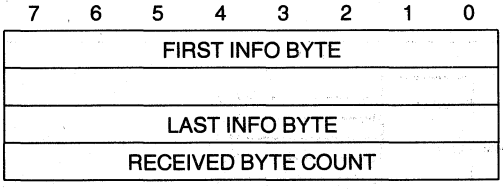

Figure 5.3. Format of Receive Block

Following the byte count, a few more bytes relating to the received frame such as the source address and the control byte may be transferred to the system memory using DMA. As an example, see the 8044 receive block in Figure 7.3.

Note that the format of a frame received by the microcontroller serial channel is configured by the CONFIGURE command.

If the E bit is set, buffer overrun has occurred.

RECEPTION-DISABLED

This event is issued as a result of a RCV-DISABLE operation that causes part of a frame to be disabled.

If the E bit is set, the serial port was already disabled, and the RCV-DISABLE is not accepted.

TRANSMISSION-DISABLED

This event is issued as a result of a TRA-DISABLE operation that causes transmission of a frame to be disabled.

The E bit, if set, indicates that the TRA-DISABLE operation was not accepted since the serial port was already idle, or transmission of a frame has already been accomplished.

EXECUTION-ABORTED

This event indicates that the execution of the last operation was aborted by the ABORT command.

If the E bit is set, ABORT was issued when the microcontroller was not executing any commands.

6.0 HARDWARE DESCRIPTION

The interface hardware shown in Figures 6.1 and 6.2 are identical. The difference is the status register. In Figure 6.2, an external latch is used to latch the status byte. This hardware is recommended if an extra I/O port on the microcontroller is required for some other applications, or external program and data memory is required for the microcontroller. The hardware shown in Figure 6.1 makes use of one of the microcontroller's I/O ports (Port 1) to latch the status to minimize hardware. The discussion of Sections 1 through 5 apply to both schematics.

6.1 Reset

After an 80186 hardware reset, the microcontroller is also reset. The on-chip registers are initialized as explained in the Intel Microcontroller Handbook. The reset signal also clears the 80186 interrupt and the microcontroller interrupt signals by resetting FF3 (Flip-Flop 3) and FF2 (Flip-Flop 2). Figure 4.5 shows the RESET timing.

6.2 Sending Commands

A bidirectional latched transceiver (74ALS646) is used for the Command/Data register. When the 80186 writes a command to the Command/Data register, it interrupts the microcontroller. The interrupt is generated only when bit 7 (INTA) of the command byte is set. When the 80186 PCS0 and WR signals go active to write the command, FF2 will be set and FF3 will be cleared. The output of FF3 is the interrupt to the 80186 and the INT status bit. The INT bit is cleared immediately to indicate that the status is no longer valid. The output of FF2 is the interrupt to the microcontroller. A high to low transition on this line will interrupt the microcontroller. The interrupt signal will be cleared as soon as the microcontroller reads the command from the Command/Data register.

6.3 DMA Transfers

In the interrupt service routine the command is decoded. If it requires a DMA transfer, the microcontroller sets the DMA bit of the status register which activates the DMA request signal. DRQ active causes the 80186 on-chip DMA to perform a fetch and a deposit bus cycle. The first DMA cycle clears the DRQ signal (FF1 is cleared). When the microcontroller performs a read or write operation, the output of the FF1 will be set, and DRQ goes active again.

The DMA controller transfers a byte from system memory to the Command/Data register. Data is latched when the 80186 PCS1 and WR signals go active. PCS1 and WR active also clear FF1. The microcontroller monitors the output of FF1 by polling the P3.3 pin. When FF1 is cleared the microcontroller reads the byte from the Command/Data register. The P3.3 pin is also the interrupt pin. If a slow rate of transfer is acceptable, every DMA transfer can be interrupt driven to allow the microcontroller to perform other tasks.

The DMA controller transfers a byte from the Command/Data register to system memory by activating the 80186 PCS1 and RD signals. PCS1 and RD active also clear FF1. When FF1 is cleared the microcontroller writes the next byte to the Command/Data register.

When all the data is transferred, the microcontroller clears the DMA status bit to disable DRQ. It then updates the status, sets the INT bit, and interrupts the 80186.

If the interface hardware in Figure 6.1 is used P1.1 is the DMA status bit and P1.0 is the INT bit. The microcontroller enables or disables them by writing to port 1. In Figure 6.2, DRQ or INT is disabled or enabled by writing to the 74LS374 status register. Note that the INT status bit is cleared by the hardware when the 80186 writes a command.

6.4 Reading Status

The command is written and the status is read with the same chip select (PCS0), although the status is read through the 74LS245 transceiver and the command is written to the Command/Data register.

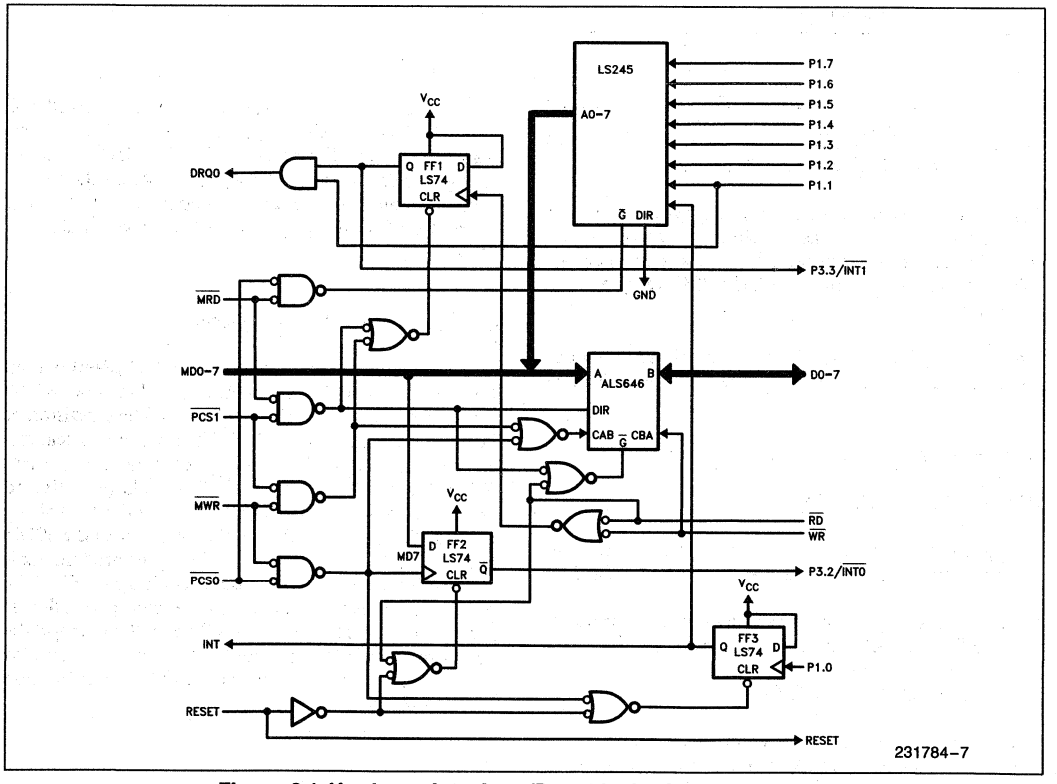

Figure 6.1. Hardware Interface (Port 1 is the Status Register)

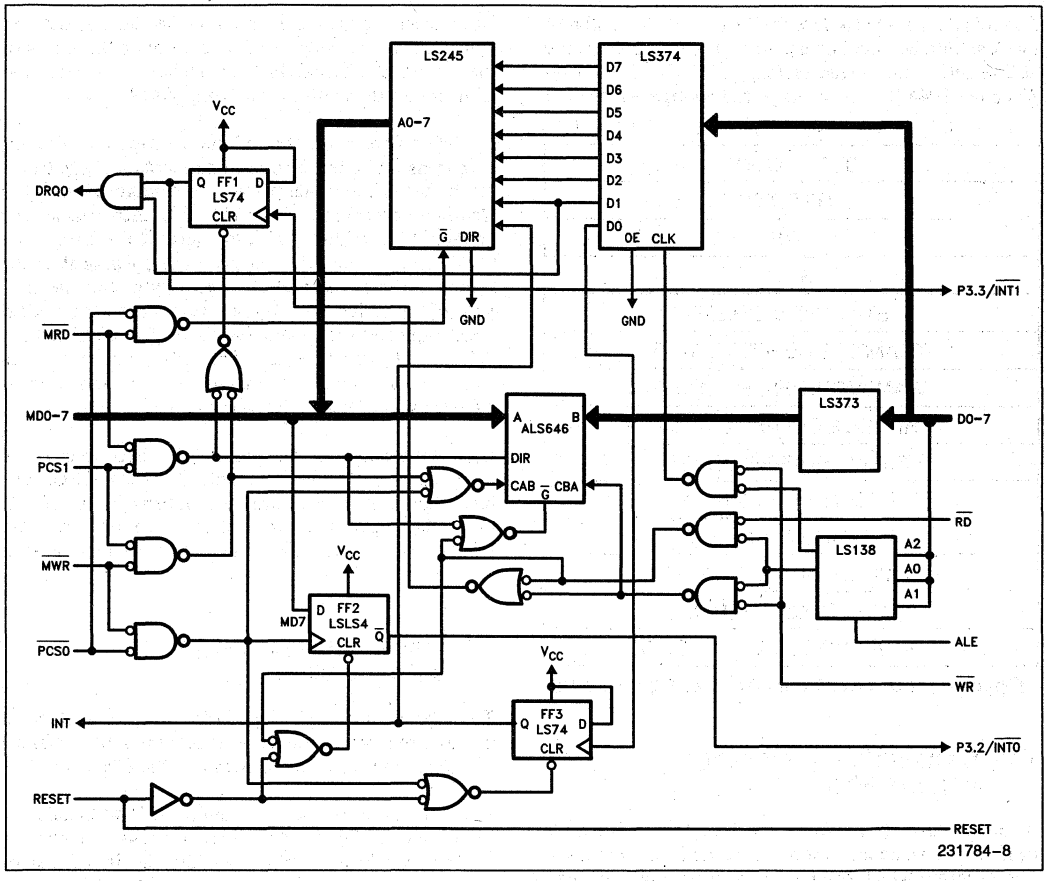

Figure 6.2. Hardware Interface

The microcontroller updates the status byte whenever a change occurs in the status and outputs the result to the status register. In order to read status, the 80186 activates the PCS0 line, and then activates the RD line. The contents of the status are put on the data bus, through the 74LS245 transceiver.

For systems that require two DMA channels, a second pair of DRQ1/DACK1 signals may easily be added to the hardware. In that case one of the status bits (DMA2) ANDed with the output of FF1 will serve as the second DMA request signal (DRQ1). DACK1 can be generated with the 80186 PCS2.

7.0 8044/80186 INTERFACE

This section shows how to make use of the status and commands described in section 5 and the hardware given in Figure 6.1 to interface the 80186 with the 8044. The 8044 code to implement these functions is shown in Appendix A.

7.1 Configuring the 8044

This operation configures the 8044 registers. The format of the configure block is shown in Figure 7.1. The part of the configuration block that is modified is determined by the first two bytes of the command parameter. The FIRST BYTE specifies the first register in the configure block that will be configured, and the BYTE COUNT specifies the number of registers that will be configured starting with the FIRST BYTE. For example, if the FIRST BYTE is 1 and the BYTE COUNT is 13, then all of the registers are updated. If FIRST BYTE is 4 and BYTE COUNT is 2, then transmit buffer start register is configured.

The configure command performs the following: 1) configures the interrupts and assigns their priorities; 2) assigns the start address and length of the transmit and receive buffers; 3) sets the station address; 4) sets the clock option and the frame format.

For other microcontrollers the format of the configure block should be modified accordingly. For example, the 80C51 serial port registers (e.g., T2CON, SCON) replace the 8044 SIU registers in the configure block.

7	6	5	4	3	2	1	0
BYTE COUNT							
FIRST BYTE							
STS							
SMD							
STATION ADDRESS							
TRANSMIT BUFFER START							
TRANSMIT BUFFER LENGTH							
RECEIVE BUFFER START							
RECEIVE BUFFER LENGTH							
INTERRUPT PRIORITY							
INTERRUPT ENABLE							
TIMER/COUNTER MODE							
TIMER/COUNTER MODE							
PROCESSOR STATUS WORD							

Figure 7.1. Format of the 8044 Configure Block

7.2 Transmitting a Message with the 8044

A message is a block of data which represents a text file or a set of instructions for a remote node or an application program which resides on the 8044 program memory. A message can be a frame (packet) by itself or can be comprised of multiple frames. An SDLC frame is the smallest block of data that the 8044 transmits. The 8044 can receive commands from the 80186 to transmit and receive messages. The 8044 on-chip CPU can be programmed to divide messages into frames if necessary. Maximum frame size is limited by the transmit or receive buffer.

To transmit a message, the 80186 prepares a transmit data block in memory as shown in Figure 7.2. Its first byte specifies the length of the rest of the block. The next two bytes specify the destination address of the node the message is being sent to and the control byte of the message. The 80186 programs the DMA controller with the start address of the block, length of the block and other control information and then issues the Transmit command to the 8044.

Upon receiving the command, the 8044 fetches the first byte of the block using DMA to determine the length of the rest of the block. It then fetches the destination address and the control byte using DMA.

The 8044 fetches the rest of the message into the on-chip transmit buffer. The size and location of the transmit buffer in the on-chip RAM is configured with the Configure command. The 8044 CPU then enables the Serial Interface Unit (SIU) to transmit the data as an SDLC frame. The SIU sends out the opening flag, the station address, the SDLC control byte, and the contents of transmit buffer. It then transmits the calculated CRC bytes and the closing flag. The 8044 CPU and the SIU operate concurrently. The CPU can fetch bytes from system memory or execute a command such as TRANSMIT-DISABLE while the SIU is active.

Upon completion of transmission, the SIU updates the internal registers and interrupts the 8044 CPU. The 8044 then updates the status and interrupts the 80186. Note that baud rate generation, zero bit insertion, NRZI encoding, and CRC calculation are automatically done by the SIU.

7.3 Receiving a Message with the 8044

To receive a message, the 80186 allocates a block of memory to store the message. It sets the DMA channel and sends the Receive command to the 8044.

Upon reception of the command, the 8044 enables its serial channel. The 8044 receives and passes to memory all frames whose address matches the individual or broadcast address and passes the CRC test.

The SIU performs NRZI decoding and zero bit deletion, then stores the information field of the received frame in the on-chip receive buffer. At the end of reception, the CPU requests the transfer of data bytes to 80186 memory using DMA. After transferring all the bytes, the 8044 transfers the data length, source address, and control byte of the received frame to the memory (see Figure 7.3). Upon completion of the transfers, the 8044 updates the status register and raises the interrupt signal to inform the 80186.

If the SIU is not ready when the first byte of the frame arrives, then the whole frame is ignored. Disabling reception after the first byte was passed to memory causes the rest of the frame to be ignored and an interrupt with Receive-Aborted event to be issued.

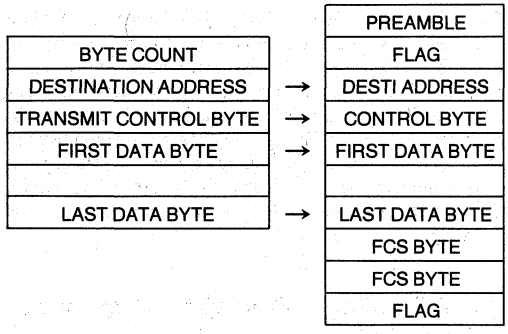

Figure 7.2. The 8044 Transmit Frame Structure and Location of Data Element in System Memory

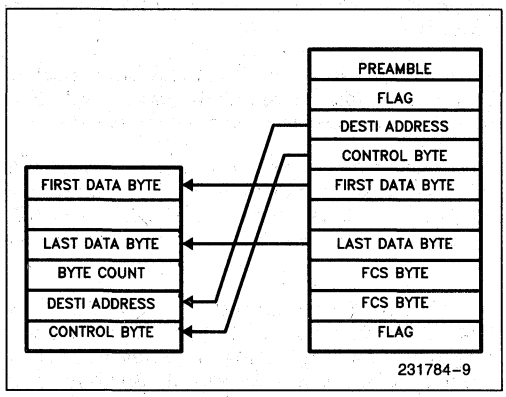

Figure 7.3. The 8044 Receive Frame Structure and Location of Received Data Element in System Memory

7.4 Dumping the 8044 Registers

Upon reception of the Dump command, the 8044 transfers the contents of its internal registers to the system memory (See Figure 7.4).

7	6	5	4	3	2	1	0
STS REG.							
SMD REG.							
STAD REG.							
TBS REG.							
TBL REG.							
TCB REG.							
RBS REG.							
RBL REG.							
RCB REG.							
RFL REG.							
PSW REG.							
IP REG.							
IE REG.							
TMOD REG.							
TCON REG.							

Figure 7.4. Format of the 8044 Dumped Registers

7.5 Aborting an Operation

To abort a DMA operation, the 80186 sends an Abort command to the Command/Data latch and interrupts the 8044. During a DMA operation, the 8044 puts the external interrupt to high priority; therefore, the Abort interrupt will suspend the execution of the operation in progress and update the status register with the Execution-Aborted event. It then returns the 8044 program counter to a location before the aborted operation started. The Abort software procedure given in Appendix A gives the details of the execution of the ABORT command.

7.6 Disabling the Transmission or Reception

Transmission of a frame is aborted if the 80186 sends a TRANSMIT-DISABLE command to the 8044. The command causes the 8044 to clear the Transmit Buffer

Full (TBF) bit. During transmission, if the TBF bit is cleared, the SIU will discontinue the transmission and interrupt the 8044 CPU.

The RECEIVE-DISABLE command causes the 8044 to clear the Receive Buffer Empty (RBE) bit. The SIU aborts the reception, if the RBE bit is cleared by the CPU.

When transmission or reception of a frame is discontinued, the SIU interrupts the 8044 CPU. The CPU then updates the status and interrupts the 80186.

7.7 Handling Interrupts

When the 80186 sends a command, it sets the 8044 external interrupt flag. The 8044 services the interrupt at its own convenience. In the interrupt service routine the 8044 executes the appropriate instructions for a given command. During execution of a command the 8044 ignores any command, except ABORT, sent by the 80186 (see section 5.1.2). This is accomplished by clearing the interrupt flag before the 8044 returns from the interrupt service routine. During DMA operations the 8044 sets the external interrupt to high priority. An interrupt with high priority can suspend execution of an interrupt service routine with low priority. The ABORT command given by the 80186 will interrupt the execution of the DMA transfer in progress. Upon completion of ABORT, execution of the last operation will not be resumed (see Appendix A). Note that any other command given during the DMA operation will also abort the operation in progress and should be avoided.

8.0 8044 IN EXPANDED OPERATION

To increase the number of information bytes in a frame, the 8044 can be operated in Expanded mode. In Expanded operation the system memory can be used as the transmit and receive buffer instead of the 8044 internal RAM. AP-283, "Flexibility in Frame Size Operation with the 8044", describes Expanded operation in detail.

8.1 Transmitting a Message in Expanded Operation

In Expanded operation the 8044 transmits the frame while it is fetching the data from the system memory using DMA. An internal transmit buffer is not necessary. The system memory can be used as the transmit buffer by the 8044.

Upon receiving the Transmit command, the 8044 enables the SIU and fetches the first data byte from the Command/Data register. The SIU transmits the opening flag, station address, and the control byte if the frame format includes these fields. It then transmits the fetched data. The 8044 CPU fetches the next byte while the previously fetched byte is being transmitted by the SIU. The CPU fetches the remaining bytes using DMA, then the SIU transmits them simultaneously until the end of message is reached. The SIU then transmits the FCS bytes, the closing flag and interrupts the 8044 CPU. The 8044 updates the status with the Transmit-Done event and interrupts the 80186. If the DMA does not keep up with transmission, the transmission is an underrun.

8.2 Receiving a Message in Expanded Operation

In Expanded operation the DMA controller transfers data to the system memory while the 8044 SIU is receiving them.

To receive a message, the 80186 allocates a block of memory for storing the message. It sets the DMA channel and sends the Receive command to the 8044.

Upon reception of the command, the 8044 enables its serial channel and waits for a frame. The SIU performs flag detection, address filtering, zero bit deletion, NRZI decoding, and CRC checking as it does in Normal operation.

After the SIU receives the first byte of the frame, the 8044 CPU requests the transfer of the byte to memory using DMA. The 80186 DMA moves the information byte into the system memory while the SIU is receiving the next byte. The next byte is transferred to the memory after the SIU receives it. When the entire frame is received, the SIU checks the received Frame Check Sequence bytes. If there is no CRC error, the SIU updates the 8044 registers and interrupts the 8044 CPU. The CPU updates the status and interrupts the 80186.

9.0 CONCLUSION

This application note describes an efficient way to interface the 80186 and the 80188 microprocessors to the Intel 8-bit microcontrollers like the 80C51, 8052, and 8044. To illustrate this point the 80186 microprocessor interface to the 8044 microcontroller based serial communication chip was described. The hardware interface given here is very general and can interface the 8-bit microcontrollers to a variety of Intel microprocessors and DMA controllers. The microcontrollers with this interface hardware have the same benefits as both the Intel UPI-41/42 family and data communication peripheral chips such as the 82588 and the 82568 LAN controllers. Like the Intel UPI chips, they can be easily interfaced to microprocessors, and like the data communication peripherals, they execute high level commands. A similar approach can be used to interface Intel microprocessors to the 16-bit 8096 microcontroller.

APPENDIX A
SOFTWARE

The software modules shown here implement the execution of commands and status explained in sections 5 and 7. The 80186 software provides procedures to send commands and read status. The 8044 software decodes and executes the commands, updates the status, and interrupts the 80186. The procedures given here are called by higher level software drivers. For example, an 80186 application program may use the Transmit command to send a block of data to an application program that resides in the 8044 ROM or in another remote node. The application programs and the drivers that perform the communication tasks run asynchronously since all communication tasks are interrupt-driven.

Figure A-1 shows how to assign the ports and control registers for an 80186-based system. The software is written for an Intel iSBC® 186/51 computer board. The 8044 hardware is connected to the computer board iSBX™ connector.

Figure A-2 shows the 80186 command procedures. These procedures are used by the data link driver.

Figure A-3 shows how the DMA controller is loaded and initialized for data and parameter transfer from the 80186 memory to the 8044. This procedure is used by the TRANSMIT and CONFIGURE commands.

Figure A-4 shows how the DMA controller is loaded and initialized for data and parameter transfer from the 8044 to the 80186 memory. This procedure is used by the RECEIVE and DUMP commands.

Figure A-5 shows an interrupt service routine which handles interrupts resulting from various events. Note that this routine is not complete. The user should write the software to respond to events.

Figure A-6 shows an example of the 80186 software. It shows how to start various operations. This is not a data link driver, but it gives the procedures needed to write a complete driver.

Figure A-7 shows how to initialize the 8044. The user application program should be inserted here.

Figures A-8 through A-13 show the 8044 external interrupt service routine. In this routine a command received from the 80186 is decoded, and one of the command procedures shown in Figures A-9 through A-13 is executed.

Figure A-14 shows the serial channel (SIU) interrupt service routine. Note that execution of TRANSMIT, RECEIVE, and TRANSMIT-DISABLE commands are completed in this routine.

```
NAME COM_DRIVER

;**   80186 SOFTWARE FOR THE 80186/MICROCONTROLLER INTERFACE

;* 8044 BOARD CONNECTED TO THE SBX1 OF THE SBC 186/51 BOARD.
;* SBX1 INT0 TIED TO 80130 IR[0-7]. CONNECT JUMPER 30 TO 46.
;* 80186 DMA CHANNEL 1 USED. CONNECT JUMPER 202 TO 203.


TRUE          EQU   0FFFFH
FALSE         EQU   0H

; 8044 REGISTERS

CMD_44        EQU   080H            ; ADDRESS OF THE COMMAND REGISTER
ST_44         EQU   080H            ; ADDRESS OF THE STATUS REGISTER
DATA_44       EQU   0D4H            ; ADDRESS OF THE DATA REGISTER


; EVENTS

CON_DONE      EQU   01H             ; CONFIGURE_DONE
TRA_DONE      EQU   02H             ; TRANSMIT_DONE
DUM_DONE      EQU   03H             ; DUMP_DONE
REC_DONE      EQU   04H             ; RECEIVE_DONE
REC_DISA      EQU   05H             ; RECEPTION_DISABLE
TRA_DISA      EQU   06H             ; TRANSMISSION_DISABLE
ABO_DONE      EQU   07H             ; EXECUTION_ABORTED                    231784-10
; COMMANDS (INTA=1)

ABO_CMD       EQU   080H            ; ABORT
REC_DIS_CMD   EQU   081H            ; RECEIVE DISABLE
XMIT_DIS_CMD  EQU   082H            ; TRANSMIT DISABLE
REC_CMD       EQU   083H            ; RECEIVE
TRA_CMD       EQU   084H            ; TRANSMIT
DUM_CMD       EQU   085H            ; DUMP
CON_CMD       EQU   086H            ; CONFIGURE
NOP_CMD       EQU   087H            ; NOP


; 80186 DMA CHANNEL 1 REGISTERS

SL_DMA1       EQU   0FFD0H          ; SOURCE ADDRESS (LO WORD)
SH_DMA1       EQU   0FFD2H          ; SOURCE ADDRESS (HI WORD)
DL_DMA1       EQU   0FFD4H          ; DESTINATION ADDRESS (LO WORD)
DH_DMA1       EQU   0FFD6H          ; DESTINATION ADDRESS (HI WORD)
CNT_DMA1      EQU   0FFD8H          ; TRANSFER COUNT ADDRESS
CTL_DMA1      EQU   0FFDAH          ; CONTROL ADDRESS


; 80186 INTERRUPT CONTROLLER REGISTERS

CTL0_INTR     EQU   0FF38H          ; INT 0 CONTROL ADDRESS
CTL1_INTR     EQU   0FF3AH          ; INT 1 CONTROL REGISTER
MASK_INTR     EQU   0FF28H          ; INT MASK REGISTER
EOI_INTR      EQU   0FF22H          ; INT EOI REGISTER
NSPEC_BIT     EQU   08000H          ; NON-SPECIFIC EOI


; 80130 INTERRUPT CONTROLLER REGISTERS

EOI_SINTR     EQU   0E0H            ; INT EOI REGISTER
MASK_SINTR    EQU   0E2H            ; MASK REGISTER

RD_IRR        EQU   010H            ; COMMAND TO 80130 TO READ IRR REG
RD_ISR        EQU   011H            ; COMMAND TO 80130 TO READ ISR REG


IV_BASE       EQU   20H             ; BASE OF 80130 INT CONTROLLER VECTOR
                                                                    231784-11
```

Figure A-1. Port and Register Definitions for 80186 System

```
;*************************************************************************
; INTERRUPT TABLE

INTERRUPTS      SEGMENT  AT 0

                ORG    (IV_BASE+1)*4H

IV_INTR0        LABEL    DWORD          ; IR1 VECTOR

INTERRUPTS      ENDS

;*************************************************************************

STACK           SEGMENT    STACK  'STACK'

THE_STACK       DW      200H     DUP(?)
TOS     LABEL           WORD

STACK           ENDS

;*************************************************************************

DATA            SEGMENT    PUBLIC  'DATA'

REC_BUFFER       DB      1024    DUP(?)

CON_BUFFER       DB      08H,01H,00H,0D0H,55H,20H,05H,30H,05H

DUM_BUFFER       DB      0FH      DUP(?)

TRA_BUFFER       DB      07H,55H,11H,01H,02H,03H,04H,05H

CMND_FLAG       DW       FALSE

DATA            ENDS
```

231784-12

Figure A-1. Port and Register Definitions for 80186 System (Continued)

```
;*************************************************************

CODE        SEGMENT  PUBLIC  'CODE'

ASSUME      CS:CODE,
&           DS:DATA,
&           ES:NOTHING,
&           SS:STACK

;*************************************************************

RECV_COMMAND     PROC    FAR

      PUSH    BP
      MOV     BP,SP
      LES     SI,DWORD PTR [BP+6]      ; LOAD BUFFER POINTER
      MOV     AX,WORD PTR[BP+10]       ; LOAD BUFFER SIZE
      MOV     AH,0H
      CALL    REC_DMA                  ; CALL REC-DMA
      MOV     AL,REC_CMD               ; LOAD RECEIVE COMMAND
      OUT     CMD_44,AL                ; SEND TO COMMAND/DATA REG
      POP     BP
      RET

RECV_COMMAND     ENDP

;*************************************************************

XMIT_COMMAND    PROC     FAR

      PUSH    BP
      MOV     BP,SP
      LES     SI,DWORD PTR [BP+6]      ; LOAD BUFFER POINTER
      MOV     AX,WORD PTR[BP+10]       ; LOAD BUFFER SIZE
      MOV     AH,0H
      CALL    TRA_DMA                  ; CALL TRA-DMA
      MOV     AL,TRA_CMD               ; LOAD TRANSMIT COMMAND
      OUT     CMD_44,AL                ; SEND TO COMMAND/DATA REG
      POP     BP
      RET

XMIT_COMMAND    ENDP
```

231784-13

Figure A-2. Setup and Execution of Commands

```
;*************************************************************

CONF_COMMAND   PROC    FAR

      PUSH   BP
      MOV    BP,SP
      LES    SI,DWORD PTR[BP+6]      ; LOAD BUFFER POINTER
      MOV    AX,WORD PTR[BP+10]      ; LOAD BUFFER SIZE
      MOV    AH,0H
      CALL   TRA_DMA                 ; CALL TRA-DMA
      MOV    AL,CON_CMD              ; LOAD CONFIGURE COMMAND
      OUT    CMD_44,AL               ; SEND TO COMMAND/DATA REG
      POP    BP
      RET

CONF_COMMAND   ENDP

;*************************************************************

DUMP_COMMAND    PROC    FAR

      PUSH   BP
      MOV    BP,SP
      LES    SI,DWORD PTR[BP+6]      ; LOAD BUFFER POINTER
      MOV    AX,WORD PTR[BP+10]      ; LOAD BUFFER SIZE
      MOV    AH,0H
      CALL   REC_DMA                 ; CALL REC-DMA
      MOV    AL,DUM_CMD              ; LOAD DUMP COMMAND
      OUT    CMD_44,AL               ; SEND TO COMMAND/DATA REG
      POP    BP
      RET

DUMP_COMMAND    ENDP                                          231784-14
;*************************************************************

XMIT_DIS_COMMAND     PROC     FAR

      MOV    AL,XMIT_DIS_CMD         ; LOAD XMIT-DIS  COMMAND
      OUT    CMD_44,AL               ; SEND TO COMMAND/DATA REG
      RET

XMIT_DIS_COMMAND     ENDP

;*************************************************************

REC_DIS_COMMAND     PROC     FAR

      MOV    AL,REC_DIS_CMD          ; LOAD REC-DIS  COMMAND
      OUT    CMD_44,AL               ; SEND TO COMMAND/DATA REG
      RET

REC_DIS_COMMAND     ENDP

;*************************************************************

ABOR_COMMAND     PROC     FAR

      MOV    AL,ABO_CMD              ; LOAD ABORT COMMAND
      OUT    CMD_44,AL               ; SEND TO COMMAND/DATA REG
      RET

ABOR_COMMAND     ENDP

;*************************************************************

NOP_COMMAND     PROC     FAR

      MOV    AL,NOP_CMD              ; LOAD NOP COMMAND
      OUT    CMD_44,AL               ; SEND TO COMMAND/DATA REG
      RET

NOP_COMMAND     ENDP
                                                              231784-15
```

Figure A-2. Setup and Execution of Commands (Continued)

```
;*************************************************************
; **  RECEIVE DMA
; ARGS       AX      BUFFER SIZE
;            ES:SI   BUFFER POINTER

REC_DMA      PROC          NEAR
     MOV    DX,CNT_DMA1              ; LOAD ADD OF TRANSFER COUNT REG
     OUT    DX,AX                    ; PROGRAM TRANSFER COUNT REGISTER

     XOR    BX,BX                    ; CLEAR BX
     MOV    AX,ES                    ; LOAD SEG ADDRESS OF BUFFER
     SHL    AX,1                     ; CALCULATE LINEAR ADDRESS OF THE BUFFER
     RCL    BX,1
     SHL    AX,1
     RCL    BX,1
     SHL    AX,1
     RCL    BX,1
     SHL    AX,1
     RCL    BX,1
     ADD    AX,SI                    ; ADD THE OFFSET TO BASE
     ADC    BX,0
     MOV    DX,DL_DMA1               ; LOAD ADDRESS OF DEST POINTER (LO WORD)
     OUT    DX,AX                    ; PROGRAM DEST POINTER REGISTER (LO WORD)
     MOV    AX,BX
     MOV    DX,DH_DMA1               ; LOAD ADDRESS OF DEST POINTER (HI WORD)
     OUT    DX,AX                    ; PROGRAM DEST POINTER REGISTER (HI WORD)

     MOV    AX,DATA_44               ; LOAD ADDRESS OF DATA REGISTER
     MOV    DX,SL_DMA1               ; LOAD ADDRESS OF SOURCE POINTER
     OUT    DX,AX                    ; PROGRAM SOURCE POINTER REGISTER (LO WORD)

     XOR    AX,AX                    ; CLEAR AX
     MOV    DX,SH_DMA1               ; LOAD ADDRESS OF SOURCE POINTER (HI WORD)
     OUT    DX,AX                    ; PROGRAM SOURCE POINTER REGISTER (HI WORD)

     MOV    DX,CTL_DMA1              ; LOAD ADDRESS OF CONTROL REGISTER
     MOV    AX,1010001010100110B     ; LOAD THE CONTROL WORD
     OUT    DX,AX                    ; PROGRM THE CONTRL REGISTER
     RET

REC_DMA      ENDP
```

231784-16

Figure A-3. Loading and Starting the 80186 DMA Controller

5

```
;*****************************************************************
; ** TRANSMIT DMA
; ARGS  AX        BUFFER SIZE
;       ES:SI     BUFFER POINTER
;
TRA_DMA      PROC     NEAR
     INC    AX
     MOV    DX,CNT_DMA1                 ; LOAD ADD OF TRANSFER COUNT REG
     OUT    DX,AX                    ; PROGRAM TRANSFER COUNT REGISTER

     XOR    BX,BX                    ; CLEAR BX
     MOV    AX,ES                    ; LOAD SEG ADDRESS OF BUFFER
     SHL    AX,1                     ; CALCULATE LINEAR ADDRESS OF THE BUFFER
     RCL    BX,1
     SHL    AX,1
     RCL    BX,1
     SHL    AX,1
     RCL    BX,1
     SHL    AX,1
     RCL    BX,1
     ADD    AX,SI                    ; ADD THE OFFSET TO BASE
     ADC    BX,0
     MOV    DX,SL_DMA1               ; LOAD ADDRESS OF SOURCE POINTER (LO WORD)
     OUT    DX,AX                    ; PROGRAM SOURCE POINTER REGISTER (LO WORD)
     MOV    AX,BX
     MOV    DX,SH_DMA1               ; LOAD ADDRESS OF SOURCE POINTER (HI WORD)
     OUT    DX,AX                    ; PROGRAM SOURCE POINTER REGISTER (HI WORD)

     MOV    AX,DATA_44               ; LOAD ADDRESS OF DATA REGISTER
     MOV    DX,DL_DMA1               ; LOAD ADDRESS OF DEST POINTER
     OUT    DX,AX                    ; PROGRAM DEST POINTER REGISTER (LO WORD)

     XOR    AX,AX                    ; CLEAR AX
     MOV    DX,DH_DMA1               ; LOAD ADDRESS OF DEST POINTER (HI WORD)
     OUT    DX,AX                    ; PROGRAM DEST POINTER REGISTER (HI WORD)

     MOV    DX,CTL_DMA1              ; LOAD ADDRESS OF CONTROL REGISTER
     MOV    AX,0001011010100110B     ; LOAD THE CONTROL WORD
     OUT    DX,AX                    ; PROGRAM THE CONTRL REGISTER
     RET

TRA_DMA      ENDP
```

231784-17

Figure A-4. Loading and Starting the 80186 DMA Controller

```
;*******************************************************************
;  80186 INTERRUPT ROUTINE

INT_186:

     PUSH  AX
     PUSH  DX
     MOV   AX,NSPEC_BIT                ; SEND NSPEC END OF INT
     MOV   DX,EOI_INTR
     OUT   DX,AX

     MOV   AL,01100001B
     OUT   EOI_SINTR,AL

     IN    AL,ST_44                    ; READ THE STATUS
     AND   AX,0FFH

; DECODE STATUS AND TAKE APPROPRIATE ACTION

     MOV   DX,CTL_DMA1                 ; DISABLE DMA
     IN    AX,DX
     OR    AX,0100B
     AND   AX,NOT 010B
     OUT   DX,AX

     MOV   CMND_FLAG,TRUE

     POP   DX
     POP   AX
     IRET
```

231784-18

Figure A-5. Interrupt Service Routine

```
;*************************************************************

BEGIN:
        CLI
        CLD

; SET ALL REGISTERS SMALL MODEL

         MOV     SP,DATA
         MOV     DS,SP
         MOV     ES,SP
         MOV     SP,STACK
         MOV     SS,SP
         MOV     SP,OFFSET TOS


; SETUP INTERRUPT VECTORS

         PUSH    ES
         XOR     AX,AX
         MOV     ES,AX
         MOV     WORD PTR ES:IV_INTR0 +0, OFFSET INT_186
         MOV     WORD PTR ES:IV_INTR0 +2, CS
         POP     ES


SETUP 80130 INTERRUPT CONTROLLER

         MOV     AL,00010011B              ; ICW1
         OUT     EOI_SINTR,AL
         MUL     AL

         MOV     AL,IV_BASE                ; ICW2
         OUT     MASK_SINTR,AL
         MUL     AL

         MOV     AL,00000000B              ; ICW4
         OUT     MASK_SINTR,AL
         MUL     AL

         MOV     AL,0FCH                   ;MASK
         OUT     MASK_SINTR,AL
```

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Figure A-6. Example of Executing Commands

```
; SETUP 80186 INTERRUPT CONTROLLER

          MOV       AX,0000000000100000B
          MOV       DX,CTL0_INTR
          OUT       DX,AX

          MOV       DX,CTL1_INTR
          IN        AX,DX
          OR        AX,0000000000101000B
          OUT       DX,AX

          MOV       AX,000EDH                   ; MASK ALL BUT I0
          MOV       DX,MASK_INTR
          OUT       DX,AX
          STI                                   ;ENABLE INTERRUPTS

;***  SEND CONFIURE COMMAND

          PUSH      WORD PTR CON_BUFFER         ; PUSH BUFFER SIZE
          PUSH      DS                          ; PUSH BUFFER SEGMENT REGISTER
          PUSH      OFFSET CON_BUFFER           ; PUSH  OFFSET OF BUFFER
          CALL      CONF_COMMAND                ; CALL CONFIGURE
          ADD       SP,3*2

; WAIT FOR END OF COMMAND

WAIT1:
          CMP       CMND_FLAG,TRUE
          JNE       WAIT1
          MOV       CMND_FLAG,FALSE                                    231784-20
;***  SEND DUMP COMMAND

          PUSH      WORD PTR DUM_BUFFER         ; PUSH BUFFER SIZE
          PUSH      DS                          ; PUSH BUFFER SEGMENT REGISTER
          PUSH      OFFSET DUM_BUFFER           ; PUSH  OFFSET OF BUFFER
          CALL      DUMP_COMMAND                ; CALL CONFIGURE
          ADD       SP,3*2

WAIT2:
          CMP       CMND_FLAG,TRUE
          JNE       WAIT2
          MOV       CMND_FLAG,FALSE

;*** SEND TRANSMIT COMMAND

          PUSH      WORD PTR TRA_BUFFER         ; PUSH BUFFER SIZE
          PUSH      DS                          ; PUSH BUFFER SEGMENT REGISTER
          PUSH      OFFSET TRA_BUFFER           ; PUSH  OFFSET OF BUFFER
          CALL      XMIT_COMMAND                ; CALL COMMAND
          ADD       SP,3*2

WAIT3:
          CMP       CMND_FLAG,TRUE
          JNE       WAIT3
          MOV       CMND_FLAG,FALSE

;*** SEND RECEIVE COMMAND

          PUSH      WORD PTR REC_BUFFER         ; PUSH BUFFER SIZE
          PUSH      DS                          ; PUSH BUFFER SEGMENT REGISTER
          PUSH      OFFSET REC_BUFFER           ; PUSH  OFFSET OF BUFFER
          CALL      RECV_COMMAND                ; CALL COMMAND
          ADD       SP,3*2

WAIT4:
          CMP       CMND_FLAG,TRUE
          JNE       WAIT4
          MOV       CMND_FLAG,FALSE


CODE            ENDS
        END     BEGIN
                                                                       231784-21
```

Figure A-6. Example of Executing Commands (Continued)

5

```
$DEBUG NOMOD51
$INCLUDE (REG44.PDF)

; THE 8044 SOFTWARE DRIVER FOR THE 80186/8044 INTERFACE.

        ORG   00H               ; LOCATIONS 00 THRU 26H ARE USED
        SJMP  INIT              ; BY INTERRUPT SERVICE ROUTINES.
        ORG   03H               ; VECTOR ADDRESS FOR EXT INT0.
        JMP   EINT0
        ORG   23H               ; VECTOR ADDRESS FOR SERIAL INT
        JMP   SIINT

;********************* INITIALIZATION **************************

        ORG   26H
INIT:   MOV   TCON,#00000001B   ; EXT INT0: EDGE TRIGGER
        MOV   IE,#00010001B     ; SI=EX0=1
        CLR   P1.1              ; CLEAR DRQ STATUS BIT
        SETB  EA                ; ENABLE INTERRUPTS
DOT:    SJMP  DOT               ; WAIT FOR AN INTERRUPT
```

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Figure A-7. Initialization Routine

```
;*******************EXTERNAL INTERRUPT 0 *********************
EINT0:  CLR   P1.5              ; CLEAR THE E BIT
        MOV   DPTR,#100H        ; LOAD DATA POINTER WITH A DUMY NUMBER
        MOVX  A,@DPTR           ; READ THE COMMAND BYTE.
        ANL   A,#00001111B      ; KEEP THE OPERATION FIELD
        MOV   R2,A              ; SAVE COMMAND

; DECODE COMMAND AND JUMP TO THE APPROPRIATE ROUTINE
;         COMMAND           OPERATION (BITS0-3)
;
;          ABORT              00H
;          REC-DISABLE        01H
;          TRA-DISABLE        02H
;          RECEIVE            03H
;          TRANSMIT           04H
;          DUMP               05H
;          CONFIGURE          06H
;          NOP                07H

        JNB    PX0,J1           ; IF INT0 IS SET TO PRIORITY 1,
        JMP    CABO             ;THEN DMA OPERATION WAS IN PROGRESS.
                                ; EXECUTE ABORT REGARDLESS OF THE
                                ;COMMAND ISSUED.
J1:     CJNE  A,#00H,J2         ; EXECUTE ABORT
        JMP   CABO              ; THIS LINE WILL BE EXECUTED IF ABORT WAS
                                ;ISSUED WHEN THE 8044 IS NOT EXECUTING
                                ;ANY COMMANDS.
J2:     CJNE  A,#01H,J3
        JMP   CRDIS             ; EXECUTE RECEIVE-DISCONNECT
J3:     CJNE  A,#0B5H,J4
        JMP   CTDIS             ; EXECUTE TRANSMIT-DISCONNECT
J4:     CJNE  A,#03H,J5
        JMP   CREC              ; EXECUTE RECEIVE
J5:     CJNE  A,#04H,J6
        JMP   CTRA              ; EXECUTE TRANSMIT
J6:     CJNE  A,#05H,J7
        JMP   CDUMP             ; EXECUTE DUMP
J7:     CJNE  A,#06H,J8
        JMP   CCON              ; EXECUTE CONFIGURE
J8:     CJNE  A,#07H,J9
        JMP   CNOP              ; EXECUTE NOP
J9:     RETI                    ; RETURN. OPERATION NOT RECOGNIZED.
```

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Figure A-8. External Interrupt Service Routine

```
; **  NOP COMMAND

CNOP:    CLR    IE0              ; IGNORE PENDING EXT INT0 (IF ANY).
                                 ; ANY INTERRUPT (COMMNAD) DURING
                                 ; EXECUTION OF AN OPERATION IS IGNORED
         RETI                    ; RETURN

; **  ABORT COMMAND

CABO:    JNB    PX0,CABOJ1       ; WAS DMA IN PROGRESS?
         CLR    PX0              ; YES. EXT INT0: PRIORITY 0
         CLR    P1.1             ; CLEAR DMA REQUEST

         SETB   P1.2             ; UPDATE STATUS WITH
         SETB   P1.3             ;ABORT-DONE EVENT
         SETB   P1.4             ; (STATUS=DDH; E=0)

         CLR    IE0              ; IGNORE PENDING EXT INT0 (IF ANY).
         CLR    P1.0
         SETB   P1.0             ; SET INT BIT AND INTERRUPT 80186
         JB     P3.2,$           ; WAIT TILL INTERRUPT IS ACKNOWLEDGED
                                 ; EXECUTE THE NEXT "RETI" TWICE
         POP    ACC              ; POP OUT THE OLD HI BYTE PC
         POP    ACC              ; POP OUT THE OLD LOW BYTE PC
         MOV    B,#HIGH($+10)    ; HI BYTE ADDRESS OF CABOJ2
         MOV    ACC,#LOW($+7)    ; LOW BYTE ADDRESS OF CABOJ2
         PUSH   ACC              ; PUSH THE ADDRESS OF THE NEXT
         PUSH   B                ;"RETI" INSTRUCTION INTO STACK
CABOJ2:  RETI                    ; RETURN

CABOJ1:  NOP                     ; DMA WAS NOT IN PROGRESS
         SETB   P1.5             ; SET THE E BIT

         SETB   P1.2             ; UPDATE STATUS WITH
         SETB   P1.3             ;ABORT-DONE EVENT
         SETB   P1.4             ; (STATUS=FDH; E=1)

         CLR    IE0              ; IGNORE PENDING EXT INT0 (IF ANY).
         CLR    P1.0
         SETB   P1.0             ; SET INT BIT AND INTERRUPT 80186
         JB     P3.2,$           ; WAIT TILL INTERRUPT IS ACKNOWLEDGED
         RETI                    ; RETURN
```

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Figure A-9. Execution of NOP and ABORT Commands

```
; ** CONFIGURE COMMNAD

CCON:    MOV    DPTR,#100H
         CLR    IE0              ; IGNORE PENDING EXT INT0 (IF ANY)
         SETB   PX0              ; EXT INT0: PRIORITY 1
                                 ; PX0 IS SET TO ACCEPT ABORT
                                 ;DURING DMA OPERATION.
         SETB   P1.1             ; ENABLE DMA REQUEST
         JB     P3.3,$           ; WAIT FOR DMA ACK.
         MOVX   A,@DPTR          ; READ FROM COMMAN/DATA REGISTER
         MOV    R0,A             ; LOAD BYTE COUNT
         DEC    R0               ; DECREMENT BYTE COUNT
         JB     P3.3,$           ; WAIT FOR DMA ACK.
         MOVX   A,@DPTR          ; READ FROM COMMAND/DATA REGISTER
         MOV    R1,A             ; LOAD FIRST-BYTE
         JB     P3.3,$           ; WAIT FOR DMA ACK.
         MOVX   A,@DPTR          ; READ FROM COMMAND/DATA REGISTER
         CJNE   R1,#01H,CCONJ1   ; CHECK THE FIRST-BYTE
         MOV    STS,A            ; UPDATE THE STS REGISTER
         INC    R1               ; INC. POINTER TO THE CONF. BLOCK
         DJNZ   R0,CCONF4        ; CHECK THE BYTE COUNT
         JMP    CCONT1
CCONF4:  JB     P3.3,CCONF4
         MOVX   A,@DPTR
CCONJ1:  CJNE   R1,#02H,CCONJ2
         MOV    SMD,A
         INC    R1
         DJNZ   R0,CCONF5
         JMP    CCONT1
CCONF5:  JB     P3.3,CCONF5
         MOVX   A,@DPTR
CCONJ2:  CJNE   R1,#03H,CCONJ3
         MOV    STAD,A
         INC    R1
         DJNZ   R0,CCONF6
         JMP    CCONT1
CCONF6:  JB     P3.3,CCONF6
         MOVX   A,@DPTR
CCONJ3:  CJNE   R1,#04H,CCONJ4
```

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Figure A-10. Execution of CONFIGURE Command

5

```
          MOV   TBS,A
          INC   R1
          DJNZ  R0,CCONF7
          JMP   CCONT1
CCONF7:   JB    P3.3,CCONF7
          MOVX  A,@DPTR
CCONJ4:   CJNE  R1,#05H,CCONJ5
          MOV   TBL,A
          INC   R1
          DJNZ  R0,CCONF8
          JMP   CCONT1
CCONF8:   JB    P3.3,CCONF8
          MOVX  A,@DPTR
CCONJ5:   CJNE  R1,#06H,CCONJ6
          MOV   RBS,A
          INC   R1
          DJNZ  R0,CCONF9
          JMP   CCONT1
CCONF9:   JB    P3.3,CCONF9
          MOVX  A,@DPTR
CCONJ6:   CJNE  R1,#07H,CCONJ7
          MOV   RBL,A
          INC   R1
          DJNZ  R0,CCONFA
          JMP   CCONT1
CCONFA:   JB    P3.3,CCONFA
          MOVX  A,@DPTR
CCONJ7:   CJNE  R1,#08H,CCONJ8
          MOV   IP,A
          INC   R1
          DJNZ  R0,CCONFB
          JMP   CCONT1
CCONFB:   JB    P3.3,CCONFB
          MOVX  A,@DPTR
CCONJ8:   CJNE  R1,#09H,CCONJ9
          MOV   IE,A
          INC   R1
          DJNZ  R0,CCONFC
          JMP   CCONT1                                    231784-26
CCONFC:   JB    P3.3,CCONFC
          MOVX  A,@DPTR
CCONJ9:   CJNE  R1,#0AH,CCONJA
          MOV   TMOD,A
          INC   R1
          DJNZ  R0,CCONFD
          JMP   CCONT1
CCONFD:   JB    P3.3,CCONFD
          MOVX  A,@DPTR
CCONJA:   CJNE  R1,#0BH,CCONJB
          MOV   TCON,A
          INC   R1
          DJNZ  R0,CCONFE
          JMP   CCONT1
CCONFE:   JB    P3.3,CCONFE
          MOVX  A,@DPTR
CCONJB:   CJNE  R1,#0CH,ERROR1
          MOV   PSW,A
          INC   R1
          DJNZ  R0,ERROR1
          JMP   CCONT1

ERROR1:   NOP                   ; ILLEGAL BYTE COUNT
          SETB  P1.5            ; SET THE E STATUS BIT

CCONT1:   NOP
          CLR   P1.1            ; CLEAR DMA REQUEST
          CLR   PX0             ; EXT INT0: PRIORITY 0

          SETB  P1.2            ; UPDATE STATUS WITH
          CLR   P1.3            ;CONFIGURE-DONE EVENT
          CLR   P1.4            ; (STATUS=C5H IF E=0)

          CLR   IE0             ; IGNORE PENDING EXT INT0 (IF ANY)
          CLR   P1.0
          SETB  P1.0            ; INTERRUPT THE 80186
          JB    P3.2,$          ; WAIT TILL INTERRUPT IS ACKNOWLEDGED
          RETI                  ; RETURN
                                                          231784-27
```

Figure A-10. Execution of CONFIGURE Command (Continued)

```
; ** DUMP COMMAND

CDUMP:  MOV   A,STS          ; LOAD THE FIRST DUMP REG INTO ACC
        MOVX  @DPTR,A        ; WRITE TO THE COMMAND/DATA REGISTER
        CLR   IE0            ; IGNORE PENDING EXT INT0 (IF ANY)
        SETB  PX0            ; INTRERRUPT 0: PRIORITY 1
        SETB  P1.1           ; ENABLE DMA REQUEST
        JB    P3.3,$         ; WAIT FOR DMA ACK
        MOV   A,SMD
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,STAD
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,TBS
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,TBL
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,TCB
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,RBS
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,RBL
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,RCB
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,RFL
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,PSW
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,IP                                          231784-28
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,IE
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,TMOD
        MOVX  @DPTR,A
        JB    P3.3,$
        MOV   A,TCON
        MOVX  @DPTR,A
        JB    P3.3,$
        CLR   P1.1           ; DISABLE DRQ
        CLR   PX0            ; EXTERNAL INT0: PRIORITY 0

        SETB  P1.2           ; UPDATE STATUS WITH
        SETB  P1.3           ;DUMP-DONE EVENT
        CLR   P1.4           ; (STATUS=CDH)

        CLR   IE0            ; IGNORE PENDING EXT INT0
        CLR   P1.0
        SETB  P1.0           ; INTERRUPT THE 80186
        JB    P3.2,$         ; WAIT TILL INTERRUPT IS ACKNOWLEDGED
        RETI                 ; RETURN
                                                            231784-29
```

Figure A-11. Execution of DUMP Command

```
; ** RECEIVE COMMAND.
CREC:     JNB   RBE,CRECJ1        ; IS SIU ALREADY IN RECEIVE MODE?
          SETB  P1.5              ; YES. SET THE E BIT
CRECJ1:   SETB  RBE               ; NO. ENABLE RECEPTION
          CLR   RBP               ; CLEAR RECEIVE BUFFER PROTECT BIT
          CLR   IE0               ; IGNORE PENDING EXT INT0 (IF ANY)
          RETI                    ; RETURN. UPDATE STATUS IN THE
                                  ;SIU INTERRUPT ROUTINE.

; ** TRANSMIT COMMAND.
CTRA:     MOV   R1,TBS            ; LOAD TRANSMIT BUFFER START
          CLR   IE0               ; IGNORE PENDING EXT INT0 (IF ANY)
          SETB  PX0               ; EXT INT0: PRIROITY 1
          SETB  P1.1              ; ENABLE DMA REQUEST
          JB    P3.3,$            ; WAIT FOR DMA ACK.
          MOVX  A,@DPTR           ; READ FROM COMMAND/DATA REG.
          MOV   R0,A              ; LOAD THE BYTE COUNT
          DEC   A                 ; SUBTRACT 2 FROM THE BYTE
          DEC   A                 ;COUNT AND LOAD INTO XMIT
          MOV   TBL,A             ; LOAD BUFFER LENGTH
CTRAJ2:   JB    P3.3,CTRAJ2       ; WAIT FOR DMA ACK.
          MOVX  A,@DPTR           ; READ FROM COMMAND/DATA REG.
          MOV   STAD,A            ; LOAD DESTINATION ADDRESS
          DEC   R0                ; DECREMENT THE BYTE COUNT
CTRAJ3:   JB    P3.3,CTRAJ3       ; WAIT FOR DMA ACK.
          MOVX  A,@DPTR           ; READ FROM COMMAND/DATA REG.
          MOV   TCB,A             ; LOAD THE TRANSMIT CONTROL BYTE
          DJNZ  R0,CTRAJ4         ; IS THERE ANY INFO. BYTE?
          SJMP  CTRAJ5            ; NO.
CTRAJ4:   JB    P3.3,CTRAJ4       ; YES. WAIT FOR DMA ACK.
          MOVX  A,@DPTR           ; READ FROM COMMAND/DATA REG.
          MOV   @R1,A             ; MOVE DATA TO THE TRANSMIT BUFFER
          INC   R1                ; INC. POINTER TO BUFFER
          DJNZ  R0,CTRAJ4         ; LAST BYTE FETCHED INTO THE BUFFER?
                                  ; NO. FETCH THE NEXT BYTE
CTRAJ5:   CLR   P1.1              ; YES. DISABLE DMA REQUEST
          CLR   PX0               ; EXT INT0: PRIORITY 0
          SETB  TBF               ; SET TRANSMIT BUFFER FULL
          SETB  RTS               ; ENABLE TRANSMISSION
          CLR   IE0               ; IGNORE PENDING EXT INT0 (IF ANY)
          RETI                    ; RETURN. UPDATE STATUS IN THE
                                  ;SIU INTERRUPT ROUTINE
```

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Figure A-12. Execution of RECEIVE and TRANSMIT Commands

```
; ** TRANSMIT-DISCONNECT COMMAND

CTDIS:    JB    TBF,CTDIJ1        ; IS TRANSMIT BUFFER ALREADY EMPTY?
          SETB  P1.5              ; YES, SET THE E BIT
CTDIJ1:   CLR   TBF               ; NO. CLEAR TRANSMIT BUFFER
          CLR   IE0               ; IGNORE PENDING EXT INT0 (IF ANY)
          RETI                    ; RETURN. UPATE STATUS IN THE
                                  ;SIU INTERRUPT ROUTINE.



; ** RECEIVE-DISCONNECT COMMAND

CRDIS:    JB    RBE,CRDIJ1        ; IS RECEIVE BUFFER ALREADY EMPTY?
          SETB  P1.5              ; YES. SET THE E BIT
CRDIJ1:   CLR   RBE               ; NO. CLEAR RECEIVE BUFFER

          SETB  P1.2              ; UPDATE STATUS WITH
          CLR   P1.3              ;RECEPTION-DISABLED EVENT
          SETB  P1.4              ; (STATUS=D5 IF E=0)

          CLR   IE0
          CLR   P1.0
          SETB  P1.0              ; INTERRUPT THE 80186
          JB    P3.2,$            ; WAIT TILL INTERRUPT IS ACKNOWLEDGED
          RETI                    ; RETURN
```

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Figure A-13. Execution of RECEIVE-DISCONNECT and TRANSMIT-DISCONNECT Commands

```
;************ SERIAL CHANNEL (SIU) INTERRUPT ******************

SIINT:   CLR   SI
         MOV   A,R2              ; LOAD THE OPERATION FIELD
         CJNE  A,#03H,SINTJ1     ; RECEIVE COMMAND PENDING?
         JMP   SIREC             ; YES.
SINTJ1:  CJNE  A,#02H,SINTJ2     ; TRANSMIT-DISCONNECT PENDING?
         JMP   SITDIS            ; YES.
SINTJ2:  JMP   SITRA             ; TRANSMIT COMMAND IS PENDING


;** TRANSMISSION IS DISABLED

SITDIS:  JB    RTS,SINTJ3        ; REQUEST TO SEND ENABLED?
         JNB   TBF,SINTJ3        ; YES. TRANSMISSION DISABLED?
                                 ; YES.
         CLR   P1.2              ; UPDATE STATUS WITH
         SETB  P1.3              ;TRANSMISSION-DISABLED EVENT
         SETB  P1.4              ; (STATUS=D9H)

         CLR   IE0               ; IGNORE PENDING EXT INT0
         CLR   P1.0
         SETB  P1.0              ; INTERRUPT THE 80186
         JB    P3.2,$            ; WAIT TILL INTERRUPT IS ACKNOWLEDGED
         RETI

;** A FRAME IS TRANSMITTED

SITRA:   JB    RTS,SINTJ3        ; A FRAME TRANSMITTED?
                                 ; YES.
         CLR   P1.2              ; UPDATE STATUS WITH
         SETB  P1.3              ;TRANSMIT-DONE EVENT
         SETB  P1.4              ; (STATUS=C9).

         CLR   IE0
         CLR   P1.0
         SETB  P1.0              ; INTERRUPT THE 80186
         JB    P3.2,$            ; WAIT TILL INTERRUPT IS ACKNOWLEDGED
         RETI                                                    231784-32
; ** A FRAME IS RECEIVED

SIREC:   JB    RBE,SINTJ3        ; RECEIVE BUFFER FULL?
         JNB   BOV,SINTJ4        ; YES. BUFFER OVERRUN?
         SETB  P1.5              ; YES. SET THE E BIT
SINTJ4:  MOV   R0,RFL            ; LOAD R0 WITH RECEIVE BYTE COUNT
         MOV   R1,RBS            ; LOAD R1 WITH RECEIVE BUFFER ADDRESS
         CLR   IE0               ; IGNORE PENDING EXT INTO (IF ANY)
         SETB  PX0               ; EXT INT0: PRIORITY 1

         MOV   A,@R1             ; MOVE FIRST BYTE INTO ACC.
         MOVX  @DPTR,A           ; WRITE TO THE COMMAND/DATA REG
         SETB  P1.1              ; ENABLE DMA REQUEST
         INC   R1                ; INC POINTER TO RECEIVE BUFFER
         JB    P3.3,$            ; WAIT FOR DMA ACK.
         DJNZ  R0,CINTJ7         ; LAST BYTE MOVED?
         SJMP  CINTJ8            ; YES

CINTJ7:  MOV   A,@R1             ; LOAD RECEIVED DATA INTO ACC.
         MOVX  @DPTR,A           ; WRITE TO THE COMMAND/DATA REG.
         INC   R1                ; INC POINTER TO RECEIVE BUFFER
         JB    P3.3,$            ; WAIT TILL DMA ACK
         DJNZ  R0,CINTJ7         ; LAST BYTE MOVED TO COMMAND/DATA REG?
                                 ; NO. DEPOSIT THE NEXT BYTE
CINTJ8:  MOV   A,RFL             ; LOAD BYTE COUNT
         MOVX  @DPTR,A           ; WRITE TO THE COMMAND/DATA REG
         JB    P3.3,$            ; WAIT FOR DMA ACK.
         MOV   A,STAD            ; LOAD STATION ADDRESS
         MOVX  @DPTR,A           ; WRITE TO THE COMMAND/DATA REG
         JB    P3.3,$            ; WAIT FOR DMA ACK.
         MOV   A,RCB             ; LOAD RECEIVE CONTROL BYTE
         MOVX  @DPTR,A           ; WRITE TO THE COMMAND/DATA REG
         JB    P3.3,$            ; WAIT FOR DMA ACK.
         CLR   P1.1              ; CLEAR DMA REQUEST
         CLR   PX0               ; EXTERNAL INTERRUPT: PRIORITY 0
                                                         231784-33
```

Figure A-14. Serial Channel Interrupt Routine

```
                CLR     P1.2            ; UPDATE STATUS WITH
                CLR     P1.3            ;RECEIVE-DONE EVENT
                SETB    P1.4            ; (STATUS=D1H IF E=0)
                CLR     IE0             ; IGNORE PENDING EXT INT0
                CLR     P1.0
                SETB    P1.0            ; INTERRUPT THE 80186
                JB      P3.2,$          ; WAIT TILL INTERRUPT IS ACKNOWLEDGED
                RETI

SINTJ3:         NOP
                RETI
END
```

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Figure A-14. Serial Channel Interrupt Routine (Continued)

April 1989

80186/80188 DMA Latency

STEVE FARRER
APPLICATIONS ENGINEER

Order Number: 270525-001

80186/80188 DMA LATENCY

CONTENTS

PAGE

When using the DMA controller of the 80186 and 80188, there are several operating conditions which affect the service time (latency) between when the DMA request is generated and when the bus cycles associated to the DMA transfer are actually run. This application brief describes those conditions which affect DMA Latency.

DMA REQUEST GENERATION

The minimum DMA latency is 4 clocks and, depending on when the signal arrives (i.e. if the signal just missed the setup time), it might appear to be almost 5 clocks. This 4 to 5 clock delay is due to a two phase synchronizer and various transfer gate delays the DRQ signal must take before reaching the BIU. Conceptually the circuit looks like Figure 1.

If the Bus Interface Unit (BIU) is available when the DRQ signal reaches it, then a DMA cycle will proceed at T1 of the bus cycle as the next clock.

Also note that the DRQ signal is not latched, and must remain active until serviced. If the DRQ signal is brought low after being asserted high, then a '0' will propagate through and; if the request had not yet been serviced, then the BIU will see a '0' and the cycle will never take place.

Conditions Affecting DMA Latency

The circumstances that affect DMA latency in order of worst case are as follows:

1) HOLD
2) LOCK - INTA
3) Odd byte accesses
4) Effective Address Calculations (EA)

HOLD can indefinitely delay a DMA cycle. There is no mechanism internally to remove HLDA when a DMA request is pending.

LOCKed instructions can also delay a DMA cycle by a significant amount, depending on the type of instruction locked. A typical locked XCHG instruction from memory to register could delay the DMA cycle by as much as 18 clocks if the memory access required two bus cycles (80188 or odd locations on the 80186). On the other hand, a locked repeat MOVS could delay a DMA cycle by up to 1.05 million clocks depending on the number of transfers and the number of bus cycles per transfers.

Interrupt acknowledges can also affect DMA latency because the bus is locked out during the first two bus cycles required to fetch the interrupt vector type. This causes the worst case latency during interrupt acknowledges to be:

4	Clocks (Minimum Setup)
10	Clocks (2 Bus Cycles + 2 Idle Clocks) Min
14	Clocks Total

Both HOLD and LOCK are extremely dependent on the type of system being designed and therefore are not really considered to be normal worst case latency. However, odd byte accesses and effective address calculations are conditions that frequently occur in almost all systems. Under these conditions of no HOLD, no LOCK, and no wait states, the worst case occurs when the DMA request loses to an instruction data cycle requiring an effective address calculation.

Effective addresses (EA) always require 4 clocks for calculation and can only take place during T3-T4-TI-TI, T4-TI-TI-TI, or TI-TI-TI-TI. This creates an extra minimum insertion of 2 T-idle cycles. If the EA requires an immediate value in the prefetch queue, then a signal goes active which places the EA bus cycle at a higher priority than any other BIU requests. This is so the execution unit won't be waiting on the bus interface unit. If the EA hadn't required the value in the queue, then the EU could proceed with the next instruction shortly after it had sent the request to the BIU. Figure 2 shows the effects EA calculations have on DMA Latency.

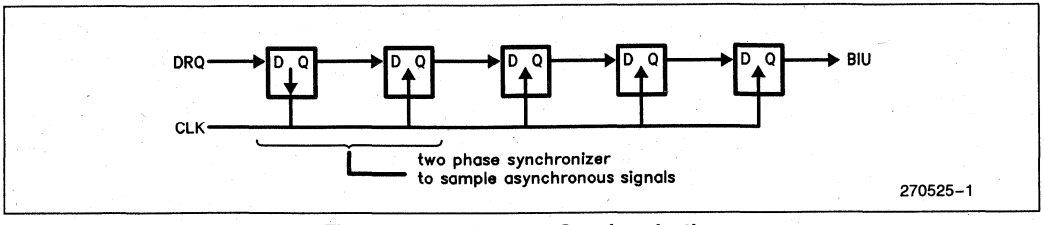
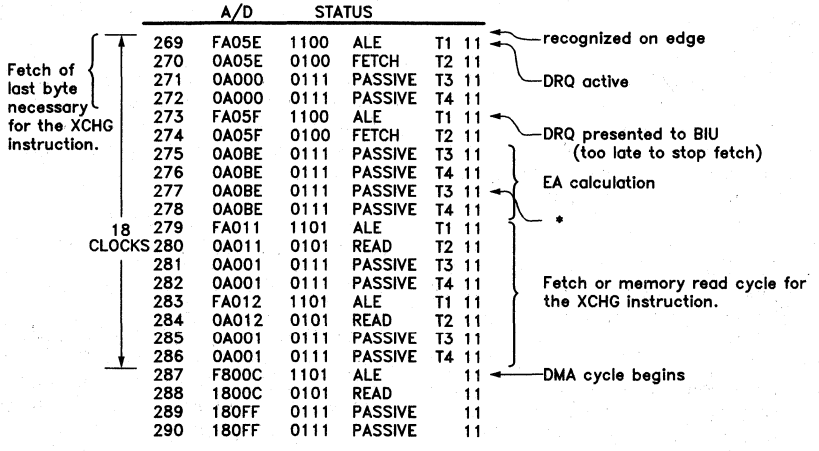


Figure 1. DMA Request Synchronization

Address	Code	Instruction
FA058	90	NOP
FA059	90	NOP
FA05A	2E87060100	XCHG AX, CS:WORD PTR 0001



* If an immediate value had not been used, the EA would have been aborted and the DMA would have begun its bus cycle. In this case, the latency would be 8 clocks.

Figure 2. Logic State Analyzer Trace and Accompanying Program Code

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APPLICATION BRIEF

AB-37

April 1989

80186/80188 EFI Drive and Oscillator Operation

STEVE FARRER
APPLICATIONS ENGINEER

Order Number: 270526-001

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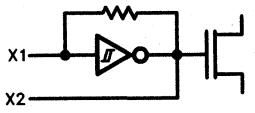
80186/80188 EFI DRIVE AND OSCILLATOR OPERATION

CONTENTS

There has been some confusion in the past regarding the correct input for EFI (External Frequency Input) use and what parameters should be used for crystal selection. This Application Brief discusses the trade-offs with each input so that one can decide which input suits his design and also lists the parameters for crystal selection.

EFI Operation

The oscillator circuit on the 186/188 is as shown in Figure 1 (simplified). Either input may be used for an EFI signal. Using X1 requires very little drive from an external oscillator since it is essentially the gate of an NMOS transistor. Clock operation works fine using this input, but at higher frequencies the stray capacitance on X2 begins to change the duty cycle of the clock. This will eventually cause the part to fail.



NOTE:
Driving X_2 does not allow compatibility with future CMOS designs.

Figure 1. Oscillator Circuit on the 186/188

Using X2 as an EFI gives a broader frequency range but places a more stringent requirement on the drive capability of the external oscillator. Since X1 is an input, it may be grounded to minimize the capacitance. This in turn allows for a higher frequency range since the duty cycle remains closer to 50%. But with X1 grounded, the output of the inverter (which is directly connected to X2) is always trying to output a high. This means the oscillator driving X2 must be capable of sinking up to 15 mA at cold temperatures when trying to drive it low. If the external oscillator is capable of supplying 15 mA, then this method is preferred. Otherwise, X1 should be used as an EFI.

Caution: using X2 for EFI does not allow for CMOS compatibility at a future date.

Crystal Operation

The oscillator circuit is a single stage amplifier connected as a Pierce oscillator. There are no passive components in the oscillator circuit, only a unique combination of depletion and enhancement mode FET's. Characterization of the oscillator circuit showed that operation was optimum with crystal parameters as follows:

ESR (Equivalent Series Resistance)	30 ohms maximum
Co (Shunt Capacitance)	7.0 pf max.
C1 (Load Capacity)	20 pf ±2 pf
Drive Level	1 mW max.

This characterization data was supplied by:

Standard Crystal Corporation
9940 East Baldwin Place
El Monte, CA 91731
(213) 443-2121

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APPLICATION BRIEF

AB-31

August 1990

The 80C186/80C188 Integrated Refresh Control Unit

GARRY MION
ECO SENIOR APPLICATIONS ENGINEER

Order Number: 270520-002

THE 80C186/80C188 INTEGRATED REFRESH CONTROL UNIT

CONTENTS

The 80C186 and 80C188 incorporate a special control unit that integrates address and clock counters which, along with the Bus Interface Unit (BIU), facilitates dynamic memory refreshing. Refreshing is an operation required by dynamic memory to ensure data retention.

Dynamic memory refreshing can be controlled using anything from an exotic memory controller to a simple timer along with a DMA controller. In fact, the 80186 device accomplishes the task memory refreshing by using one of the internal timer/counters and a DMA channel. However, doing this meant that desirable internal functions were no longer available to do more useful work.

Dynamic memory, unlike static or non-volatile memory, always require some form of a memory controller to enable read and write operations. Therefore, even the most basic dynamic memory interface has a minimum set of support logic. The advent of programmable logic and highly integrated dynamic memory has made the job of designing a memory controller somewhat straightforward. However, directly supporting memory refresh can still complicate many controller designs.

The designer of a memory controller must take into account CPU-versus-refresh arbitration and must provide a mechanism to generate periodic refresh requests. Most dynamic memory devices now contain internal refresh address counters which eliminate the need for external refresh address generation. However, such devices tend to complicate a memory controller design. The 80C186 simplifies dynamic memory controller design by integrating a refresh mechanism into the operation of the CPU.

This application brief is not intended to be a discussion of dynamic memory controller design. Instead, it will concentrate on the operation of the Refresh Control Unit of the 80C186, and how it can help simplify a memory controller.

The discussions on the following pages apply to BOTH the 80C186 and 80C188 except where noted.

UNDERSTANDING DYNAMIC MEMORY

Before explaining how memory refreshing is accomplished, some understanding of a Dynamic Random Access Memory (DRAM) device is needed. Figure 1 shows a simplified block diagram of a DRAM device, while a block diagram of a typical dynamic memory controller is shown in Figure 2.

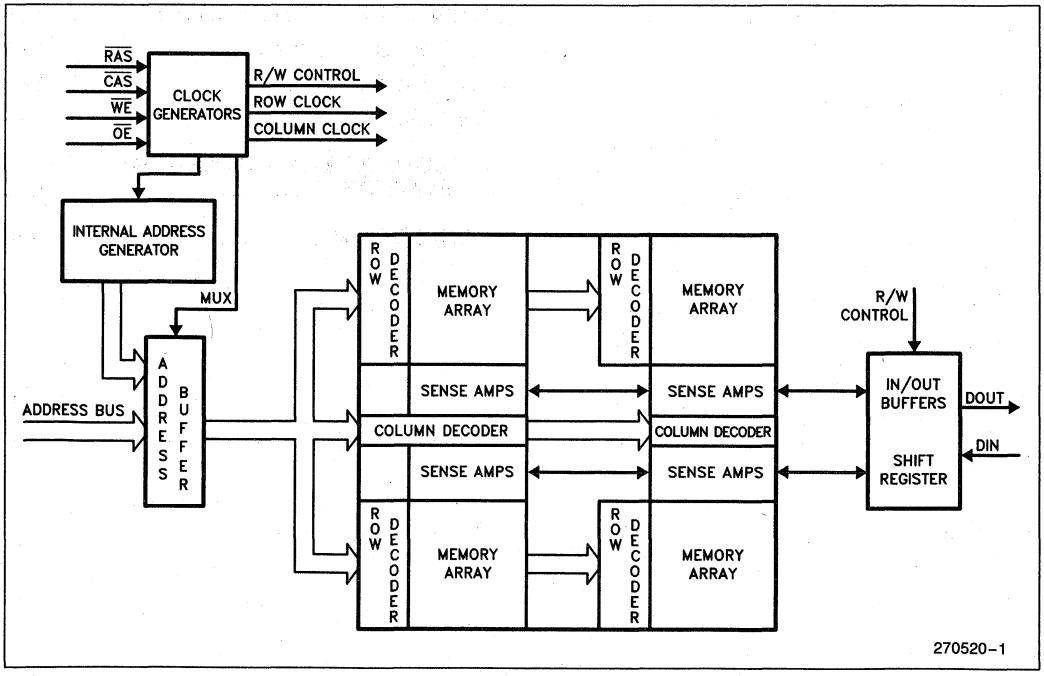


Figure 1. Random Access Memory Device

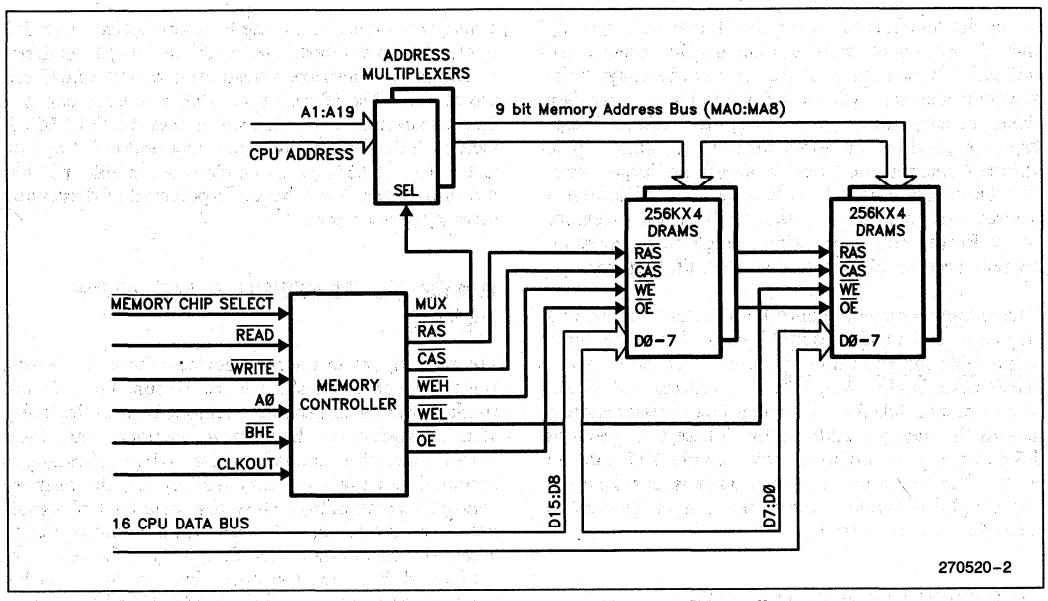


Figure 2. Minimum Configuration Memory Controller

The typical DRAM memory array is built as a matrix. Any bit or cell in the memory array is accessed by specifying a unique row and column address. As shown in Figure 1, the row and column addresses are multiplexed through one set of address inputs. Multiplexing the address inputs helps reduce the number of pins required to support large memory arrays. For instance, adding only one address bit will result in a memory array 4 times as large.

Two control lines, $\overline{RAS}$ and $\overline{CAS}$, are used to strobe an address into the memory chip. Figure 3 illustrates a timing diagram for a typical memory read access and the relationship between the $\overline{RAS}$ and $\overline{CAS}$ signals. The signal $\overline{MUX}$ controls which half of the address is presented to the memory devices. After generating the row address strobe ($\overline{RAS}$), the decoder selects a row of memory cells whose data value will be detected by a Sense Amplifier. The Sense Amplifier then presents the data to the column decoder. **Note that all cells associated to a row get accessed.** The fact that all cells within a row are accessed will be used later to explain why only the $\overline{RAS}$ portion of the memory address is required to refresh a device.

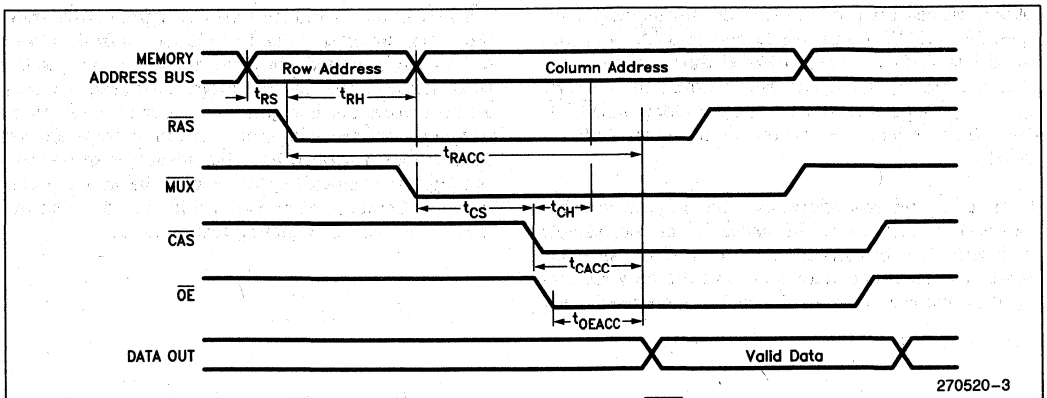


Figure 3. DRAM Signal Timings

When the column address is strobed, it is here that only one of the memory cells is selected. The memory cell will either be written to or read from depending on the the control signals $\overline{WE}$ and $\overline{OE}$ respectively. Since data from one entire row is presented to the column decoder, it is possible (on some devices) to simply cycle through column addresses to access additional data. The basic idea, however, is that two sets of addresses are required to access a memory cell within a memory array. Furthermore, specifying a single row address internally accesses all memory cells within that row.

The minimum memory controller interface consists of a sequencer and an address multiplexer. The sequencer is responsible for generating the correct control signals: $\overline{RAS}$; $\overline{CAS}$; $\overline{MUX}$; $\overline{WE}$; $\overline{OE}$. The address multiplexer logic is responsible for translating the processor address bus to the memory address bus. These two pieces of logic can exist in any form, from simple TTL gates to single chip solutions. However, what is missing from the simplified memory controller is a mechanism to perform memory refresh.

UNDERSTANDING MEMORY REFRESH

As indicated earlier, dynamic memory needs to be refreshed in order to maintain its data. Refreshing is accomplished whenever a memory cell is **accessed**. It is not necessary to read a memory location and then write the value back in order to refresh a memory cell. Simply cycling through a complete set of row addresses is all that is required. Remember, since a row accesses all memory cells associated to it, accessing all rows will access all the cells within the device.

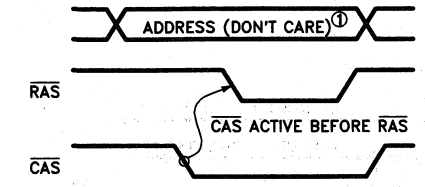
Referring back to Figure 2, the 9 address bits presented to the memory devices are multiplexed from the 18 bits of address generated by the 80C186. In the design, address bits A1-A9 are presented during $\overline{RAS}$, while address bits A10-A18 are presented during $\overline{CAS}$. Note that address bit A0 is not used because the memory array is organized as word wide; A0 along with $\overline{BHE}$ are used to select one or both of the bytes within a word.

Cycling through row addresses is the only requirement needed to refresh a DRAM device. Using the example in Figure 2, 9 bits of address are needed. Nine bits represent 512 unique addresses, and the only requirement is that each unique address be regenerated every 8 ms (maximum refresh rate for most devices with 512 rows). An 8 ms refresh interval divided by 512 addresses results in an average refresh cycle rate of 15.625 microseconds. Therefore, every 15.625 microseconds a mechanism must exist that will access the DRAM device, each time presenting a new row address. Any rate faster than 15.625 microseconds is acceptable, but significantly faster times have the potential of decreasing memory performance.

WAYS TO REFRESH A MEMORY DEVICE

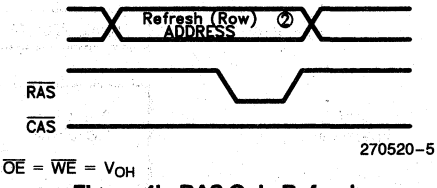
For most dynamic memory devices, there are several ways in which a refresh cycle can be run. The first and simplest way is to generate memory read cycles every 15.6 microseconds. Each new memory read cycle would generate a unique address. When refreshing is accomplished using memory read cycles, the memory controller is simplified. Only the basic control signals need to be generated, which are the minimum needed to access the memory anyway. Simplicity is, however, accompanied by one drawback; bus overhead. Using memory reads to perform DRAM refreshing means that one bus cycle every 15.6 microseconds is wasted. When operating at very slow speeds, a wasted bus cycle might appear to be significant. But if a bus cycle takes only, say, 320 nanoseconds to complete, running a refresh cycle every 15.6 microseconds represents a two percent hit in bus performance.

A second method relies on the fact that most dynamic memory devices now have built in refresh address mechanisms. DRAM refreshing can be accomplished by generating $\overline{CAS}$ before $\overline{RAS}$ signaling (see Figure 4a). This method requires that an external signal generate a periodic request to the DRAM controller to initiate the refresh cycle. A method similar to $\overline{CAS}$ before $\overline{RAS}$ refreshing is hidden refresh. Figure 4c illustrates the timing involved to perform hidden refresh. No request logic is needed, since the memory access itself is what initiates the refresh cycle. However, constant memory accessing is required in order to maintain refreshing. Once accessing stops, refreshing stops. Both of the methods described have the advantage of not consuming bus bandwidth, but require the memory controller to handle the somewhat different (from normal memory accessing) signaling requirements.



$\overline{OE}$ = $\overline{WE}$ = V_{OH}

Figure 4a. $\overline{CAS}$ before $\overline{RAS}$ Refresh



$\overline{OE}$ = $\overline{WE}$ = V_{OH}

Figure 4b. RAS Only Refresh

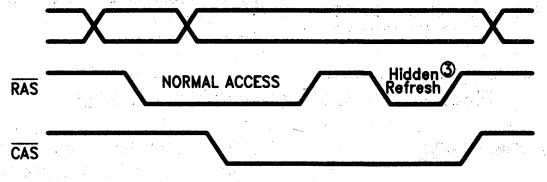


Figure 4c.

NOTES:
1. Refresh address provided internal to memory device.
2. Refresh address presented external to memory device.
3. Refresh address generated internally, and cycle does not effect memory access in progress (i.e. hidden).

Figure 4. Alternate Refreshing Methods

A final method is to implement a discrete design that supports refresh control and refresh address generation. The circuit details are shown in Figure 4b. A discrete design allows the most design flexibility and can be tailored to meet any system-to-memory interfacing requirements.

There are other methods available, most of which involve single-chip dedicated memory controllers. However, any memory controller design that performs the function of refreshing either directly or through external support circuitry has one major concern; arbitration between the refresh cycle and a normal memory access. The best way to make the operation of the DRAM memory controller a true slave to the operation of the CPU is to include refreshing as part of the functionality of the CPU. By offloading the task of memory refreshing onto the CPU, the memory controller can be simplified and dedicated to the duty of DRAM interfacing.

The idea that the 80C186 refresh cycle is simply a memory read means that the dynamic memory control logic does not need to differentiate between refresh cycles and normal memory read cycles. This simplifies the design of the memory controller. There are no special signaling requirements needed, and $\overline{RAS}$ only refreshing (for low-power designs) can be easily accommodated. Further, since the request is generated internally and synchronous with the operation of the BIU, no special external logic needs to detect when a refresh cycle conflicts with a CPU access.

5

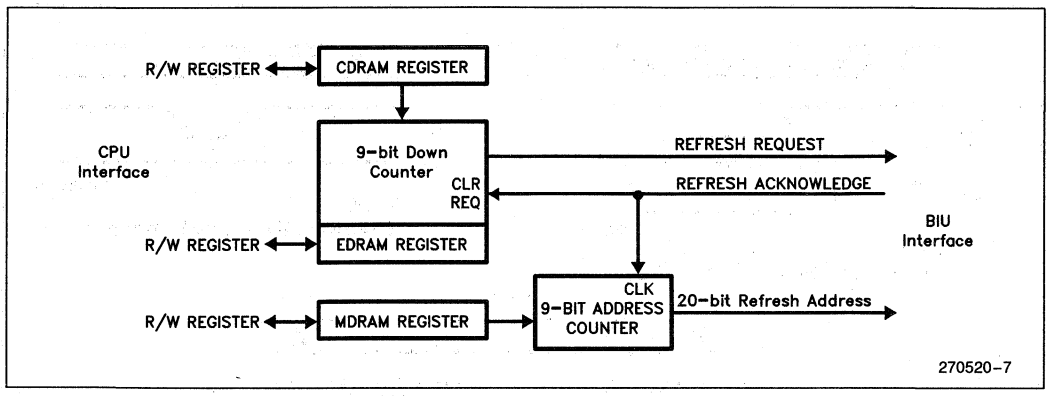


Figure 5. Refresh Control Unit Block Diagram

80C186 REFRESH CONTROL FEATURES

The Refresh Control Unit (RCU) of the 80C186 consists of a 9-bit address counter, a 9-bit down counter, and support logic. The block diagram can be seen in Figure 5.

The 9-bit address counter is controlled by the BIU and used whenever a refresh bus cycle is executed. Thus, any dynamic memory device whose refresh address requirement does not exceed nine bits can be directly supported by the 80C186. A special register has been defined to allow the base (starting) address of the refresh memory region to be specified. This base address can be located on any 4 kilobyte boundary. Furthermore, if this refresh base address overlaps any of the defined chip select regions, the chip select defined for that region will go active.

The 9-bit down counter initiates a refresh request. When the counter decrements to 1 (it decrements every clock cycle), a refresh request is presented to the BIU. When the bus is free, the BIU will run the refresh (memory) bus cycle. Note that since a refresh bus cycle is executed by the BIU, the faster refresh cycles are requested the greater the impact on bus performance. Referring back to the discussion of request rates, the maximum refresh period is typically 15.6 microseconds. With the 80C186 operating at 12.5 MHz, this represents a refresh bus impact of only 2%. However, at 5 microseconds the bus impact is 15%. Therefore, the refresh request rate should be tailored to meet the needs of the dynamic memory and the system. The 80C186 provides flexibility by allowing the request rate to be programmable in 80 ns steps (at 12.5 MHz).

To facilitate low power designs, the refresh bus cycle provides a mechanism whereby the dynamic memory devices can be turned off during refresh accesses. Low power control is accomplished by driving both address bit A0 and the control signal $\overline{BHE}$ to a high level. Essentially an invalid bus access condition exists, since A0 and $\overline{BHE}$ are used to indicate which half of the data bus is being accessed. When both are high during the access, the indication is that neither half of the bus is being used for the data transfer. This is acceptable for refresh bus cycles since no data is actually being transferred. If the memory controller takes advantage of this condition, the output enables of the dynamic memory devices (as well as the $\overline{CAS}$ strobe) can be disabled during refresh bus cycles, providing overall lower power consumption.

PROGRAMMING CHARACTERISTICS OF THE REFRESH CONTROL UNIT

A block of control registers are defined in the Peripheral Control Block (PCB) that define the operating characteristics of the refresh control unit (refer to Figure 5). These registers are only accessible when the 80C186 is operating in enhanced mode. When in compatibility mode, the 80C186 will ignore any reads or writes to the RCU registers.

The three registers associated with the refresh unit (MDRAM, CDRAM, EDRAM) provide the following features:

1) Enable/disable refresh unit
2) Establish a refresh request rate
3) Establish a refresh memory region
4) Examine the refresh down counter

It is not necessary to program any of these registers in a specific sequence, although the refresh request rate and refresh base address registers should be programmed before the refresh unit is enabled.

Programming the Memory Partition Register

The MDRAM register (Figure 6) is used to define address bits A13 through A19 of the 20 bit refresh address. This essentially establishes a memory region which will be accessed during refresh bus cycles. Typically, the refresh memory region will overlap a chip select that is used to access the dynamic memory. Overlapping the refresh memory region with a chip select memory region, means no additional external hardware is needed to support refresh bus cycles since it essentially operates the same as memory read cycles. When the 80C186 is reset, the MDRAM register is initialized to zero.

Figure 7 illustrates how the refresh address is generated. Address bits A10-A12 are not programmable and are always driven to a zero during a refresh bus cycle. Address bits A1 through A9 are derived by a 9-bit linear-feedback shift counter. The address counter is not ascending or contiguous, meaning that the counter does not start at 0 and increment to 511 before resetting back to 0. For refreshing purposes, it is not important that the address be contiguous and count up or down. Rather, the only requirement is that all combinations of the 512 addresses be cycled through before being repeated. Equation 1 provides the state definition of the 9-bit refresh address counter and can be used to determine the exact counting sequence. Figure 8 illustrates the gate logic used to create such a counter.

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MDRAM:	M6	M5	M4	M3	M2	M1	M0	0	0	0	0	0	0	0	0	0

bits 0–8: Reserved, should be written as a 0 to maintain future compatibility, will be read back as 0.
bits 9–15: M0–M6, are used to define address bits A13–A19 (respectively) of the 20-bit memory refresh address. These bits are set to 0 on RESET.

Figure 6. MDRAM Register Format

Address Bit	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Physical Refresh Address	M6	M5	M4	M3	M2	M1	M0	0	0	0	C_{A8}	C_{A7}	C_{A6}	C_{A5}	C_{A4}	C_{A3}	C_{A2}	C_{A1}	C_{A0}	1

Bit 0: Always driven to a 1 (Logic High). This is true for both the 80C186/80C188.
Bits 1–9: C_{A0}–C_{A8}, are generated by the 9-bit Linear-Feedback shift counter.
Bits 10–12: Always driven to a 0 (Logic Low).
Bits 13–19: M0–M6, are defined by the MDRAM Register.

Figure 7. Physical Refresh Address Generation

$$
\begin{aligned}
C_{A0} &\leftarrow C_{A1}\\
C_{A1} &\leftarrow C_{A2}\\
C_{A2} &\leftarrow C_{A3}\\
C_{A3} &\leftarrow C_{A4}\\
C_{A4} &\leftarrow C_{A5}\\
C_{A5} &\leftarrow C_{A6}\\
C_{A6} &\leftarrow \text{If } (C_{A1}\text{–}C_{A6} = 111111B),\\
&\qquad \text{then } C_{A6} = \text{Inverted } C_{A0}\\
&\qquad \text{else } C_{A6} = ((C_{A0}\ .XOR.\ C_{A1})\ .XNOR.\ (C_{A2}\ .XOR.\ C_{A3}))\\
C_{A7}, C_{A8} &\leftarrow \text{If } (C_{A0} - C_{A6} = 0111111B)\\
&\qquad \text{then } C_{A7}, C_{A8} = C_{A7}, C_{A8} + 1\\
&\qquad \text{else } C_{A7}, C_{A8} = C_{A7}, C_{A8}
\end{aligned}
$$

Equation 1. Refresh Counter Operation

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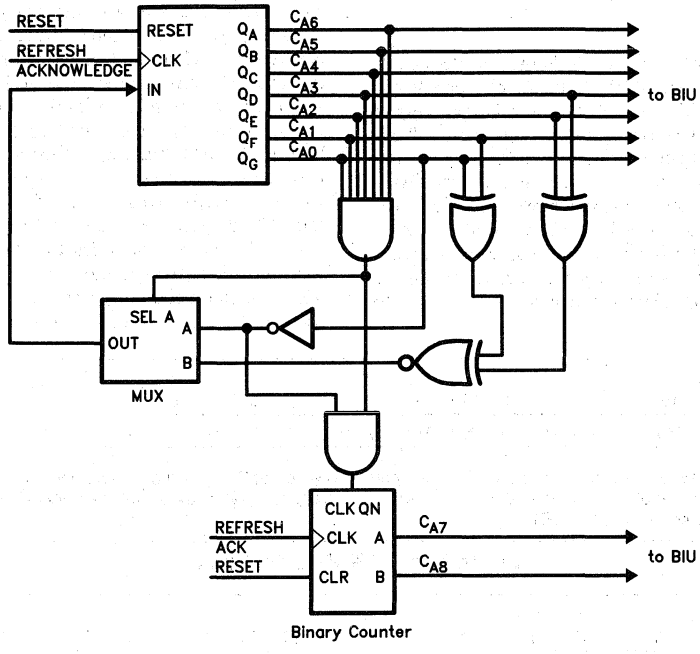


Figure 8. Logic Representation of Refresh Address Counter

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CDRAM:	0	0	0	0	0	0	0	C_8	C_7	C_6	C_5	C_4	C_3	C_2	C_1	C_0

Bits 0–8: C_0–C_8, define the number of CLKOUT cycles between each Refresh Request
0 = 512, 1 = 1, 2 = 2, ... These bits are set to 0 on RESET.
Bits 9–15: Reserved, should be written as 0 to maintain future compatibility, will always be read back as 0.

Figure 9. CDRAM Register Format

There are no limitations placed on the programming of the MDRAM register, but be aware that any chip select **memory** region that overlaps the address established by the MDRAM register will be activated during refresh bus cycles. Therefore, the register should be programmed to correspond to the chip select address that is activated for the dynamic memory partition.

Programming the Refresh Clock Register

The CDRAM register (Figure 9) is used to define the rate at which refresh requests will be internally generated. The CDRAM register is used to maintain the starting value of a down counter, which decrements each falling edge of CLKOUT. When the counter decrements to 1, a refresh request is generated and the counter is again loaded with the value contained in the CDRAM register. Initially, however, the contents of the CDRAM register is loaded into the down counter when the enable bit in the EDRAM register set. Thus, if the CDRAM register is changed, the new value will take effect when either the down counter reaches 1 and reloads itself, or whenever the E bit is written to a 1 (this is true whether the bit was previously set or not). When the 80C186 is reset, the CDRAM register is initialized to zero. A value of zero in the CDRAM register is used to indicate the maximum count rate of 512 clocks.

$$\left| \frac{R_{PERIOD}\ (\mu s) * FREQ\ (MHz)}{\#Refresh\ Rows + (\#Refresh\ Rows * \%\ Overhead)} \right| = CDRAM\ Register\ Valve$$

R_{Period} = Maximum Refresh period specified by the DRAM manufacturer (time in microseconds).
FREQ = Operating Frequency at 80C186 in megahertz.
#Refresh Rows = Total number of rows to be refreshed.
% Overhead = Derating factor that estimates the number of missed refresh requests (typically 1–5%).

Figure 10. Equation to Calculate Refresh Interval

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	E	0	0	0	0	0	0	T_8	T_7	T_6	T_5	T_4	T_3	T_2	T_1	T_0

Bits 0–8: T_0–T_8, Refresh request down counter clock count. These bits are read only and represent the current value of the counter. Any write operation to these bits is ignored. These bits are set to 0 on $\overline{RESET}$ or when the E bit is cleared.
Bits 9–14: Reserved, should be written to as a 0 to maintain future compatibility, will always be read back as zero.
Bit 15: E, enables the operation of the refresh control unit. Setting the E bit will automatically load the request down counter. Clearing the E bit stops refresh operation and clears the Down Counter.

Figure 11. EDRAM Register Format

The equation shown in Figure 10 can be used to determine the value of the CDRAM register needed to establish a desired refresh request rate. **Note that the equation is based on the internal operating frequency of the 80C186.** Therefore, the request rate is effected by any change in operating frequency. Modification of the operating frequency can occur in two ways: modifying the input clock or entering power-save mode. There is no upper limitation as to the frequency of refresh requests (other than programming), but there is a lower limit. This lower limit is based on the fact that the request rate can be no faster than the time it takes to service the request. Subsequently, **the minimum programming value of the CDRAM register should be 18 (12H).** It is very doubtful that this will ever become a problem when operating at normal frequencies, since the refresh rate of most dynamic memories is well above this minimum programming value.

However, when making use of the power-save feature of the 80C186, it is possible to lower the operating frequency such that it will prevent adequate refreshing rates. When operating at 12.5 MHz, dividing the clock by 16 results in a cycle time of 1.28 microseconds. Since the minimum value of the CDRAM is 18, the minimum refresh rate is 23.04 microseconds. 23 microseconds is not fast enough to service most dynamic memories. Therefore, caution must be exercised when using the power-save feature of the 80C186. When there is a need to keep dynamic memory alive, the clock should not be divided much below 2 MHz to avoid monopolizing the bus with refresh activity. If there is no desire to keep memory alive during power-save operation, then the refresh unit can simply be disabled during this time.

Programming the Refresh Enable Register

The EDRAM register (Figure 11) is used to enable and disable the refresh control unit. Furthermore, reading the register returns the current value of the down counter.

Setting the E bit enables the RCU and loads the value of the CDRAM register into the down counter. Whenever the E bit is cleared, the refresh control unit is disabled and the down counter is cleared. Disabling the refresh control unit does not change the contents of the refresh address counter (i.e. it is not cleared or initialized to any specific value). Thus, when the refresh unit is again enabled, the address generated will continue from where it left off. Resetting the 80C186 automatically clears the E bit. There are no refresh bus cycles during a reset.

The current value of the down counter, as well as the present state of the E bit can be examined whenever the EDRAM register is read. Any unused bits will be returned as zero. Whenever the E bit is cleared, the T0 through T8 bits will be read as zero.

REFRESH CONTROL UNIT OPERATION

Figure 12 illustrates the two major operational functions of the refresh control unit that are responsible for initiating and controlling DRAM refresh bus cycles.

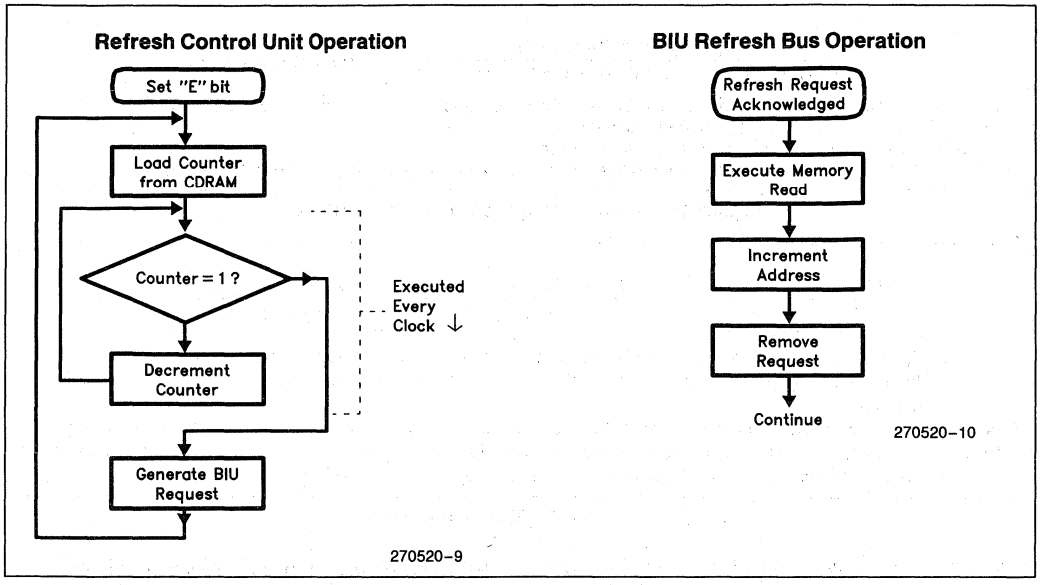


Figure 12. Flowchart of RCU Operation

The down counter is loaded (with the contents of the CDRAM register) on the falling edge of CLKOUT, either when the E bit is set or whenever the counter decrements to 1. Once loaded, the down counter will decrement every falling edge of CLKOUT. It will continue to decrement as long as the E bit remains set.

When the down counter finally decrements to 1, two things will happen. First, a request is generated to the BIU to run a refresh bus cycle. The request remains active until the bus cycle is run. Second, the down counter is reloaded with the value contained in the CDRAM register. At this time, the down counter will again begin counting down every clock cycle, **it does not wait until the request has been serviced.** This is done to ensure that each refresh request occurs at the correct interval. Otherwise, if the down counter only started after the previous request were service, the time between refresh requests would also be a function of bus activity, which for the most part is unpredictable. When the BIU services the refresh request, it will clear the request and increment the refresh address.

80C188 Address Considerations

The physical address that is generated during a refresh bus cycle is shown in Figure 7, and it applies to both the 80C186 and 80C188. For the 80C188, this means that the lower address bit A0 will not toggle during refresh operation. Since the 80C188 has an 8-bit external bus, A0 is used as part of memory address decoding. Whereas the 80C186, with its 16-bit external bus, uses A0 (along with $\overline{BHE}$) to select memory banks. Therefore, when designing 80C188 memory subsystems it is important not to include A0 as part of the ROW address that is used as a refresh address. Appendix A illustrates Memory Address Multiplexing Techniques that can be applied to the 80C186 and the 80C188.

MISSING REFRESH REQUESTS

Under most operating conditions, the frequency of refresh requests is a small percentage of the bus bandwidth. Still, there are several conditions that may prevent a refresh request from being serviced before another request is generated. These conditions include:

1) LOCKED Bus Cycles
2) Long Bus accesses (wait states)
3) Bus HOLD

LOCKED Bus Cycles

Whenever the bus is LOCKED, the CPU maintains control of the BIU and will not relinquish it until the locked operation is complete. Therefore, internal operations like refresh and DMA are not allowed to execute until the LOCKED instruction has completed. Where this presents the greatest problem is when an instruction such as a move string is executed, and is locked. The move string instruction can take from several clocks to hundreds of thousands of clocks to complete. Obviously anything that takes longer than 512 clocks to complete will always cause a refresh overflow.

Care should be taken not to generate long executing instructions that require bus accesses and are locked. The refresh request interval can be shortened to compensate for missing requests.

Long Bus Accesses

The 80C186 does not provide any mechanism to abort or terminate a bus access in the event ready is not returned within a specified amount of time (the 80C186 will infinitely wait for ready). Therefore, if a bus access is in progress when a refresh request is generated, the bus access must complete before the request will be serviced.

Bus HOLD

Special consideration is given when a refresh request is generated and the 80C186 is currently being held off the bus due to a HOLD request.

When another bus master has control of the bus, the HLDA signal is kept active as long as the HOLD input remains active. If a refresh request is generated while HOLD is active, the 80C186 will remove (drive inactive) the HLDA signal to indicate to the other bus master that the 80C186 wishes to regain control of the bus (see Figure 13). If, **and only if**, the HOLD input is removed will the BIU begin to run the refresh bus cycle.

Therefore, it is the responsibility of the system designer to ensure that the 80C186 can regain the bus if a refresh request is signaled. The sequence of HLDA going inactive while HOLD is active can be used to signal a pending refresh request. HOLD need only go inactive for one clock period to allow the refresh bus cycle to be run. If HOLD is again asserted, the 80C186 will give up the bus after the refresh bus cycle has been run (provided there is not another refresh request generated during that time).

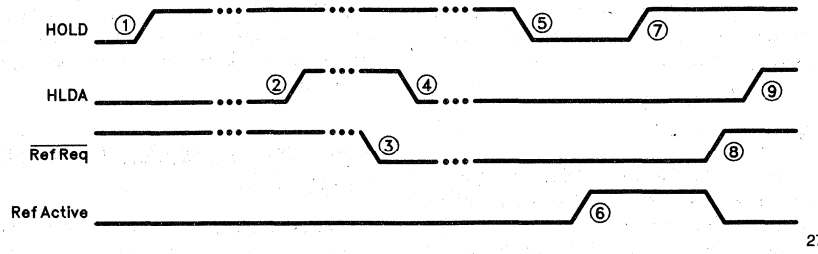
EFFECTS OF MISSING REFRESH REQUESTS

If a refresh request has not been serviced before another request is generated, the new request is not recorded and is lost. For instance, if the interval between refresh request is 15 microseconds and one request is lost, then the time between two requests will be 30 microseconds when the next request is finally serviced. In this example, missing one request will add 15 μs to the total refresh time. If it is anticipated that refresh requests may be missed (due to programming or system operation), then the refresh request interval should be shortened to allow for missed requests.

Since the BIU is responsible for maintaining the refresh address counter, missing a refresh requests does **not** imply that refresh addresses are skipped. In fact, an address can never be skipped unless a reset occurs.

CONCLUSION

The Internal Refresh Control Unit of the 80C186 and 80C188 helps solve three issues concerning DRAM refreshing: a way to generate periodic refresh requests; a way to generate refresh addresses; a way to simplify DRAM memory controllers. Once a memory controller has been designed to handle the simple tasks of reading and writing the task of refreshing has already been built in.



NOTES:
1. System generates HOLD request.
2. HLDA is returned and 80C186 floats bus/control.
3. Refresh request is generated internal to 80C186.
4. 80C186 lowers (removes) HLDA to signal that it wants the bus back.
5. 80C186 waits until HOLD is lowered (removed) for at least 1 clock cycle (minimum HOLD setup and hold time) to execute the refresh bus cycle. If HOLD is never lowered, the 80C186 will not take over the bus.
6. 80C186 runs the refresh bus cycle.
7. HOLD can be again asserted after the 1 clock duration.
8. The refresh request is cleared after the bus cycle has been executed.
9. If HOLD was again asserted, the 80C186 will immediately relinquish the bus back. If no HOLD occurred, normal CPU operation will resume.

Figure 13. HOLD/HLDA Timing and Refresh Request

APPENDIX A
TYPICAL DRAM ADDRESS GENERATION CONSIDERATIONS FOR 80C186/80C188

80C186 DESIGNS

		Row Address (A0–AX)	Column Address (A0–AX)
64K x 1	(128K Bytes)	A1–A8	A9–A16
16K x 4	(32K Bytes)	A1–A8	A9–A14
256K x 1	(512K Bytes)	A1–A9	A10–A18
64K x 4	(128K Bytes)	A1–A8	A9–A16
1M x 1	(2M Bytes)	A1–A10	A11–A19 (+ Bank)
256K x 4	(512K Bytes)	A1–A9	A10–A18

80C188 DESIGNS

NOTE:
Address bit A0 can be used in either RAS or CAS addresses, so long as it is not included in any refresh address bits.

		Row Address (A0–AX)	Column Address (A0–AX)
64K x 1	(64K Bytes)	A1–A7, A0	A8–A15
16K x 4	(16K Bytes)	A1–A7, A0	A8–A13
256K x 1	(256K Bytes)	A1–A8, A0	A9–A17
64K x 4	(64K Bytes)	A1–A8	A0, A9–A15
1M x 1	(1M Byte)	A1–A9, A0	A10–A19
256K x 4	(256K Bytes)	A1–A9	A0, A10–A17

RAM Type	RAS Add	CAS Add	Refresh Add
64K x 1	A0–A7	A0–A7	A0–A6
16K x 4	A0–A7	A0–A5	A0–A6
256K x 1	A0–A8	A0–A8	A0–A7
64K x 4	A0–A7	A0–A7	A0–A7
1M x 1	A0–A9	A0–A9	A0–A8
256K x 4	A0–A8	A0–A8	A0–A8

intel®

APPLICATION BRIEF

AB-35

August 1990

DRAM Refresh/Control with the 80186/80188

STEVE FARRER
APPLICATIONS ENGINEER

Order Number: 270524-002

DRAM REFRESH/ CONTROL WITH THE 80186/80188

CONTENTS

In many low-cost 80186/80188 designs, dynamic memory offers an excellent cost/performance advantage. However, DRAM interfacing is often complicated by the need to perform memory refreshing. This application brief describes how to use the Timer and DMA functionality of the 80186/80188 to perform memory refresh.

THEORY OF OPERATION

Dynamic RAM refreshing is accomplished by strobing a ROW address to every ROW of the DRAM within a given period of time. One way to do this is to perform periodic sequential reads to the DRAM using a DMA controller and a Timer. This can be achieved with the 80186/188 by Programming Timer 2 and one of the DMA channels such that the timer generated one DMA cycle approximately every 15 micro-seconds. Please note that this is a single row refresh method and not a burst refresh. Single row refreshing reduces the bus overhead considerably when compared to burst refreshing.

The control logic of the DRAM is such that a RAS (row address strobe) occurs on every memory read, regardless of the address. This is necessary because the DMA channel is cycling through the entire 1 MByte address space and the address of the refresh cycle does not always fall within the range of the DRAM bank.

Although the address may be outside the DRAM range, the lower address bits continue to change and roll over to provide the row address.

READY LOGIC WITH MEMORY

Since the DMA controller is cycling through the entire 1 MByte address space, care must be taken to ensure that a READY signal is available for all addresses. One way to do this is to use only the internal wait state generator for memory areas and to strap the SRDY and ARDY pins HIGH. Whenever a refresh cycle occurs outside of a predefined internal wait state area, the external ready pins, which are active HIGH, will complete the bus cycle.

If it is necessary to use the external ready signals for certain memory regions, then it will be necessary to add logic which will generate a ready signal whenever the address of a refresh cycle falls where there is no memory. This can easily be accomplished by either decoding a couple of high order address lines, or by AND-ing all the chip selects so that READY goes active whenever all the memory chip selects are inactive (i.e. the cycle is not in a valid memory region).

BUS OVERHEAD

The absolute maximum overhead can be calculated at a given speed by taking the number of refresh cycles divided by the total number of bus cycles for a given period of time. At 8 MHz these values can be calculated as follows:

$$\frac{\text{2 bus cycles}}{\text{15.2 } \mu\text{s/500 ns}} \times 100 = 6.6\% \text{ maximum overhead}$$

In reality, the bus overhead associated with the DMA cycles is much lower due to the instruction prefetch queue. When a DMA cycle is requested by the timer for a refresh cycle, the Bus Interface Unit honors the request on the next bus cycle boundary (with the exception of LOCKed bus cycles and odd aligned accesses). Typically this time is idle time on the bus and the impact on the overall performance is extremely small. The following table shows more realistic data which was acquired by running 6 different benchmarks with and without the DMA channel enabled to provide refresh every 15.2μs.

BENCHMARK RESULTS @ 8 MHz

	Minimum	Maximum	Average
80186	1.3%	5.9%	2.5%
80188	2.4%	6.5%	3.4%

The programs which showed the highest bus overhead tended to be very bus intensive. Also note that at faster frequencies the bus overhead becomes even less.

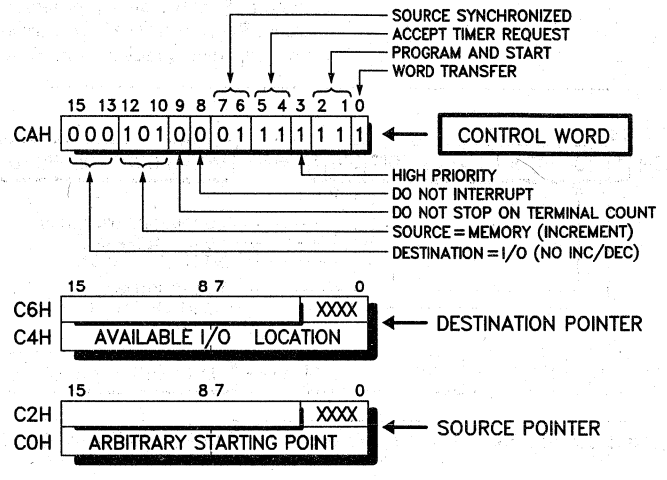
DMA OPERATION

The DMA controller is programmed to be source synchronized with the TC (transfer count) bit cleared. This ensures that the DMA controller never reaches a final count. The source pointer continues to increment through memory on every cycle. When FFFFFH is reached, the address rolls over to 00000H

The programming values for the DNA registers are shown in Figure 1. The source pointer may be initialized to any location since the starting location of the refresh is arbitrary.

The value of the Transfer Count register is also arbitrary since the TC bit is not set. The DMA channel will continue to run cycles upon request from Timer 2 even after the Transfer Count register has reached zero. Once zero is reached, the Transfer Count register will roll over to FFFFH and continue to count down.

The destination pointer may be set to any available memory or I/O location. This pointer must be set so that it neither increments nor decrements. Otherwise, the address of the deposit cycle would cycle through memory or I/O doing writes which could possibly be destructive. Thus the INC and DEC bits of the control register should be cleared.



NOTES:
1. Locations of registers are relative to the base address of the peripheral control block. The offsets shown are for Channel 0.
2. The byte/word bit is a don't care in a 80188 system. In a 80186 system this bit should be set to a 1 to represent word transfers.
3. The transfer count register is located at offset C8H. It is not necessary to program this register.

Figure 1. DMA Registers

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TIMER OPERATION

Timer 2 must be programmed to generate a DMA request every time a row must be refreshed. Since we are not using a burst refresh, the refresh time is divided up evenly among the number of rows. For a 2 ms refresh DRAM with 128 rows, the time between rows equals 15.62 microseconds.

When setting the count value of the timer, keep in mind the timer clock is operating at one-fourth the CPU clock frequency. Thus, the equation for setting the timer count is:

$$\frac{(\text{CPU CLOUT FREQ}) \times (\text{Time Between ROWS})}{4} = \text{COUNT\_\_VALUE (decimal)}$$

For an 8 MHz clock, programming the Maximum Count Register to 1EH provides a 15.2 μs refresh. This programming is indicated in Figure 2.

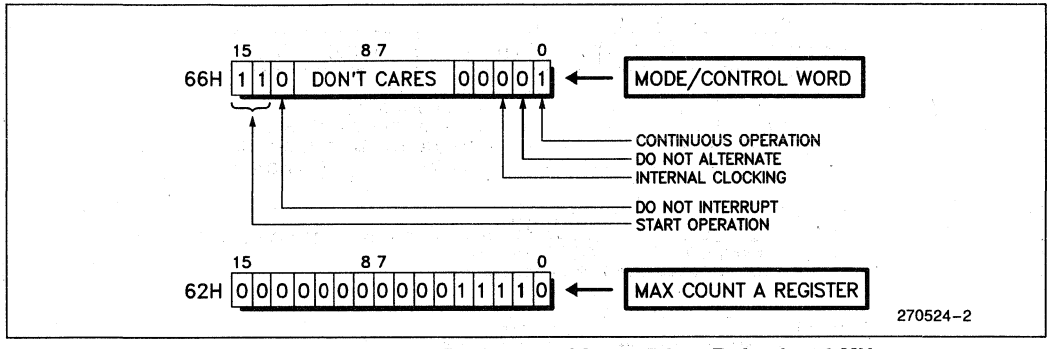

Figure 2. Timer 2 Registers Programmed for a 15.2 μs Refresh at 8 MHz

EXAMPLE 1: DRAM CONTROL WITH A DELAY LINE

This is the most straight forward way of implementing the $\overline{RAS}$ and $\overline{CAS}$ logic. A $\overline{RAS}$ signal is generated by either $\overline{RD}$ or $\overline{WR}$ going active while the address is within the corresponding range. Normally the logic for $\overline{RAS}$ would also go active for a refresh cycle status, but since this information is not available on the 80186/80188, a $\overline{RAS}$ must be generated for every $\overline{RD}$ and $\overline{WR}$, regardless address.

The $\overline{MUX}$ signal is used to change from the $\overline{RAS}$ address to the $\overline{CAS}$ address after latching with $\overline{RAS}$. This is accomplished by using a delay line which generates a $\overline{MUX}$ signal by a fixed number of nano-seconds after $\overline{RAS}$ is generated. The important timing here is the necessary hold time for the row address into the DRAM.

The $\overline{MUX}$ signal is initially HIGH which sends the A side (see Figure 3) Row address through the multiplexer to the DRAM. This address consists of A0 through A7. The B address (A8 through A16) is selected when $\overline{MUX}$ goes LOW. The system shown in Figure 3 represents that of an 80188 system.

For an 80186 system, the A address would start at A1. The least significant address line A0 along with $\overline{BHE}$ would be used to decode $\overline{WE}$ into $\overline{WEH}$ and $\overline{WEL}$ which will be shown in the second example. Also, the 186 DMA must be set to do word transfers so that the address is incremented by 2 after each refresh cycle. This is necessary to ensure A1 increments by 1 every refresh cycle.

$\overline{CAS}$ is generated in the same manner by delaying the $\overline{MUX}$ signal a fixed number of nano-seconds. Typically $\overline{CAS}$ goes inactive at the same time as $\overline{RAS}$ to ensure a valid $\overline{CAS}$ precharge time before the next DRAM access. The 80186/188 chip selects are used to ensure that CAS only goes active when the address falls within the DRAM bank range, and to ensure that $\overline{CAS}$ does not go active during I/O cycles.

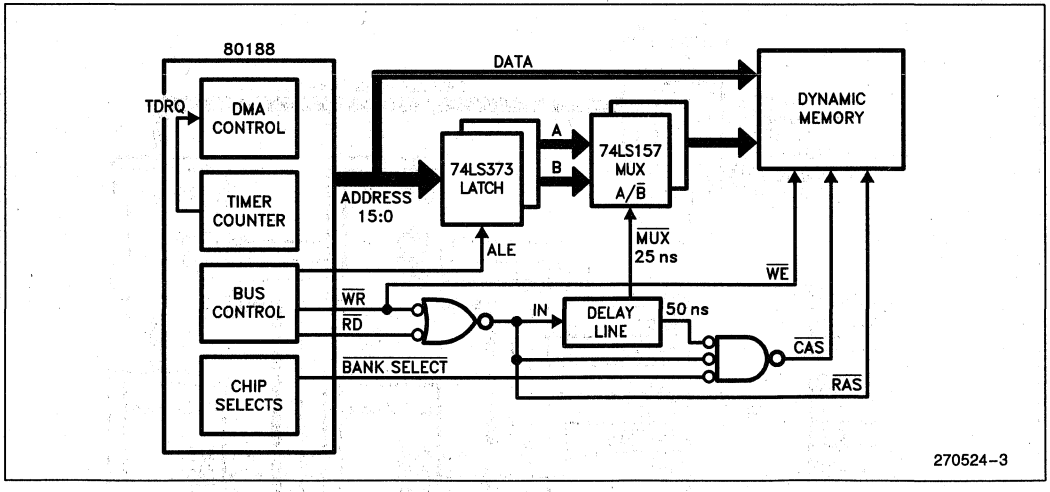

Figure 3. Using A Delay Line for DRAM Control

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EXAMPLE 2: DRAM CONTROL WITH A PAL*

This design uses a PAL to generate all the control logic for the DRAM array. Internal feedback is used on the signals to control the timing and states of the $\overline{RAS}$, $\overline{MUX}$ and $\overline{CAS}$ signals.

This design uses 256k X 4 DRAMs. With minor changes to the PAL equations this design could just as easily make use of 64k X 1, 64k X 4, or 256k X 1 DRAMs.

The $\overline{RAS}$ signal is generated off ALE going LOW, bus cycle status active, and $\overline{PRE\_RAS}$ being active. The $\overline{PRE\_RAS}$ signal is necessary to ensure that a $\overline{RAS}$ is not accidentally generated when S2-SO are becoming valid and ALE has not yet gone HIGH in T4 phase 2. $\overline{PRE\_RAS}$ does not go active until ALE has gone HIGH.

$\overline{RAS}$ is initiated for every memory read and write regardless of the bus cycle address. This ensures a row refresh when the refresh address falls outside of the DRAM bank and also a refresh to both banks simultaneously so that the frequency of the refresh can be set for the number of rows in one bank of DRAM.

The $\overline{UCS}$ (Upper Chip Select) from the 80186/188 is used to disable DRAM signals when the processor is attempting to access upper memory control ROM. Thus the portion of memory used by the $\overline{UCS}$ (maximum 256k) is unavailable in the upper DRAM. However, the $\overline{RAS}$ signal must still be allowed during $\overline{UCS}$ access to ensure refreshing when the DMA refresh cycle occurs in the $\overline{UCS}$ region.

$\overline{MUX}$ is generated off T2 phase 1 and $\overline{RAS}$ active. $\overline{MUX}$ will remain low until the current $\overline{RAS}$ signal goes inactive during T3 phase 2.

$\overline{CAS0}$ and $\overline{CAS1}$ are generated off $\overline{MUX}$ being active and T2 phase 2 of the bus cycle. $\overline{CAS}$ goes inactive at the start of T4 phase 2.

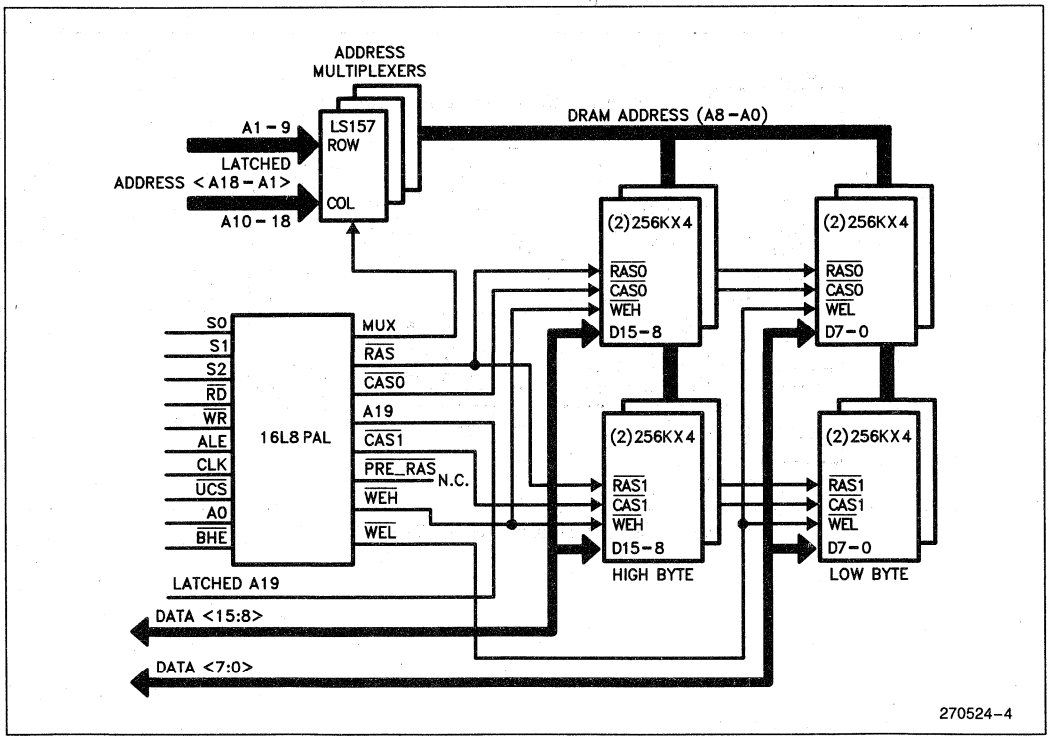

Figure 4. Using a PAL for DRAM Control

*PAL® is a registered trademark of Monolithic Memories.

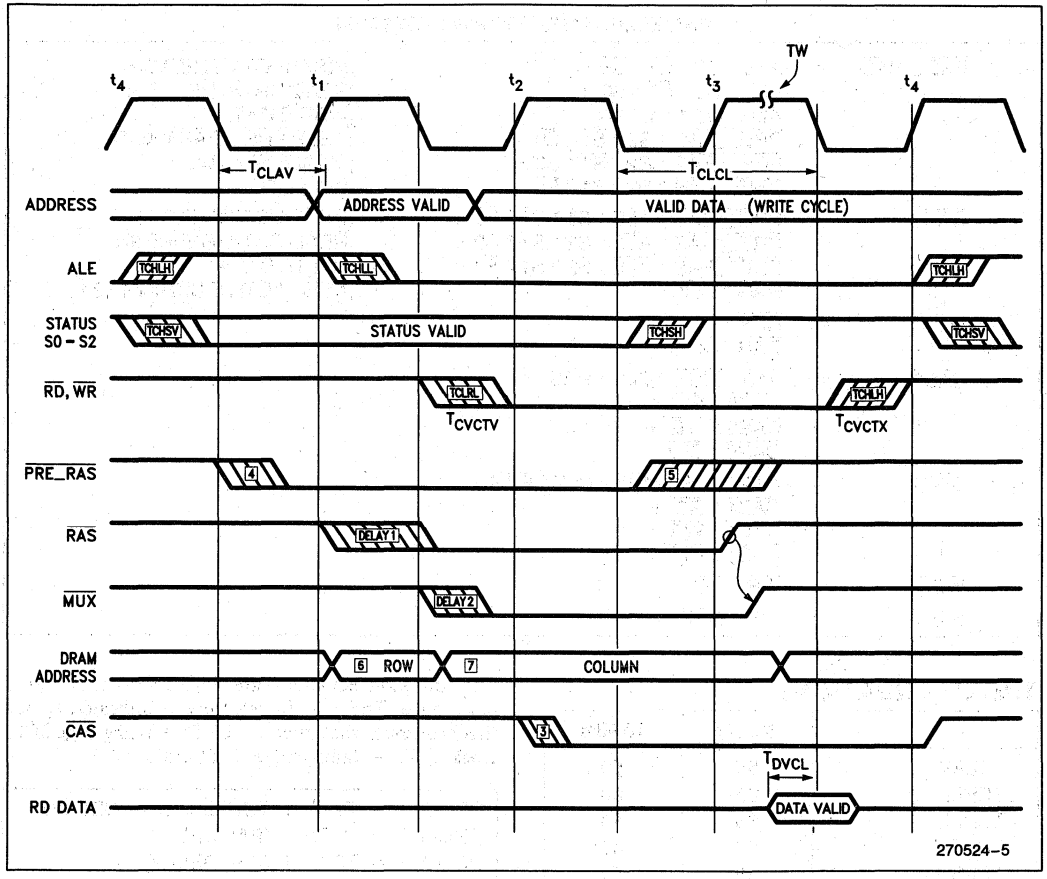

Figure 5. Timing Diagram for PAL DRAM Controller

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PAL EQUATIONS FOR 80186 SYSTEM

```
PRE_RAS  =  ALE * S2 * S1 * S0 +          ;INSTRUCTION FETCH
            ALE * S2 * S1 * S0 +          ;READ DATA/REFRESH
            ALE * S2 * S1 * S0 +          ;WRITE DATA
            PRE_RAS * S2 * S1 * S0 +      ;KEEP PRE_RAS VALID
            PRE_RAS * S2 * S1 * S0 +      ; WHILE STATUS
            PRE_RAS * S2 * S1 * S0        ;IS VALID

RAS      =  PRE_RAS * ALE * S2 * S1 * S0 +  ;INSTRUCTION FETCH
            PRE_RAS * ALE * S2 * S1 * S0 +  ;READ DATA/REFRESH
            PRE_RAS * ALE * S2 * S1 * S0 +  ;WRITE DATA
            RAS * CLK                       ;KEEP ACTIVE DURING T3A

MUX      =  RAS * CLK +
            RAS * MUX

CAS0     =  A19 * MUX * CLK * RAS +
            CAS0 * RD +
            CAS0 * WR +
            CAS0 * CLK

CAS1     =  A19 *UCS * MUX * CLK * RAS +
            CAS1 * RD +
            CAS1 * WR +
            CAS1 * CLK

WEL      =  WR * AO

WEH      =  WR * BHE
```

TIMING EQUATIONS

	8 MHz	10 MHz
TCLAV	55	50
TCHLH	35	30
TCHLL	35	30
TCHSV	55	45
TCLSH	65	50
TCLRL/TCVCTV	70	56
TCLRH	55	44
TDVCL	20	15

The following equations are with reference to given clock edge. The edge in reference is indicated by the first element in the equation: T3 ↑ = rising edge of T3 clock ↓T1 = falling edge of T1 clock.

```
DELAY 1 = T1 ↑ + TCHLL + (PAL DELAY)
DELAY 2 = ↓ T2 + (PAL DELAY)
DELAY 3 = T2 ↑ + (PAL DELAY)
DELAY 4 = ↓ T1 + (PAL DELAY)
DELAY 5 = ↓ T3 + TCLSH + (PAL DELAY)
DELAY 6 = ↓ T1 + TCLAV + (MUX DELAY)
DELAY 7 = ↓ T2 + DELAY 2 + (MUX DELAY)
```

ACCESS TIME FROM $\overline{RAS}$ = 2.5 (TCLCL) − DELAY 1 − TDVCL

ACCESS TIME FROM $\overline{CAS}$ = 1.5 (TCLCL) − DELAY 3 − TDVCL

MCS®-96 Application Notes & Article Reprint

6

September 1987

Using The 8096

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MCO APPLICATIONS ENGINEER

Order Number: 270061-002

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1.0 INTRODUCTION

High speed digital signals are frequently encountered in modern control applications. In addition, there is often a requirement for high speed 16-bit and 32-bit precision in calculations. The MCS®-96 product line, generically referred to as the 8096, is designed to be used in applications which require high speed calculations and fast I/O operations.

The 8096 is a 16-bit microcontroller with dedicated I/O subsystems and a complete set of 16-bit arithmetic instructions including multiply and divide operations. This Ap-note will briefly describe the 8096 in section 2, and then give short examples of how to use each of its key features in section 3. The concluding sections feature a few examples which make use of several chip features simultaneously and some hardware connection suggestions. Further information on the 8096 and its use is available from the sources listed in the bibliography.

2.0 8096 OVERVIEW

2.1. General Description

Unlike microprocessors, microcontrollers are generally optimized for specific applications. Intel's 8048 was optimized for general control tasks while the 8051 was optimized for 8-bit math and single bit boolean operations. The 8096 has been designed for high speed/high performance control applications. Because it has been designed for these applications the 8096 architecture is different from that of the 8048 or 8051.

There are two major sections of the 8096; the CPU section and the I/O section. Each of these sections can be subdivided into functional blocks as shown in Figure 2-1.

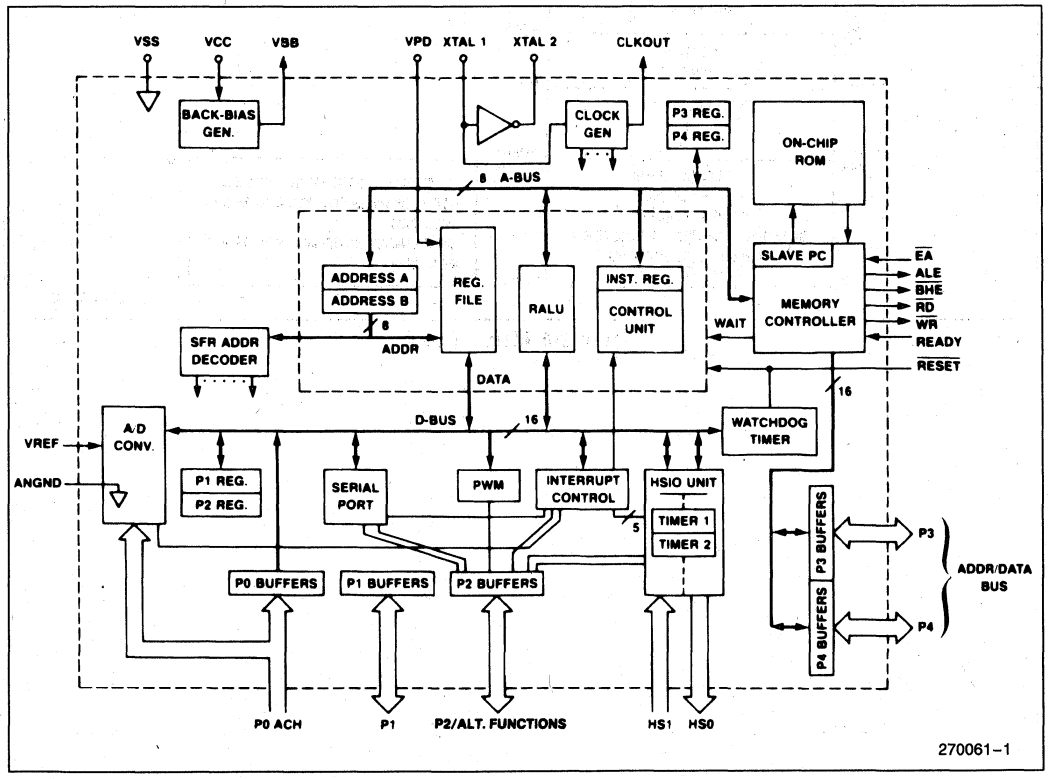


Figure 2-1. 8096 Block Diagram

2.1.1. CPU SECTION

The CPU of the 8096 uses a 16-bit ALU which operates on a 256-byte register file instead of an accumulator. Any of the locations in the register file can be used for sources or destinations for most of the instructions. This is called a register to register architecture. Many of the instructions can also use bytes or words from anywhere in the 64K byte address space as operands. A memory map is shown in Figure 2-2.

In the lower 24 bytes of the register file are the register-mapped I/O control locations, also called Special Function Registers or SFRs. These registers are used to control the on-chip I/O features. The remaining 232 bytes are general purpose RAM, the upper 16 of which can be kept alive using a low current power-down mode.

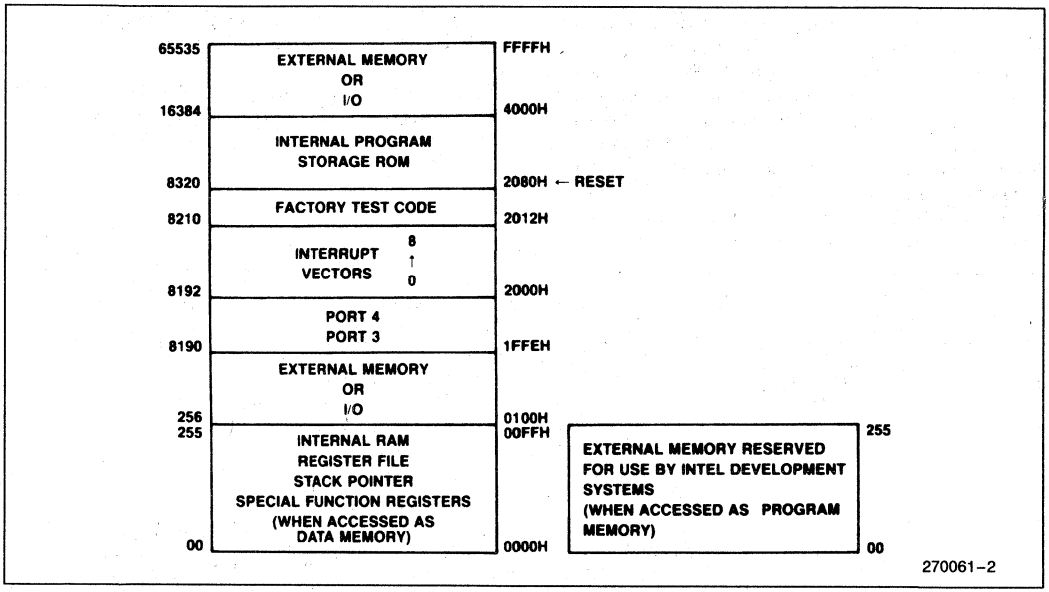


Figure 2-2. Memory Map

Figure 2-3 shows the layout of the register mapped I/O. Some of these registers serve two functions, one if they are read from and another if they are written to. More information about the use of these registers is included in the description of the features which they control.

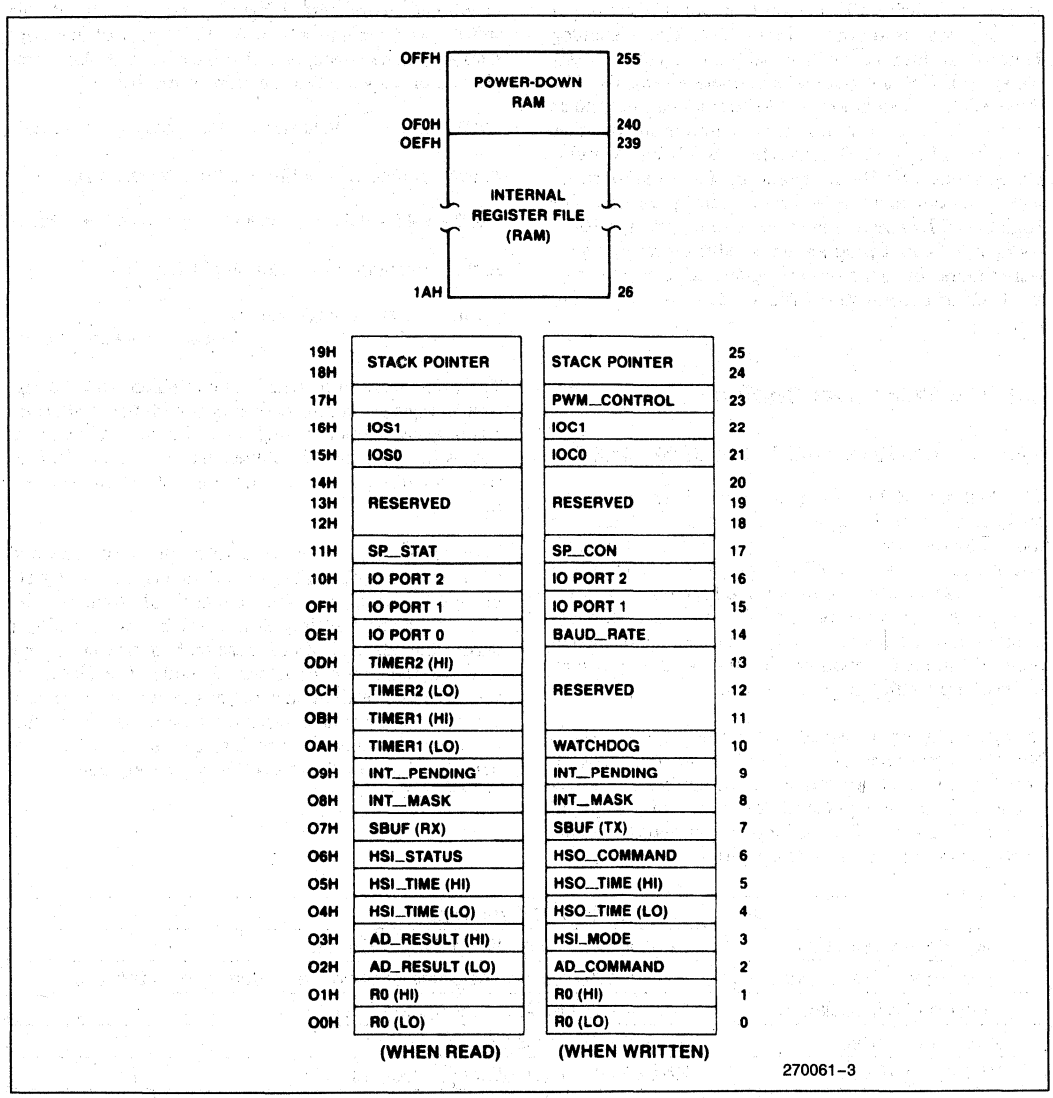


Figure 2-3: SFR Layout

2.1.2. I/O FEATURES

Many of the I/O features on the 8096 are designed to operate with little CPU intervention. A list of the major I/O functions is shown in Figure 2-4. The Watchdog Timer is an internal timer which can be used to reset the system if the software fails to operate properly. The Pulse-Width-Modulation (PWM) output can be used as a rough D to A, a motor driver, or for many other purposes. The A to D converter (ADC) has 8 multiplexed inputs and 10-bit resolution. The serial port has several modes and its own baud rate generator. The High Speed I/O section includes a 16-bit timer, a 16-bit counter, a 4-input programmable edge detector, 4 software timers, and a 6-output programmable event generator. All of these features will be described in section 2.3.

2.2. The Processor Section

2.2.1. OPERATIONS AND ADDRESSING MODES

The 8096 has 100 instructions, some of which operate on bits, some on bytes, some on words and some on longs (double words). All of the standard logical and arithmetic functions are available for both byte and word operations. Bit operations and long operations are provided for some instructions. There are also flag manipulation instructions as well as jump and call instructions. A full set of conditional jumps has been included to speed up testing for various conditions.

Bit operations are provided by the Jump Bit and Jump Not Bit instructions, as well as by immediate masking of bytes. These bit operations can be performed on any of the bytes in the register file or on any of the special function registers. The fast bit manipulation of the SFRs can provide rapid I/O operations.

A symmetric set of byte and word operations make up the majority of the 8096 instruction set. The assembly language for the 8096 (ASM-96) uses a "B" suffix on a mnemonic to indicate a byte operation, without this suffix a word operation is indicated. Many of these operations can have one, two or three operands. An example of a one operand instruction would be:

```
NOT   Value1 ;  Value1 : = 1's complement (Value1)
```

A two operand instruction would have the form:

```
ADD   Value2,Value1 ;  Value2 : = Value2 + Value1
```

A three operand instruction might look like:

```
MUL   Value3,Value2,Value1 ;
                        Value3 : = Value2* Value1
```

The three operand instructions combined with the register to register architecture almost eliminate the necessity of using temporary registers. This results in a faster processing time than machines that have equivalent instruction execution times, but use a standard architecture.

Long (32-bit) operations include shifts, normalize, and multiply and divide. The word divide is a 32-bit by 16-bit operation with a 16-bit quotient and 16-bit remainder. The word multiply is a word by word multiply with a long result. Both of these operations can be done in either the signed or unsigned mode. The direct unsigned modes of these instructions take only 6.5 microseconds. A normalize instruction and sticky bit flag have been included in the instruction set to provide hardware support for the software floating point package (FPAL-96).

Major I/O Functions	
High Speed Input Unit	Provides Automatic Recording of Events
High Speed Output Unit	Provides Automatic Triggering of Events and Real-Time Interrupts
Pulse Width Modulation	Output to Drive Motors or Analog Circuits
A to D Converter	Provides Analog Input
Watchdog Timer	Resets 8096 if a Malfunction Occurs
Serial Port	Provides Synchronous or Asynchronous Link
Standard I/O Lines	Provide Interface to the External World when other Special Features are not needed

Figure 2-4. Major I/O Functions

Mnemonic	Operands	Operation (Note 1)	Flags						Notes
			Z	N	C	V	VT	ST	
ADD/ADDB	2	D ← D + A	↕	↕	↕	↕	↑	—	
ADD/ADDB	3	D ← B + A	↕	↕	↕	↕	↑	—	
ADDC/ADDCB	2	D ← D + A + C	↓	↕	↕	↕	↑	—	
SUB/SUBB	2	D ← D − A	↕	↕	↕	↕	↑	—	
SUB/SUBB	3	D ← B − A	↕	↕	↕	↕	↑	—	
SUBC/SUBCB	2	D ← D − A + C − 1	↓	↕	↕	↕	↑	—	
CMP/CMPB	2	D − A	↕	↕	↕	↕	↑	—	
MUL/MULU	2	D, D + 2 ← D * A	—	—	—	—	—	?	2
MUL/MULU	3	D, D + 2 ← B * A	—	—	—	—	—	?	2
MULB/MULUB	2	D, D + 1 ← D * A	—	—	—	—	—	?	3
MULB/MULUB	3	D, D + 1 ← B * A	—	—	—	—	—	?	3
DIVU	2	D ← (D, D + 2)/A, D + 2 ← remainder	—	—	—	↕	↑	—	2
DIVUB	2	D ← (D, D + 1)/A, D + 1 ← remainder	—	—	—	↕	↑	—	3
DIV	2	D ← (D, D + 2)/A, D + 2 ← remainder	—	—	—	?	↑	—	2
DIVB	2	D ← (D, D + 1)/A, D + 1 ← remainder	—	—	—	?	↑	—	3
AND/ANDB	2	D ← D and A	↕	↕	0	0	—	—	
AND/ANDB	3	D ← B and A	↕	↕	0	0	—	—	
OR/ORB	2	D ← D or A	↕	↕	0	0	—	—	
XOR/XORB	2	D ← D (excl. or) A	↕	↕	0	0	—	—	
LD/LDB	2	D ← A	—	—	—	—	—	—	
ST/STB	2	A ← D	—	—	—	—	—	—	
LDBSE	2	D ← A; D + 1 ← SIGN(A)	—	—	—	—	—	—	3, 4
LDBZE	2	D ← A; D + 1 ← 0	—	—	—	—	—	—	3, 4
PUSH	1	SP ← SP − 2; (SP) ← A	—	—	—	—	—	—	
POP	1	A ← (SP); SP ← SP + 2	—	—	—	—	—	—	
PUSHF	0	SP ← SP − 2; (SP) ← PSW; PSW ← 0000H I ← 0	0	0	0	0	0	0	
POPF	0	PSW ← (SP); SP ← SP + 2; I ← ↕	↕	↕	↕	↕	↕	↕	
SJMP	1	PC ← PC + 11-bit offset	—	—	—	—	—	—	5
LJMP	1	PC ← PC + 16-bit offset	—	—	—	—	—	—	5
BR (indirect)	1	PC ← (A)	—	—	—	—	—	—	
SCALL	1	SP ← SP − 2; (SP) ← PC; PC ← PC + 11-bit offset	—	—	—	—	—	—	5
LCALL	1	SP ← SP − 2; (SP) ← PC; PC ← PC + 16-bit offset	—	—	—	—	—	—	5
RET	0	PC ← (SP); SP ← SP + 2	—	—	—	—	—	—	
J (conditional)	1	PC ← PC + 8-bit offset (if taken)	—	—	—	—	—	—	5
JC	1	Jump if C = 1	—	—	—	—	—	—	5
JNC	1	Jump if C = 0	—	—	—	—	—	—	5
JE	1	Jump if Z = 1	—	—	—	—	—	—	5

Figure 2-5. Instruction Summary

NOTES:
1. If the mnemonic ends in "B", a byte operation is performed, otherwise a word operation is done. Operands D, B, and A must conform to the alignment rules for the required operand type. D and B are locations in the register file; A can be located anywhere in memory.
2. D, D + 2 are consecutive WORDS in memory; D is DOUBLE-WORD aligned.
3. D, D + 1 are consecutive BYTES in memory; D is WORD aligned.
4. Changes a byte to a word.
5. Offset is a 2's complement number.

Mnemonic	Operands	Operation (Note 1)	Flags						Notes
			Z	N	C	V	VT	ST	
JNE	1	Jump if Z = 0	—	—	—	—	—	—	5
JGE	1	Jump if N = 0	—	—	—	—	—	—	5
JLT	1	Jump if N = 1	—	—	—	—	—	—	5
JGT	1	Jump if N = 0 and Z = 0	—	—	—	—	—	—	5
JLE	1	Jump if N = 1 or Z = 1	—	—	—	—	—	—	5
JH	1	Jump if C = 1 and Z = 0	—	—	—	—	—	—	5
JNH	1	Jump if C = 0 or Z = 1	—	—	—	—	—	—	5
JV	1	Jump if V = 1	—	—	—	—	—	—	5
JNV	1	Jump if V = 0	—	—	—	—	—	—	5
JVT	1	Jump if VT = 1; Clear VT	—	—	—	—	0	—	5
JNVT	1	Jump if VT = 0; Clear VT	—	—	—	—	0	—	5
JST	1	Jump if ST = 1	—	—	—	—	—	—	5
JNST	1	Jump if ST = 0	—	—	—	—	—	—	5
JBS	3	Jump if Specified Bit = 1	—	—	—	—	—	—	5, 6
JBC	3	Jump if Specified Bit = 0	—	—	—	—	—	—	5, 6
DJNZ	1	D ← D − 1; if D ≠ 0 then PC ← PC + 8-bit offset	—	—	—	—	—	—	5
DEC/DECB	1	D ← D − 1	↕	↕	↕	↕	↑	—	
NEG/NEGB	1	D ← 0 − D	↕	↕	↕	↕	↑	—	
INC/INCB	1	D ← D + 1	↕	↕	↕	↕	↑	—	
EXT	1	D ← D; D + 2 ← Sign (D)	↕	↕	0	0	—	—	2
EXTB	1	D ← D; D + 1 ← Sign (D)	↕	↕	0	0	—	—	3
NOT/NOTB	1	D ← Logical Not (D)	↕	↕	0	0	—	—	
CLR/CLRB	1	D ← 0	1	0	0	0	—	—	
SHL/SHLB/SHLL	2	C ← msb — — — — — — lsb ← 0	↕	?	↕	↕	↑	—	7
SHR/SHRB/SHRL	2	0 → msb — — — — — — lsb → C	↕	?	↕	0	—	↕	7
SHRA/SHRAB/SHRAL	2	msb → msb — — — — — — lsb → C	↕	↕	↕	0	—	↕	7
SETC	0	C ← 1	—	—	1	—	—	—	
CLRC	0	C ← 0	—	—	0	—	—	—	
CLRVT	0	VT ← 0	—	—	—	—	0	—	
RST	0	PC ← 2080H	0	0	0	0	0	0	8
DI	0	Disable All Interrupts (I ← 0)	—	—	—	—	—	—	
EI	0	Enable All Interrupts (I ← 1)	—	—	—	—	—	—	
NOP	0	PC ← PC + 1	—	—	—	—	—	—	
SKIP	0	PC ← PC + 2	—	—	—	—	—	—	
NORML	2	Left Shift Till msb = 1; D ← shift count	↕	?	0	—	—	—	7
TRAP	0	SP ← SP − 2; (SP) ← PC PC ← (2010H)	—	—	—	—	—	—	9

Figure 2-5. Instruction Summary (Continued)

NOTES:
1. If the mnemonic ends in "B", a byte operation is performed, otherwise a word operation is done. Operands D, B, and A must conform to the alignment rules for the required operand type. D and B are locations in the register file; A can be located anywhere in memory.
5. Offset is a 2's complement number.
6. Specified bit is one of the 2048 bits in the register file.
7. The "L" (Long) suffix indicates double-word operation.
8. Initiates a Reset by pulling RESET low. Software should re-initialize all the necessary registers with code starting at 2080H.
9. The assembler will not accept this mnemonic.

One operand of most of the instructions can be used with any one of six addressing modes. These modes increase the flexibility and overall execution speed of the 8096. The addressing modes are: register-direct, immediate, indirect, indirect with auto-increment, and long and short indexed.

The fastest instruction execution is gained by using either register direct or immediate addressing. Register-direct addressing is similar to normal direct addressing, except that only addresses in the register file or SFRs can be addressed. The indexed mode is used to directly address the remainder of the 64K address space. Immediate addressing operates as would be expected, using the data following the opcode as the operand.

Both of the indirect addressing modes use the value in a word register as the address of the operand. If the indirect auto-increment mode is used then the word register is incremented by one after a byte access or by two after a word access. This mode is particularly useful for accessing lookup tables.

Access to any of the locations in the 64K address space can be obtained by using the long indexed addressing mode. In this mode a 16-bit 2's complement value is added to the contents of a word register to form the address of the operand. By using the zero register as the index, ASM96 (the assembler) can accept "direct" addressing to any location. The zero register is located at 0000H and always has a value of zero. A short indexed mode is also available to save some time and code. This mode uses an 8-bit 2's complement number as the offset instead of a 16-bit number.

2.2.2. ASSEMBLY LANGUAGE

The multiple addressing modes of the 8096 make it easy to program in assembly language and provide an excellent interface to high level languages. The instructions accepted by the assembler consist of mnemonics followed by either addresses or data. A list of the mnemonics and their functions are shown in Figure 2-5. The addresses or data are given in different formats depending on the addressing mode. These modes and formats are shown in Figure 2-6.

Additional information on 8096 assembly language is available in the MCS-96 Macro Assembler Users Guide, listed in the bibliography.

```
Mnem  Dest or Src1                ; One operand direct
Mnem  Dest, Src1                  ; Two operand direct
Mnem  Dest, Src1, Src2            ; Three operand direct

Mnem  #Src1                       ; One operand immediate
Mnem  Dest, #Src1                 ; Two operand immediate
Mnem  Dest, Src1, #Src2           ; Three operand immediate

Mnem  [addr]                      ; One operand indirect
Mnem  [addr]+                     ; One operand indirect auto-increment
Mnem  Dest, [addr]                ; Two operand indirect
Mnem  Dest, [addr]+               ; Two operand indirect auto-increment
Mnem  Dest, Src1, [addr]          ; Three operand indirect
Mnem  Dest, Src1, [addr]+         ; Three operand indirect auto-increment

Mnem  Dest, offs [addr]           ; Two operand indexed (short or long)
Mnem  Dest, Src1, offs [addr]     ; Three operand indexed (short or long)

Where: "Mnem" is the instruction mnemonic
       "Dest" is the destination register
       "Src1", "Src2" are the source registers
       "addr" is a register containing a value to be used in computing the address of an operand
       "offs" is an offset used in computing the address of an operand
```

270061-B3

Figure 2-6. Instruction Format

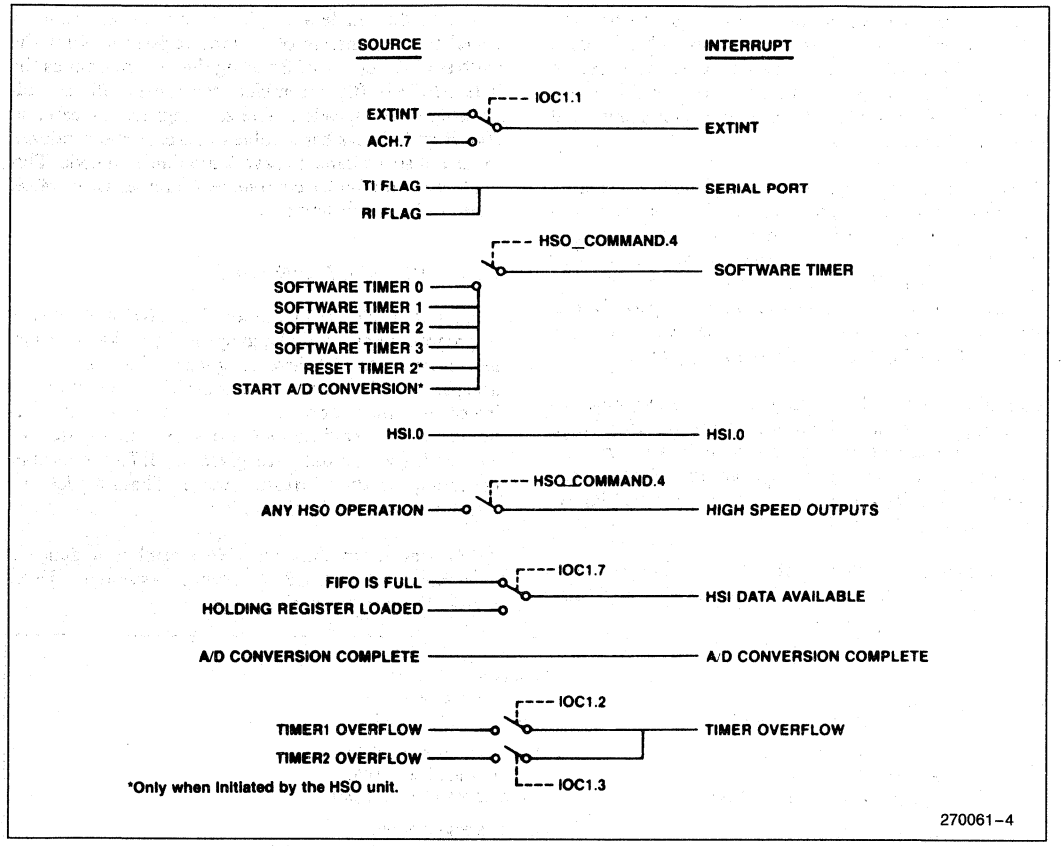


Figure 2-7. Interrupt Sources

2.2.3. INTERRUPTS

The flexibility of the instruction set is carried through into the interrupt system. There are 20 different interrupt sources that can be used on the 8096. The 20 sources vector through 8 locations or interrupt vectors. The vector names and their sources are shown in Figure 2-7, with their locations listed in Figure 2-8. Control of the interrupts is handled through the Interrupt Pending Register (INT_PENDING), the Interrupt Mask Register (INT_MASK), and the I bit in the PSW (PSW.9). Figure 2-9 shows a block diagram of the interrupt structure. The INT_PENDING register contains bits which get set by hardware when an interrupt occurs. If the interrupt mask register bit for that source is a 1 and PSW.9 = 1, a vector will be taken to the address listed in the interrupt vector table for that

Source	Vector Location		Priority
	(High Byte)	(Low Byte)	
Software	2011H	2010H	Not Applicable
Extint	200FH	200EH	7 (Highest)
Serial Port	200DH	200CH	6
Software Timers	200BH	200AH	5
HSI.0	2009H	2008H	4
High Speed Outputs	2007H	2006H	3
HSI Data Available	2005H	2004H	2
A/D Conversion Complete	2003H	2002H	1
Timer Overflow	2001H	2000H	0 (Lowest)

Figure 2-8. Interrupt Vectors and Priorities

source. When the vector is taken the INT_PENDING bit is cleared. If more than one bit is set in the INT_PENDING register with the corresponding bit set in the INT_MASK register, the Interrupt with the highest priority shown in Figure 2-8 will be executed.

The software can make the hardware interrupts work in almost any fashion desired by having each routine run with its own setup in the INT_MASK register. This will be clearly seen in the examples in section 4 which change the priority of the vectors in software. The

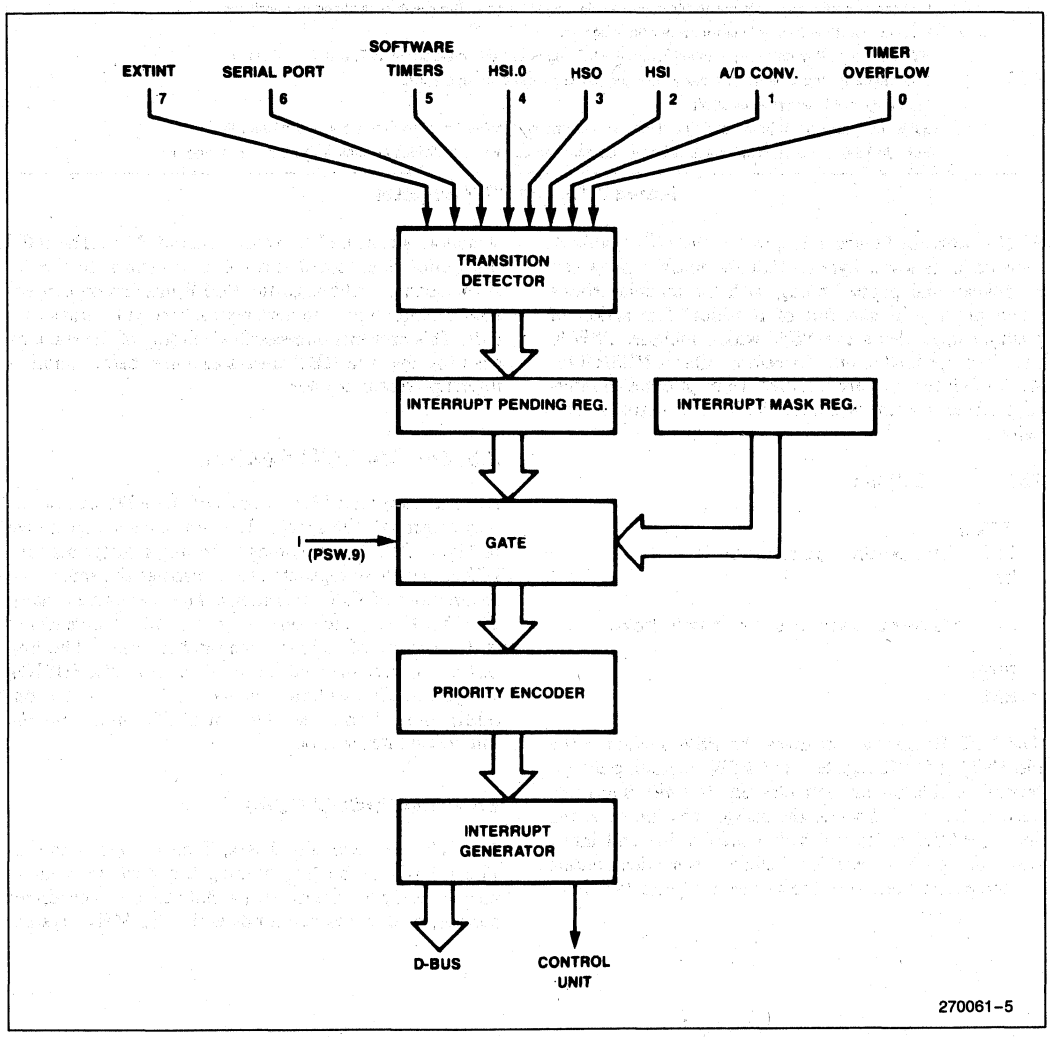


Figure 2-9. Interrupt Structure Block Diagram

6

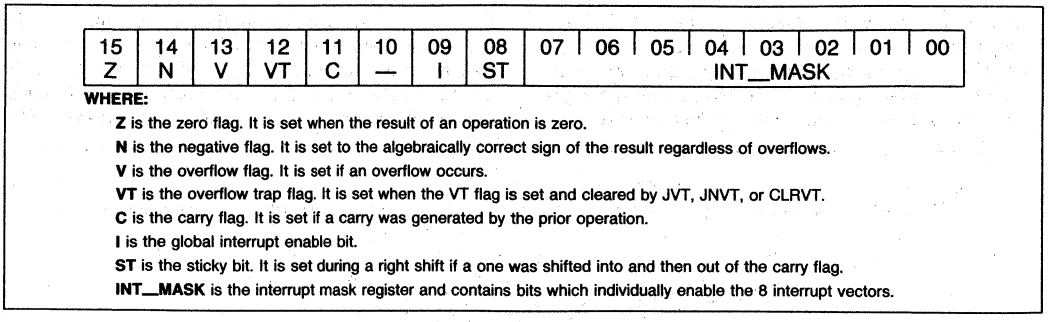


Figure 2-10. The PSW Register

PSW (shown in Figure 2-10), stores the INT_MASK register in its lower byte so that the mask register can be pushed and popped along with the machine status when moving in and out of routines. The action of pushing flags clears the PSW which includes PSW.9, the interrupt enable bit. Therefore, after a PUSHF instruction interrupts are disabled. In most cases an interrupt service routine will have the basic structure shown below.

```
INT     VECTOR:

  PUSHF
  LDB  INT_MASK, #xxxxxxxxB
  EI
   -
   -  ;Insert service routine here
   -
  POPF
  RET
```

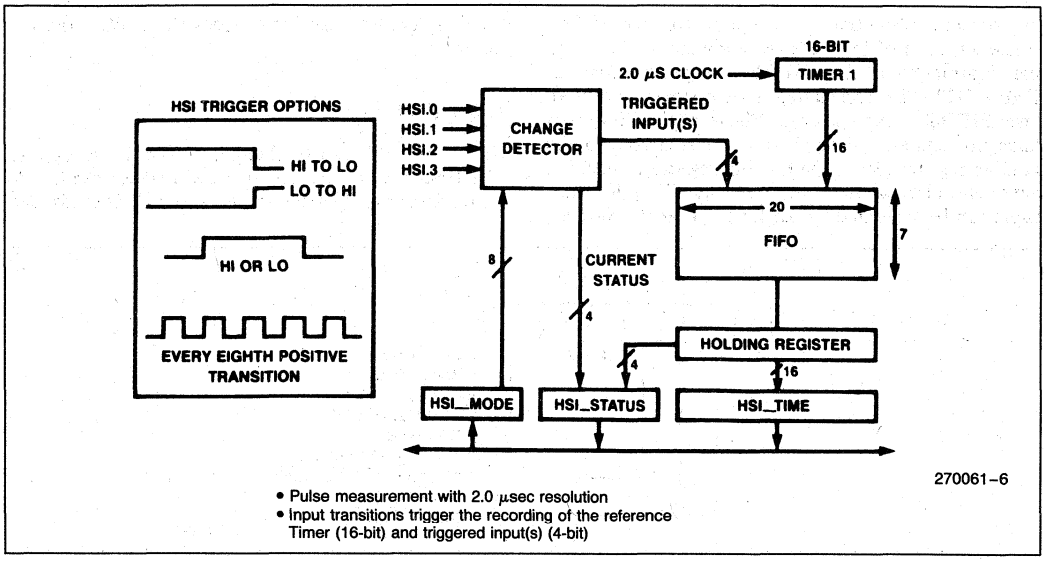
The PUSHF instruction saves the PSW including the old INT_MASK register. The PSW, including the interrupt enable bit are left cleared. If some interrupts need to be enabled while the service routine runs, the INT_MASK is loaded with a new value and interrupts are globally enabled before the service routine continues. At the end of the service routine a POPF instruction is executed to restore the old PSW. The RET instruction is executed and the code returns to the desired location. Although the POPF instruction can enable the interrupts the next instruction will always execute. This prevents unnecessary building of the stack by ensuring that the RET always executes before another interrupt vector is taken.

2.3. On-Chip I/O Section

All of the on-chip I/O features of the 8096 can be accessed through the special function registers, as shown in Figure 2-3. The advantage of using register-mapped I/O is that these registers can be used as the sources or destinations of CPU operations. There are seven major I/O functions. Each one of these will be considered with a section of code to exemplify its usage. The first section covered will be the High Speed I/O, (HSIO), subsystem. This section includes the High Speed Input (HSI) unit, High Speed Output (HSO) unit, and the Timer/Counter section.

2.3.1. TIMER/COUNTERS

The 8096 has two time bases, Timer 1 and Timer 2. Timer 1 is a 16-bit free running timer which is incremented every 8 state times. (A state time is 3 oscillator periods, or 0.25 microseconds with a 12 MHz crystal.)



- Pulse measurement with 2.0 μsec resolution
- Input transitions trigger the recording of the reference Timer (16-bit) and triggered input(s) (4-bit)

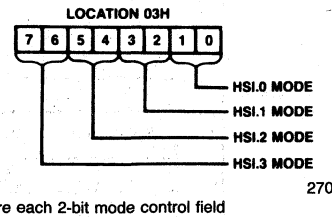
Figure 2-11. HSI Unit Block Diagram

Its value can be read at any time and used as a reference for both the HSI section and the HSO section. Timer 1 can cause an interrupt when it overflows, and cannot be modified or stopped without resetting the entire chip. Timer 2 is really an event counter since it uses an external clock source. Like Timer 1, it is 16-bits wide, can be read at any time, can be used with the HSO section, and can generate an interrupt when it overflows. Control of Timer 2 is limited to incrementing it and resetting it. Specific values can not be written to it.

Although the 8096 has only two timers, the timer flexibility is equal to a unit with many timers thanks to the HSIO unit. The HSI enables one to measure times of external events on up to four lines using Timer 1 as a timer base. The HSO unit can schedule and execute internal events and up to six external events based on the values in either Timer 1 or Timer 2. The 8096 also includes separate, dedicated timers for the baud rate generator and watchdog timer.

2.3.2. HSI

The HSI unit can be thought of as a message taker which records the line which had an event and the time at which the event occurred. Four types of events can trigger the HSI unit, as shown in the HSI block diagram in Figure 2-11. The HSI unit can measure pulse widths and record times of events with a 2



Where each 2-bit mode control field defines one of 4 possible modes:

00	8 positive transitions
01	Each positive transition
10	Each negative transition
11	Every transition (positive and negative)

Figure 2-12. HSI Mode Register

microsecond resolution. It can look for one of four events on each of four lines simultaneously, based on the information in the HSI Mode register, shown in Figure 2-12. The information is then stored in a seven level FIFO for later retrieval. Whenever the FIFO contains information, the earliest entry is placed in the holding register. When the holding register is read, the next valid piece of information is loaded into it. Interrupts can be generated by the HSI unit at the time the holding register is loaded or when the FIFO has six or more entries.

2.3.3. HSO

Just as the HSI can be thought of as a message taker, the HSO can be thought of as a message sender. At times determined by the software, the HSO sends mes-

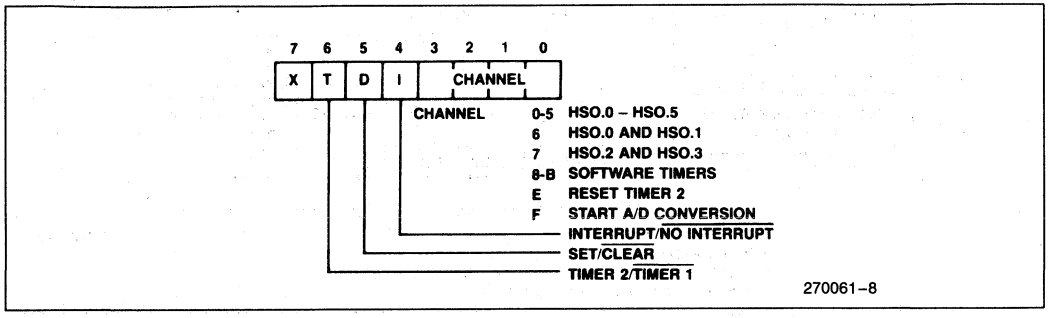


Figure 2-13. HSO Command Register

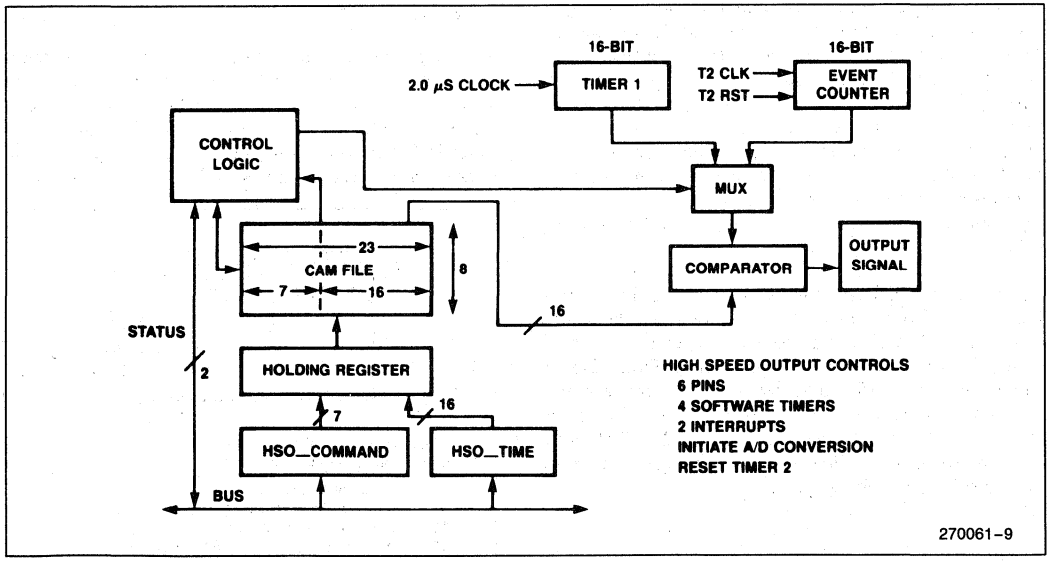


Figure 2-14. HSO Block Diagram

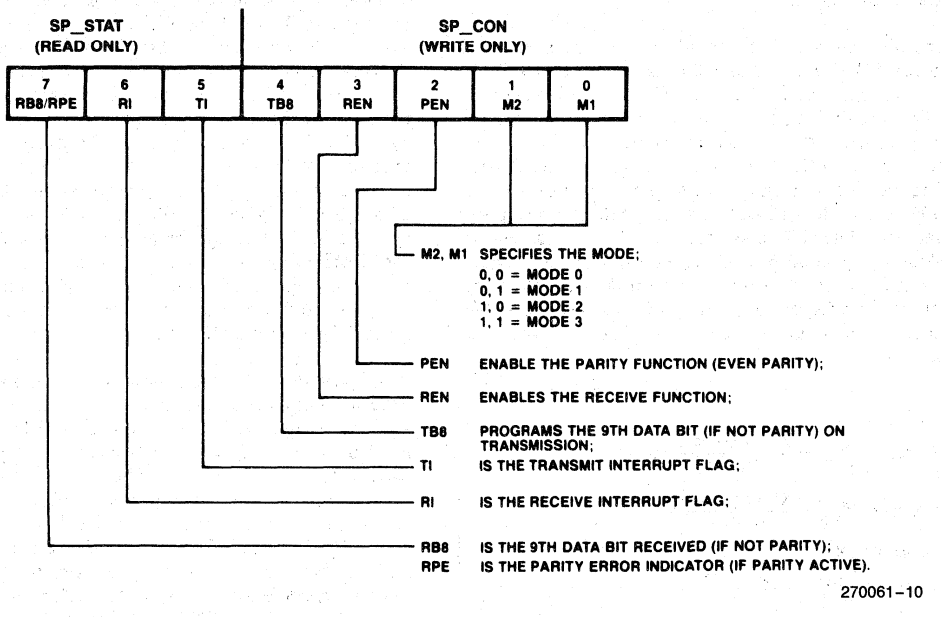
sages to various devices to have them turn on, turn off, start processing, or reset. Since the programmed times can be referenced to either Timer 1 or Timer 2, the HSO makes the two timers look like many. For example, if several events have to occur at specific times, the HSO unit can schedule all of the events based on a single timer. The events that can be scheduled to occur and the format of the command written to the HSO Command register are shown in Figure 2-13.

The software timers listed in the figure are actually 4 software flags in I/O Status Register 1 (IOS1). These flags can be set, and optionally cause an interrupt, at any time based on Timer 1 or Timer 2. In most cases these timers are used to trigger interrupt routines which must occur at regular intervals. A multitask process can easily be set up using the software timers.

A CAM (Content Addressable Memory) file is the main component of the HSO. This file stores up to eight events which are pending to occur. Every state time one location of the CAM is compared with the two timers. After 8 state times, (two microseconds with a 12 MHz clock), the entire CAM has been searched for time matches. If a match occurs the specified event will be triggered and that location of the CAM will be made available for another pending event. A block diagram of the HSO unit is shown in Figure 2-14.

2.3.4. Serial Port

Controlling a device from a remote location is a simple task that frequently requires additional hardware with many processors. The 8096 has an on-chip serial port to reduce the total number of chips required in the system.



NOTE:
TI and RI are cleared when SP_CON is read.

Figure 2-15. Serial Port Control/Status Register

The serial port is similar to that on the MCS-51 product line. It has one synchronous and three asynchronous modes. In the asynchronous modes baud rates of up to 187.5 Kbaud can be used, while in the synchronous mode rates up to 1.5 Mbaud are available. The chip has a baud rate generator which is independent of Timer 1 and Timer 2, so using the serial port does not take away any of the HSI, HSO or timer flexibility or functionality.

Control of the serial port is provided through the SPCON/SPSTAT (Serial Port CONtrol/Serial Port STATus) register. This register, shown in Figure 2-15, has some bits which are read only and others which are write only. Although the functionality of the port is similar to that of the 8051, the names of some of the modes and control bits are different. The way in which the port is used from a software standpoint is also slightly different since RI and TI are cleared after each read of the register.

The four modes of the serial port are referred to as modes 0, 1, 2 and 3. Mode 0 is the synchronous mode, and is commonly used to interface to shift registers for I/O expansion. In this mode the port outputs a pulse train on the TXD pin and either transmits or receives data on the RXD pin. Mode 1 is the standard asynchronous mode, 8 bits plus a stop and start bit are sent or received. Modes 2 and 3 handle 9 bits plus a stop and start bit. The difference between the two is, that in Mode 2 the serial port interrupt will not be activated unless the ninth data bit is a one; in Mode 3 the interrupt is activated whenever a byte is received. These two modes are commonly used for interprocessor communication.

Using XTAL1:

$$\text{Mode 0: } \frac{\text{Baud}}{\text{Rate}} = \frac{\text{XTAL1 frequency}}{4*(B+1)};\ B \neq 0$$

$$\text{Others: } \frac{\text{Baud}}{\text{Rate}} = \frac{\text{XTAL1 frequency}}{64*(B+1)}$$

Using T2CLK:

$$\text{Mode 0: } \frac{\text{Baud}}{\text{Rate}} = \frac{\text{T2CLK frequency}}{B};\ B \neq 0$$

$$\text{Others: } \frac{\text{Baud}}{\text{Rate}} = \frac{\text{T2CLK frequency}}{16*B};\ B \neq 0$$

Note that B cannot equal 0, except when using XTAL1 in other than mode 0.

Figure 2-16. Baud Rate Formulas

Baud rates for all of the modes are controlled through the Baud Rate register. This is a byte wide register which is loaded sequentially with two bytes, and internally stores the value as a word. The least significant byte is loaded to the register followed by the most significant. The most significant bit of the baud value determines the clock source for the baud rate generator. If the bit is a one, the XTAL1 pin is used as the source, if it is a zero, the T2 CLK pin is used. The formulas shown in Figure 2-16 can be used to calculate the baud rates. The variable "B" is used to represent the least significant 15 bits of the value loaded into the baud rate register.

The baud rate register values for common baud rates are shown in Figure 2-17. These values can be used when XTAL1 is selected as the clock source for serial modes other than Mode 0. The percentage deviation from theoretical is listed to help assess the reliability of a given setup. In most cases a serial link will work if there is less than a 2.5% difference between the baud rates of the two systems. This is based on the assumption that 10 bits are transmitted per frame and the last bit of the frame must be valid for at least six-eights of the bit time. If the two systems deviate from theoretical by 1.25% in opposite directions the maximum tolerance of 2.5% will be reached. Therefore, caution must be used when the baud rate deviation approaches 1.25% from theoretical. Note that an XTAL1 frequency of 11.0592 MHz can be used with the table values for 11 MHz to provide baud rates that have 0.0 percent deviation from theoretical. In most applications, however, the accuracy available when using an 11 MHz input frequency is sufficient.

Serial port Mode 1 is the easiest mode to use as there is little to worry about except initialization and loading and unloading SBUF, the Serial port BUFfer. If parity is enabled, (i.e., PEN = 1), 7 bits plus even parity are used instead of 8 data bits. The parity calculation is done in hardware for even parity. Modes 2 and 3 are similar to Mode 1, except that the ninth bit needs to be controlled and read. It is also not possible to enable parity in Mode 2. When parity is enabled in Mode 3 the ninth bit becomes the parity bit. If parity is not enabled, (i.e., PEN = 0), the TB8 bit controls the state of the ninth transmitted bit. This bit must be set prior to each transmission. On reception, if PEN = 0, the RB8 bit indicates the state of the ninth received bit. If parity is enabled, (i.e., PEN = 1), the same bit is called RPE (Receive Parity Error), and is used to indicate a parity error.

XTAL1 Frequency = 12.0 MHz		
Baud Rate	**Baud Register Value**	**Percent Error**
19.2K	8009H	+2.40
9600	8013H	+2.40
4800	8026H	−0.16
2400	804DH	−0.16
1200	809BH	−0.16
300	8270H	0.00
XTAL1 Frequency = 11.0 MHz		
19.2K	8008H	+0.54
9600	8011H	+0.54
4800	8023H	+0.54
2400	8047H	+0.54
1200	808EH	−0.16
300	823CH	+0.01
XTAL1 Frequency = 10.0 MHz		
19.2K	8007H	−1.70
9600	800FH	−1.70
4800	8020H	+1.38
2400	8040H	−0.16
1200	8081H	−0.16
300	8208H	+0.03

Figure 2-17. Baud Rate Values for 10, 11, 12 MHz

The software used to communicate between processors is simplified by making use of Modes 2 and 3. In a basic protocol the ninth bit is called the address bit. If it is set high then the information in that byte is either the address of one of the processors on the link, or a command for all the processors. If the bit is a zero, the byte contains information for the processor or processors previously addressed. In standby mode all processors wait in Mode 2 for a byte with the address bit set. When they receive that byte, the software determines if the next message is for them. The processor that is to receive the message switches to Mode 3 and receives the information. Since this information is sent with the ninth bit set to zero, none of the processors set to Mode 2 will be interrupted. By using this scheme the overall CPU time required for the serial port is minimized.

A typical connection diagram for the multi-processor mode is shown in Figure 2-18. This type of communicaton can be used to connect peripherals to a desk top computer, the axis of a multi-axis machine, or any other group of microcontrollers jointly performing a task.

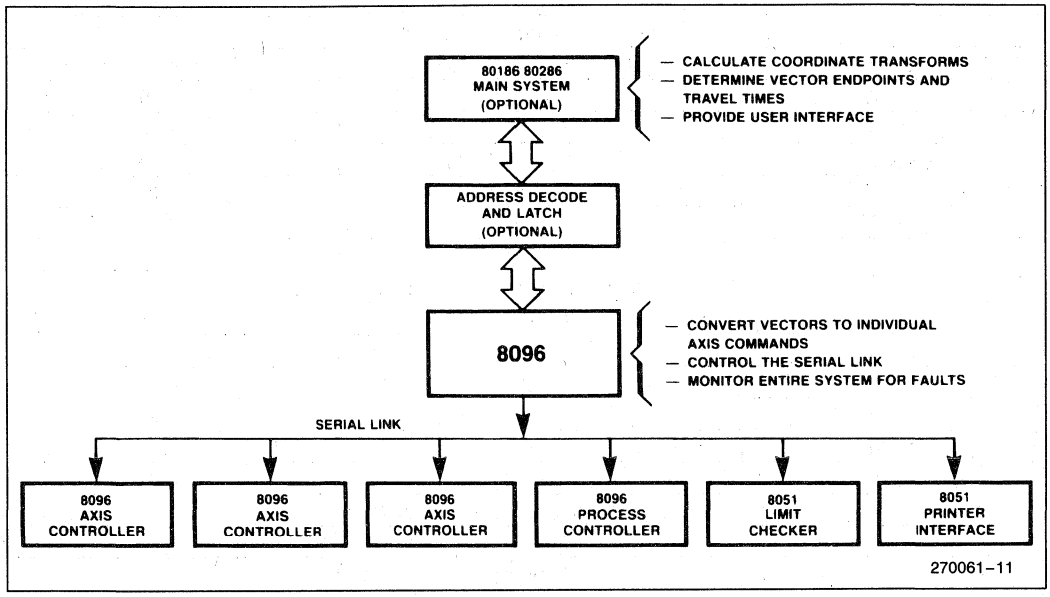


Figure 2-18. Multiprocessor Communication

Mode 0, the synchronous mode, is typically used for interfacing to shift registers for I/O expansion. The software to control this mode involves the REN (Receiver ENable) bit, the clearing of the RI bit, and writing to SBUF. To transmit to a shift register, REN is set to zero and SBUF is loaded with the information. The information will be sent and then the TI flag will be set. There are two ways to cause a reception to begin. The first is by causing a rising edge to occur on the REN bit, the second is by clearing RI with REN = 1. In either case, RI is set again when the received byte is available in SBUF.

2.3.5. A to D CONVERTER

Analog inputs are frequently required in a microcontroller application. The 8097 has a 10-bit A to D converter that can use any one of eight input channels. The conversions are done using the successive approximation method, and require 168 state times (42 microseconds with a 12 MHz clock.)

The results are guaranteed monotonic by design of the converter. This means that if the analog input voltage changes, even slightly, the digital value will either stay the same or change in the same direction as the analog input. When doing process control algorithms, it is frequently the changes in inputs that are required, not the absolute accuracy of the value. For this reason, even if the absolute accuracy of a 10-bit converter is the same as that of an 8-bit converter, the 10-bit monotonic converter is much more useful.

Since most of the analog inputs which are monitored by a microcontroller change very slowly relative to the 42 microsecond conversion time, it is acceptable to use a capacitive filter on each input instead of a sample and hold. The 8097 does not have an internal sample and hold, so it is necessary to ensure that the input signal does not change during the conversion time. The input to the A/D must be between ANGND and VREF. ANGND must be within a few millivolts of VSS and VREF must be within a few tenths of a volt of VCC.

Using the A to D converter on the 8097 can be a very low software overhead task because of the interrupt and HSO unit structure. The A to D can be started by the HSO unit at a preset time. When the conversion is complete it is possible to generate an interrupt. By using these features the A to D can be run under complete interrupt control. The A to D can also be directly

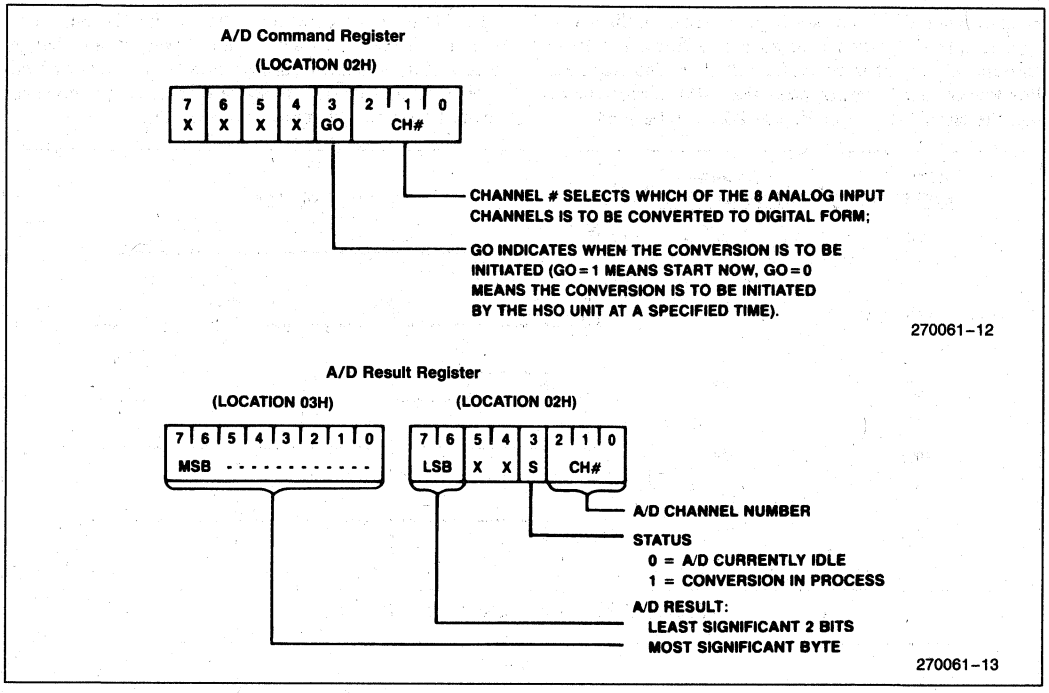


Figure 2-19. A to D Result/Command Register

controlled by software flags which are located in the AD_RESULT/AD_COMMAND Register, shown in Figure 2-19.

2.3.6. PWM REGISTER

Analog outputs are just as important as analog inputs when connecting to a piece of equipment. True digital to analog converters are difficult to make on a microprocessor because of all of the digital noise and the necessity of providing an on chip, relatively high current, rail to rail driver. They also take up a fair amount of silicon area which can be better used for other features. The A to D converter does use a D to A, but the currents involved are very small.

For many applications an analog output signal can be replaced by a Pulse Width Modulated (PWM) signal. This signal can be easily generated in hardware, and takes up much less silicon area than a true D to A. The signal is a variable duty cycle, fixed frequency waveform that can be integrated to provide an approximation to an analog output. The frequency is fixed at a period of 64 microseconds for a 12 MHz clock speed. Controlling the PWM simply requires writing the desired duty cycle value (an 8-bit value) to the PWM Register. Some typical output waveforms that can be generated are shown in Figure 2-20.

Converting the PWM signal to an analog signal varies in difficulty, depending upon the requirements of the system. Some systems, such as motors or switching power supplies actually require a PWM signal, not a true analog one. For many other cases it is necessary only to amplify the signal so that it switches rail-to-rail, and then filter it. Switching rail-to-rail means that the output of the amplifier will be a reference value when the input is a logical one, and the output will

be zero when the input is a logical zero. The filter can be a simple RC network or an active filter. If a large amount of current is needed a buffer is also required. For low output currents, (less than 100 microamps or so), the circuit shown in Figure 2-21 can be used.

The RC network determines how quiet the output is, but the quieter the output, the slower it can change. The design of high accuracy voltage followers and active filters is beyond the scope of this paper, however many books on the subject are available.

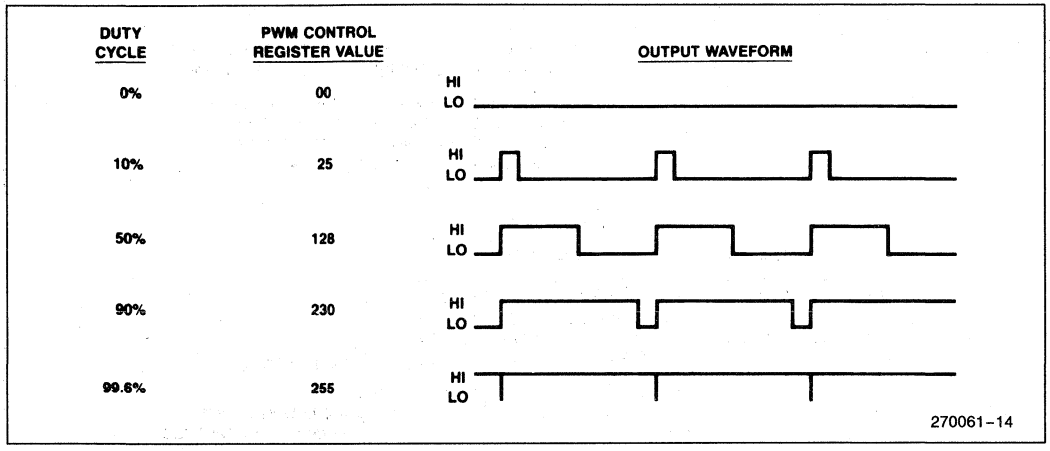


Figure 2-20. PWM Output Waveforms

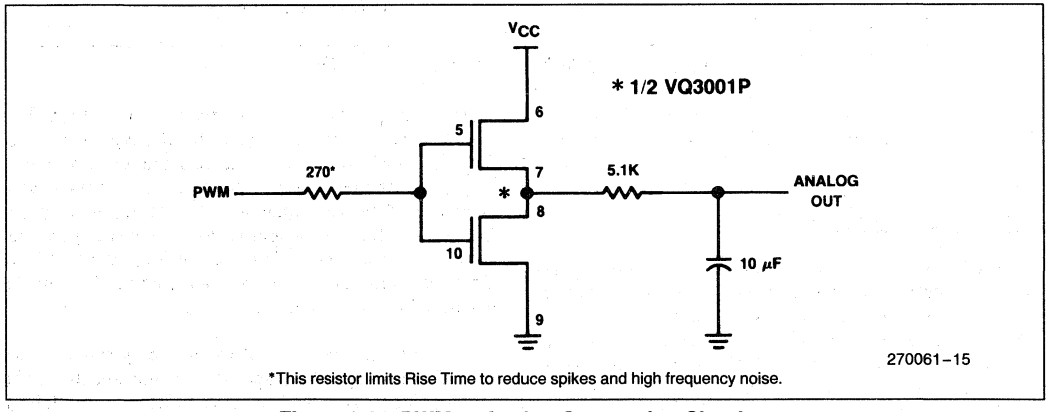


Figure 2-21. PWM to Analog Conversion Circuitry

3.0 BASIC SOFTWARE EXAMPLES

The examples in this section show how to use each I/O feature individually. Examples of using more than one feature at a time are described in section 4. All of the examples in this ap-note are set up to be used as listed. If run through ASM96 they will load and run on an SBE-96. In order to insure that the programs work, the stack pointer is initialized at the beginning of each program. If the programs are going to be used as modules of other programs, the stack pointer initialization should only be used at the beginning of the main program.

To avoid repetitive declarations the "include" file "DEMO96.INC", shown in Listing 3-1, is used. ASM-96 will insert this file into the code file whenever the directive "INCLUDE DEMO96.INC" is used. The file contains the definitions for the SFRs and other variables. The include statement has been placed in all of the examples. It should be noted that some of the labels in this file are different from those in the file 8096.INC that is provided in the ASM-96 package.

3.1. Using the 8096's Processing Section

3.1.1. TABLE INTERPOLATION

A good way of increasing speed for many processing tasks is to use table lookup with interpolation. This can eliminate lengthy calculations in many algorithms. Frequently it is used in programs that generate sine waveforms, use exponents in calculations, or require some non-linear function of a given input variable. Table lookup can also be used without interpolation to determine the output state of I/O devices for a given state of a set of input devices. The procedure is also a good example of 8096 code as it uses many of the software features. Two ways of making a lookup table are described, one way uses more calculation time, the second way uses more table space.

```
;*******************************************************************************
;
; DEMO96.INC - DEFINITION OF SYMBOLIC NAMES FOR THE I/O REGISTERS OF THE 8096
;
;*******************************************************************************
;
ZERO            EQU   00h:WORD      ; R/W
AD_COMMAND      EQU   02H:BYTE      ;   W
AD_RESULT_LO    EQU   02H:BYTE      ; R
AD_RESULT_HI    EQU   03H:BYTE      ; R
HSI_MODE        EQU   03H:BYTE      ;   W
HSO_TIME        EQU   04H:WORD      ;   W
HSI_TIME        EQU   04H:WORD      ; R
HSO_COMMAND     EQU   06H:BYTE      ;   W
HSI_STATUS      EQU   06H:BYTE      ; R
SBUF            EQU   07H:BYTE      ; R/W
INT_MASK        EQU   08H:BYTE      ; R/W
INT_PENDING     EQU   09H:BYTE      ; R/W
SPCON           EQU   11H:BYTE
SPSTAT          EQU   11H:BYTE
WATCHDOG        EQU   0AH:BYTE      ;   W  WATCHDOG TIMER
TIMER1          EQU   0AH:WORD      ; R
TIMER2          EQU   0CH:WORD      ; R
PORT0           EQU   0EH:BYTE      ; R
BAUD_REG        EQU   0EH:BYTE      ;   W
PORT1           EQU   0FH:BYTE      ; R/W
PORT2           EQU   10H:BYTE      ; R/W
IOC0            EQU   15H:BYTE      ;   W
IOS0            EQU   15H:BYTE      ; R
IOC1            EQU   16H:BYTE      ;   W
IOS1            EQU   16H:BYTE      ; R
PWM_CONTROL     EQU   17H:BYTE      ;   W
SP              EQU   18H:WORD      ; R/W STACK POINTER


RSEG at 1CH

        AX:     DSW     1
        DX:     DSW     1
        BX:     DSW     1
        CX:     DSW     1

        AL      EQU     AX      :BYTE
        AH      EQU     (AX+1)  :BYTE
```

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Listing 3-1. Include File DEMO.96.INC

In both methods the procedure is similar. Values of a function are stored in memory for specific input values. To compute the output function for an input that is not listed, a linear approximation is made based on the nearest inputs and nearest outputs. As an example, consider the table below.

If the input value was one of those listed then there would be no problem. Unfortunately the real world is never so kind. The input number will probably be 259 or something similar. If this is the case linear interpolation would provide a reasonable result. The formula is:

$$\text{Delta Out} = \frac{\text{UpperOutput-Lower Output}}{\text{Upper Input-Lower Input}} * (\text{Actual Input-Lower Input})$$

Actual Output = Lower Output + Delta Out

For the value of 259 the solution is:

$$\text{Delta Out} = \frac{900\text{-}400}{300\text{-}200} * (259\text{-}200) = \frac{500}{100} * 59 = 5 * 59 = 295$$

Actual Output = 400 + 295 = 695

To make the algorithm easier, (and therefore faster), it is appropriate to limit the range and accuracy of the function to only what is needed. It is also advantageous to make the input step (Upper Input-Lower Input) equal to a power of 2. This allows the substitution of multiple right shifts for a divide operation, thus speeding up throughput. The 8096 allows multiple arithmetic right shifts with a single instruction providing a very fast divide if the divisor is a power of two.

For the purpose of an example, a program with a 12-bit output and an 8-bit input has been written. An input step of 16 (2**4) was selected. To cover the input range 17 words are needed, 255/16 + 1 word to handle values in the last 15 bytes of input range. Although only 12 bits are required for the output, the 16-bit architecture offers no penalty for using 16 instead of 12 bits.

The program for this example, shown in Listing 3-2, uses the definitions and equates from Listing 3-1, only the additional equates and definitions are shown in the code.

Input Value	Relative Table Address	Table Value
100	0001H	100
200	0002H	400
300	0003H	900
400	0004H	1600

```
$TITLE('INTER1.APT: Interpolation routine 1')
;;;;;;;   8096 Assembly code for table lookup and interpolation

$INCLUDE(:F1:DEMO96.INC)        ; Include demo definitions


RSEG   at 22H

        IN_VAL:         dsb     1               ; Actual Input Value
        TABLE_LOW:      dsw     1
        TABLE_HIGH:     dsw     1
        IN_DIF:         dsw     1               ; Upper Input - Lower Input
        IN_DIFB         equ     IN_DIF  ;byte
        TAB_DIF:        dsw     1               ; Upper Output - Lower Output
        OUT:            dsw     1
        RESULT:         dsw     1
        OUT_DIF:        dsl     1               ; Delta Out


CSEG at 2080H

        LD      SP, #100H
```

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Listing 3-2. ASM-96 Code for Table Lookup Routine 1

```
look:   LDB     AL, IN_VAL      ; Load temp with Actual Value
        SHRB    AL, #3          ; Divide the byte by 8
        ANDB    AL, #11111110B  ; Insure AL is a word address
                                ;  This effectively divides AL by 2
                                ;  so AL = IN_VAL/16

        LDBZE   AX, AL          ; Load byte AL to word AX
        LD      TABLE_LOW, TABLE [AX]     ; TABLE_LOW is loaded with the value
                                          ;  in the table at table location AX

        LD      TABLE_HIGH, (TABLE+2)[AX]  ; TABLE_HIGH is loaded with the
                                           ; value in the table at table
                                           ; location AX+2
                                           ; (The next value in the table)

        SUB     TAB_DIF, TABLE_HIGH, TABLE_LOW
                                           ; TAB_DIF=TABLE_HIGH-TABLE_LOW

        ANDB    IN_DIFB, IN_VAL, #0FH      ; IN_DIFB=least significant 4 bits
                                           ;  of IN_VAL
        LDBZE   IN_DIF, IN_DIFB            ; Load byte IN_DIFB to word IN_DIF

        MUL     OUT_DIF, IN_DIF, TAB_DIF
                                           ; Output_difference =
                                           ;  Input_difference*Table_difference
        SHRAL   OUT_DIF, #4                ; Divide by 16 (2**4)

        ADD     OUT, OUT_DIF, TABLE_LOW ; Add output difference to output
                                        ;  generated with truncated IN_VAL
                                        ;  as input
        SHRA    OUT, #4                 ; Round to 12-bit answer

        ADDC    OUT, zero               ; Round up if Carry = 1

no_inc: ST      OUT, RESULT             ; Store OUT to RESULT

        BR      look                    ; Branch to "look:"


cseg    AT 2100H

table:  DCW     0000H, 2000H, 3400H, 4C00H  ; A random function
        DCW     5D00H, 6A00H, 7200H, 7800H
        DCW     7B00H, 7D00H, 7600H, 6D00H
        DCW     5D00H, 4B00H, 3400H, 2200H
        DCW     1000H

END
```

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Listing 3-2. ASM-96 Code for Table Lookup Routine 1 (Continued)

6

If the function is known at the time of writing the software it is also possible to calculate in advance the change in the output function for a given change in the input. This method can save a divide and a few other instructions at the expense of doubling the size of the lookup table. There are many applications where time is critical and code space is overly abundant. In these cases the code in Listing 3-3 will work to the same specifications as the previous example.

```
$TITLE('INTER2.APT: Interpolation routine 2')

;;;;;;;   8096 Assembly code for table lookup and interpolation
;;;;;;;   Using tabled values in place of division

$INCLUDE(:F1:DEMO96.INC) ; Include demo definitions


RSEG  at 24H

        IN_VAL:         dsb     1           ; Actual Input Value
        TABLE_LOW:      dsw     1           ; Table value for function
        TABLE_INC:      dsw     1           ; Incremental change in function
        IN_DIF:         dsw     1           ; Upper Input - Lower Input
        IN_DIFB         equ     IN_DIF  :byte
        OUT:            dsw     1
        RESULT:         dsw     1
        OUT_DIF:        dsl     1           ; Delta Out
```

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Listing 3-3. ASM-96 Code For Table Lookup Routine 2

```
CSEG at 2080H

        LD      SP, #100H       ; Initialize SP to top of reg. file

look:   LDB     AL, IN_VAL      ; Load temp with Actual Value
        SHRB    AL, #3          ; Divide the byte by 8
        ANDB    AL, #11111110B  ; Insure AL is a word address
                                ;  This effectively divides AL by 2
                                ;  so AL = IN_VAL/16
        LDBZE   AX, AL          ; Load byte AL to word AX

        LD      TABLE_LOW, VAL_TABLE[AX] ; TABLE_LOW is loaded with the value
                                         ;  in the value table at location AX

        LD      TABLE_INC, INC_TABLE[AX] ; TABLE_INC is loaded with the value
                                         ; in the increment table at
                                         ; location AX

        ANDB    IN_DIFB, IN_VAL, #0FH    ; IN_DIFB=least significant 4 bits
                                         ;  of IN_VAL
        LDBZE   IN_DIF, IN_DIFB          ; Load byte IN_DIFB to word IN_DIF

        MUL     OUT_DIF, IN_DIF, TABLE_INC
                                         ; Output_difference =
                                         ;  Input_difference*Incremental_change

        ADD     OUT, OUT_DIF, TABLE_LOW ; Add output difference to output
                                         ;  generated with truncated IN_VAL
                                         ;  as input
        SHR     OUT, #4                  ; Round to 12-bit answer
        ADDC    OUT, zero                ; Round up if Carry = 1

no_inc: ST      OUT, RESULT              ; Store OUT to RESULT
        BR      look                     ; Branch to "look:"

cseg    AT 2100H

val_table:
        DCW     0000H, 2000H, 3400H, 4C00H   ; A random function
        DCW     5D00H, 6A00H, 7200H, 7800H
        DCW     7B00H, 7D00H, 7600H, 6D00H
        DCW     5D00H, 4B00H, 3400H, 2200H
        DCW     1000H
inc_table:
        DCW      0200H,  0140H,  0180H,  0110H    ; Table of incremental
        DCW      00D0H,  0080H,  0060H,  0030H    ; differences
        DCW     00020H, 0FF90H, 0FF70H, 0FF00H
        DCW     0FEE0H, 0FE90H, 0FEE0H, 0FEE0H

END
```

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Listing 3-3. ASM-96 Code for Table Lookup Routine 2 (Continued)

By making use of the second lookup table, one word of RAM was saved and 16 state times. In most cases this time savings would not make much of a difference, but when pushing the processor to the limit, microseconds can make or break a design.

3.1.2. PL/M-96

Intel provides high level language support for most of its micro processors and microcontrollers in the form of PL/M. Specifically, PL/M refers to a family of languages, each similar in syntax, but specialized for the device for which it generates code. The PL/M syntax is similar to PL/1, and is easy to learn. PLM-96 is the version of PL/M used for the 8096. It is very code efficient as it was written specifically for the MCS-96 family. PLM-96 most closely resembles PLM-86, although it has bit and I/O functions similar to PLM-51. One line of PL/M-code can take the place of many lines of assembly code. This is advantageous to the programmer, since code can usually be written at a set number of lines per hour, so the less lines of code that need to be written, the faster the task can be completed.

If the first example of interpolation is considered, the PLM-96 code would be written as shown in Listing 3-4. Note that version 1.0 of PLM-96 does not support 32-bit results of 16 by 16 multiplies, so the ASM-96 procedure "DMPY" is used. Procedure DMPY, shown in Listing 3-5, must be assembled and linked with the compiled PLM-96 program using RL-96, the relocator and linker. The command line to be used is:

RL96 PLMEX1.OBJ, DMPY.OBJ, PLM96.LIB &
to PLMOUT.OBJ ROM (2080H-3FFFH)

```
/* PLM-96 CODE FOR TABLE LOOK-UP AND INTERPOLATION */

PLMEX:    DO;

DECLARE IN_VAL          WORD        PUBLIC;
DECLARE TABLE_LOW       INTEGER     PUBLIC;
DECLARE TABLE_HIGH      INTEGER     PUBLIC;
DECLARE TABLE_DIF       INTEGER     PUBLIC;
DECLARE OUT             INTEGER     PUBLIC;
DECLARE RESULT          INTEGER     PUBLIC;
DECLARE OUT_DIF         LONGINT     PUBLIC;
DECLARE TEMP            WORD        PUBLIC;

DECLARE TABLE(17)       INTEGER  DATA (
        0000H, 2000H, 3400H, 4C00H,       /* A random function */
        5D00H, 6A00H, 7200H, 7800H,
        7B00H, 7D00H, 7600H, 6D00H,
        5D00H, 4B00H, 3400H, 2200H,
        1000H);

DMPY:   PROCEDURE (A,B) LONGINT EXTERNAL;
        DECLARE (A,B) INTEGER;
END DMPY;

LOOP:
    TEMP=SHR(IN_VAL,4);      /* TEMP is the most significant 4 bits of IN_VAL */

    TABLE_LOW=TABLE(TEMP);       /* If "TEMP" was replaced by "SHR(IN_VAL,4)"  */
    TABLE_HIGH=TABLE(TEMP+1);    /* The code would work but the 8096 would     */
                                 /* do two shifts                              */

    TABLE_DIF=TABLE_HIGH-TABLE_LOW;

    OUT_DIF=DMPY(TABLE_DIF,SIGNED(IN_VAL AND 0FH)) /16;

    OUT=SAR((TABLE_LOW+OUT_DIF),4); /* SAR performs an arithmetic right shift,
                                       in this case 4 places are shifted      */

    IF CARRY=0 THEN RESULT=OUT;  /* Using the hardware flags must be done    */
      ELSE  RESULT=OUT+1;        /* with care to ensure the flag is tested   */
                                 /* in the desired instruction sequence      */
GOTO LOOP;

/* END OF PLM-96 CODE  */

END;
```

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Listing 3-4. PLM-96 Code For Table Lookup Routine 1

```
$TITLE('MULT.APT: 16*16 multiply procedure for PLM-96')


        SP      EQU     18H:word

rseg
        EXTRN   PLMREG  ;long

cseg

        PUBLIC  DMPY            ; Multiply two integers and return a
                                ; longint result in AX, DX registers

DMPY:   POP     PLMREG+4                ; Load return address
        POP     PLMREG                  ; Load one operand
        MUL     PLMREG,[SP]+    ; Load second operand and increment SP

        BR      [PLMREG+4]              ; Return to PLM code.
END
```

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Listing 3-5. 32-Bit Result Multiply Procedure For PLM-96

6

Using PLM, code requires less lines, is much faster to write, and easier to maintain, but may take slightly longer to run. For this example, the assembly code generated by the PLM-96 compiler takes 56.75 microseconds to run instead of 30.75 microseconds. If PLM-96 performed the 32-bit result multiply instead of using the ASM-96 routine the PLM code would take 41.5 microseconds to run. The actual code listings are shown in Appendix A.

3.2. Using the I/O Section

3.2.1. USING THE HSI UNIT

One of the most frequent uses of the HSI is to measure the time between events. This can be used for frequency determination in lab instruments, or speed/acceleration information when connected to pulse type encoders. The code in Listing 3-6 can be used to determine the high and low times of the signals on two lines. This code can be easily expanded to 4 lines and can also be modified to work as an interrupt routine.

Frequently it is also desired to keep track of the number of events which have occurred, as well as how often they are occurring. By using a software counter this feature can be added to the above code. This code depends on the software responding to the change in line state before the line changes again. If this cannot be guaranteed then it may be necessary to use 2 HSI lines for each incoming line. In this case one HSI line would look for falling edges while the other looks for rising edges. The code in Listing 3-7 includes both the counter feature and the edge detect feature.

The uses for this type of routine are almost endless. In instrumentation it can be used to determine frequency on input lines, or perhaps baud rate for a self adjusting serial port. Section 4.2 contains an example of making a software serial port using the HSI unit. Interfacing to some form of mechanically generated position information is a very frequent use of the HSI. The applications in this category include motor control, precise positioning (print heads, disk drives, etc.), engine control and

```
$TITLE('PULSE.APT: Measuring pulses using the HSI unit')

$INCLUDE(DEMO96.INC)

rseg    at  28H

        HIGH_TIME:      dsw     1
        LOW_TIME:       dsw     1
        PERIOD:         dsw     1
        HI_EDGE:        dsw     1
        LO_EDGE:        dsw     1


cseg    at  2080H


        LD      SP, #100H
        LDB     IOC0, #00000001B        ; Enable HSI 0
        LDB     HSI_MODE, #00001111B    ; HSI 0 look for either edge

wait:   ADD     PERIOD, HIGH_TIME, LOW_TIME
        JBS     IOS1, 6, contin         ; If FIFO is full
        JBC     IOS1, 7, wait   ; Wait while no pulse is entered

contin: LDB     AL, HSI_STATUS          ; Load status; Note that reading
                                        ;   HSI_TIME clears HSI_STATUS

        LD      BX, HSI_TIME            ; Load the HSI_TIME

        JBS     AL, 1, hsi_hi           ; Jump if HSI.0 is high

hsi_lo: ST      BX, LO_EDGE
        SUB     HIGH_TIME, LO_EDGE, HI_EDGE
        BR      wait


hsi_hi: ST      BX, HI_EDGE
        SUB     LOW_TIME, HI_EDGE, LO_EDGE
        BR      wait

        END
```

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Listing 3-6. Measuring Pulses Using The HSI Unit

transmission control. The HSI unit is used extensively in the example in section 4.3.

3.2.2. USING THE HSO UNIT

Although the HSO has many uses, the best example is that of a multiple PWM output. This program, shown in Listing 3-8, is simple enough to be easily understood, yet it shows how to use the HSO for a task which can be complex. In order for this program to operate, another program needs to set up the on and off time variables for each line. The program also requires that a HSO line not change so quickly that it changes twice between consecutive reads of I/O Status Register 0, (IOS0).

A very eye catching example can be made by having the program output waveforms that vary over time. The driver routine in Listing 3-10 can be linked to the above program to provide this function. Linking is accomplished using RL96, the relocatable linker for the 8096. Information for using RL96 can be found in the "MCS-96 Utilities Users Guide", listed in the bibliography. In order for the program to link, the register dec-

```
$TITLE ('ENHSI.APT: ENHANCED HSI PULSE ROUTINE')

$INCLUDE(DEMO96.INC)

RSEG AT 28H

        TIME:           DSW 1
        LAST_RISE:      DSW 1
        LAST_FALL:      DSW 1
        HSI_SO:         DSB 1
        IOS1_BAK:       DSB 1
        PERIOD:         DSW 1
        LOW_TIME:       DSW 1
        HIGH_TIME:      DSW 1
        COUNT:          DSW 1

cseg    at      2080H

init:   LD      SP,#100H

        LDB     IOC1,#00100101B ; Disable HSO.4,HSO.5, HSI_INT=first,
                                ; Enable PWM,TXD,TIMER1_OVRFLOW_INT

        LDB     HSI_MODE,#10011001B     ; set hsi.1 -; hsi.0 +
        LDB     IOC0,#00000111B         ; Enable  hsi 0,1
                                        ; T2 CLOCK=T2CLK, T2RST=T2RST
                                        ; Clear timer2


wait:   ANDB    IOS1_BAK,#01111111B     ; Clear IOS1_BAK.7
        ORB     IOS1_BAK,IOS1           ; Store into temp to avoid clearing
                                        ; other flags which may be needed
        JBC     IOS1_BAK,7,wait         ; If hsi is not triggered then
                                        ; jump to wait

        ANDB    HSI_SO,HSI_STATUS,#01010101B
        LD      TIME, HSI_TIME

        JBS     HSI_SO,0,a_rise
        JBS     HSI_SO,2,a_fall
        BR      no_cnt

a_rise: SUB     LOW_TIME, TIME, LAST_FALL
        SUB     PERIOD, TIME,LAST_RISE
        LD      LAST_RISE, TIME
        BR      increment

a_fall: SUB     HIGH_TIME, TIME, LAST_RISE
        SUB     PERIOD, TIME,LAST_FALL
        LD      LAST_FALL, TIME

increment:
        INC     COUNT

no_cnt: BR      wait

        END
```

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Listing 3-7. Enhanced HSI Pulse Measurement Routine

```
$TITLE ('HSOPWM.APT: 8096 EXAMPLE PROGRAM FOR PWM OUTPUTS')

; This program will provide 3 PWM outputs on HSO pins 0-2
; The input parameters passed to the program are:
;
;               HSO_ON_N    HSO on time for pin N
;               HSO_OFF_N   HSO off time for pin N

;       Where:  Times are in timer1 cycles
;               N takes values from 0 to 3

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

$INCLUDE(DEMO96.INC)

RSEG AT 28H

        HSO_ON_0:       DSW     1
        HSO_OFF_0:      DSW     1
        HSO_ON_1 :      DSW     1
        HSO_OFF_1 :     DSW     1
        OLD_STAT:       dsb     1
        NEW_STAT:       dsb     1


cseg    AT 2080H

        LD      SP,#100H
        LD      HSO_ON_0, #100H         ; Set initial values
        LD      HSO_OFF_0, #400H        ; Note that times must be long enough
        LD      HSO_ON_1, #280H         ; to allow the routine to run after each
        LD      HSO_OFF_1, #280H        ; line change.
        ANDB    OLD_STAT, IOS0, #0FH
        XORB    OLD_STAT, #0FH


wait:   JBS     IOS0, 6, wait                   ; Loop until HSO holding register
        NOP                                     ; is empty

                ; For opperation with interrupts 'store_stat:' would be the
                ; entry point of the routine.
                ; Note that a DI or PUSHF might have to be added.

store_stat:
        ANDB    NEW_STAT, IOS0, #0FH            ; Store new status of HSO
        CMPB    OLD_STAT, NEW_STAT
        JE      wait                            ; If status hasn't changed
        XORB    OLD_STAT, NEW_STAT


check_0:
        JBC     OLD_STAT, 0, check_1            ; Jump if OLD_STAT(0)=NEW_STAT(0)
        JBS     NEW_STAT, 0, set_off_0

set_on_0:
        LDB     HSO_COMMAND, #00110000B         ; Set HSO for timer1, set pin 0
        ADD     HSO_TIME, TIMER1, HSO_OFF_0     ; Time to set pin = Timer1 value
        BR      check_1                         ;  + Time for pin to be low

set_off_0:
        LDB     HSO_COMMAND, #00010000B         ; Set HSO for timer1, clear pin 0
        ADD     HSO_TIME, TIMER1, HSO_ON_0      ; Time to clear pin = Timer1 value
                                                ;  + Time for pin to be high
check_1:
        JBC     OLD_STAT, 1, check_done         ; Jump if OLD_STAT(1)=NEW_STAT(1)
        JBS     NEW_STAT, 1, set_off_1

set_on_1:
        LDB     HSO_COMMAND, #00110001B         ; Set HSO for timer1, set pin 1
        ADD     HSO_TIME, TIMER1, HSO_OFF_1     ; Time to set pin = Timer1 value
        BR      check_done

set_off_1:
        LDB     HSO_COMMAND, #00010001B         ; Set HSO for timer1, clear pin 1
        ADD     HSO_TIME, TIMER1, HSO_ON_1      ; Time to clear pin = Timer1 value
                                                ;  + Time for pin to be high
check_done:
        LDB     OLD_STAT, NEW_STAT              ; Store current status and
                                                ; wait for interrupt flag

        BR      wait
                ; use RET if "wait" is called from another routine

        END
```

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Listing 3-8. Generating a PWM with the HSO

laration section (i.e., the section between "RSEG" and "CSEG") in Listing 3-8 must be changed to that in Listing 3-9.

The driver routine simply changes the duty cycle of the waveform and sets the second HSO output to a frequency twice that of the first one. A slightly different driver routine could easily be the basis for a switching power supply or a variable frequency/variable voltage motor driver. The listing of the driver routine is shown in Listing 3-10.

```
;     NOTE: Use this file to replace the declaration section of
;           the HSO PWM program from "$INCLUDE(DEMO96.INC)" through
;           the line prior to the label "wait".  Also change the last
;           branch in the program to a "RET".

RSEG

        D_STAT:         DSB     1
        extrn   HSO_ON_0 :word , HSO_OFF_0 :word
        extrn   HSO_ON_1 :word , HSO_OFF_1 :word
        extrn   HSO_TIME :word , HSO_COMMAND :byte
        extrn   TIMER1   :word , IOS0       :byte
        extrn   SP       :word

        public  OLD_STAT
        OLD_STAT:       dsb     1
        NEW_STAT:       dsb     1


cseg
        PUBLIC  wait
```

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Listing 3-9. Changes to Declarations for HSO Routine

```
$TITLE('HSODRV.APT: Driver module for HSO PWM program')

HSODRV          MODULE  MAIN, STACKSIZE(8)


        PUBLIC  HSO_ON_0 , HSO_OFF_0
        PUBLIC  HSO_ON_1 , HSO_OFF_1
        PUBLIC  HSO_TIME , HSO_COMMAND
        PUBLIC  SP , TIMER1 , IOS0

$INCLUDE(DEMO96.INC)

rseg at 28H

        EXTRN   OLD_STAT        :byte

        HSO_ON_0:       dsw     1
        HSO_OFF_0:      dsw     1
        HSO_ON_1:       dsw     1
        HSO_OFF_1:      dsw     1
        count:          dsb     1

cseg  at 2080H

        EXTRN   wait    :entry

strt:   DI
        LD      SP, #100H
        ANDB    OLD_STAT, IOS0, #0FH
        XORB    OLD_STAT, #0FH

initial:
        LD      CX, #0100H

loop:   LD      AX, #1000H
        SUB     BX, AX, CX
        LD      AX, CX

        ST      AX, HSO_ON_0
        ST      BX, HSO_OFF_0
```

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Listing 3-10. Driver Module for HSO PWM Program

```
        SHR     AX,#1
        SHR     BX,#1
        ST      AX, HSO_ON_1
        ST      BX, HSO_OFF_1

        CALL    wait

        INC     CX
        CMP     CX, #00F00H
        BNE     loop

        BR      initial

        END
```

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Listing 3-10. Driver Module for HSO PWM Program (Continued)

Since the 8096 needs to keep track of events which often repeat at set intervals it is convenient to be able to have Timer 2 act as a programmable modulo counter. There are several ways of doing this. The first is to program the HSO to reset Timer 2 when Timer 2 equals a set value. A software timer set to interrupt at Timer 2 equals zero could be used to reload the CAM. This software method takes up two locations in the CAM and does not synchronize Timer 2 to the external world.

To synchronize Timer 2 externally the T2 RST (Timer 2 ReSeT) pin can be used. In this way Timer 2 will get reset on each rising edge of T2 RST. If it is desired to have an interrupt generated and time recorded when Timer 2 gets reset, the signal for its reset can be taken from HSI.0 instead of T2RST. The HSI.0 pin has its own interrupt vector which functions independently of the HSI unit.

Another option available is to use the HSI.1 pin to clock Timer 2. By using this approach it is possible to use the HSI to measure the period of events on the input to Timer 2. If both of the HSI pins are used instead of the T2RST and T2CLK pins the HSIO unit can keep track of speed and position of the rotating device with very little software overhead. This type of setup is ideal for a system like the one shown in Figure 3-1, and similar to the one used in section 4.3.

In this system a sequence of events is required based on the position of the gear which represents any piece of rotating machinery. Timer 2 holds the count of the number of tooth edges passed since the index mark. By using HSI.1 as the input to Timer 2, instead of T2 CLK, it is possible to determine tooth count and time information through the HSI. From this information instantaneous velocity and acceleration can be calculated. Having the tooth edge count in Timer 2 means

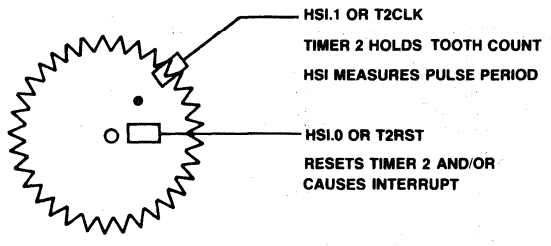

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Figure 3-1. Using the HSIO to Monitor Rotating Machinery

that the HSO unit can be used to initiate the desired tasks at the appropriate tooth count. The interrupt routine initiated by HSI.0 can be used to perform any software task required every revolution. In this system, the overhead which would normally require extensive software has been done with the hardware on the 8096, thus making more software time available for control programs.

3.2.3. USING THE SERIAL PORT IN MODE 1

Mode 1 of the serial port supports the basic asynchronous 8-bit protocol and is used to interface to most CRTs and printers. The example in Listing 3-11 shows a simple routine which receives a character and then transmits the same character. The code is set up so that minor modifications could make it run on an interrupt basis. Note that it is necessary to set up some flags as initial conditions to get the routine to run properly. If it was desired to send 7 bits of data plus parity instead of 8 bits of data the PEN bit would be set to a one. Interprocessor communication, as described in section 2.3.4, can be set up by simply adding code to change RB8 and the port mode to the listing below. The hardware shown in Figure 3-2 can be used to convert the logic level output of the 8096 to ±12 or 15 volt levels to connect to a CRT. This circuit has been found to work with most RS-232 devices, although it does not conform to strict RS-232 specifications. If true RS-232 conformance is required then any standard RS-232 driver can be used.

```
$TITLE('SP.APT: SERIAL PORT DEMO PROGRAM')

$INCLUDE(DEMO96.INC)

rseg    at 28H

        CHR:    dsb     1
        SPTEMP: dsb     1
        TEMP0:  dsb     1
        TEMP1:  dsb     1
        RCV_FLAG:       dsb     1

cseg    at 200CH

        DCW     ser_port_int

cseg    at 2080H

        LD      SP, #100H

        LDB     IOC1, #00100000B                ; Set P2.0 to TXD

                ; Baud rate = input frequency / (64*baud_val)
                ; baud_val  = (input frequency/64) / baud rate


baud_val        equ     39              ; 39 = (12,000,000/64)/4800 baud

BAUD_HIGH       equ     ((baud_val-1)/256) OR 80H       ; Set MSB to 1
BAUD_LOW        equ     (baud_val-1) MOD 256


        LDB     BAUD_REG, #BAUD_LOW
        LDB     BAUD_REG, #BAUD_HIGH

        LDB     SPCON, #01001001B       ; Enable receiver, Mode 1

                ; The serial port is now initialized


        STB     SBUF, CHR               ; Clear serial Port
        LDB     TEMP0, #00100000B       ; Set TI-temp

        LDB     INT_MASK, #01000000B    ; Enable Serial Port Interrupt
        EI
loop:   BR      loop            ; Wait for serial port interrupt


ser_port_int:
        PUSHF
rd_again:                               ; This section of code can be replaced
        LDB     SPTEMP, SPSTAT          ; with "ORB  TEMP0, SP_STAT" when the
        ORB     TEMP0, SPTEMP           ; serial port TI and RI bugs are fixed
        ANDB    SPTEMP,#01100000B
        JNE     rd_again        ; Repeat until TI and RI are properly cleared
```

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Listing 3-11. Using the Serial Port in Mode 1

```
get_byte:
        JBC     TEMP0, 6, put_byte      ; If RI-temp is not set
        STB     SBUF, CHR               ; Store byte
        ANDB    TEMP0, #11111111B       ; CLR RI-temp
        LDB     RCV_FLAG, #0FFH         ; Set bit-received flag

put_byte:
        JBC     RCV_FLAG, 0, continue   ; If receive flag is cleared
        JBC     TEMP0, 5, continue      ; If TI was not set
        LDB     SBUF, CHR               ; Send byte
        ANDB    TEMP0, #11011111B       ; CLR TI-temp

        ANDB    CHR, #01111111B         ; This section of code appends
        CMPB    CHR,#0DH                ; an LF after a CR is sent
        JNE     clr_rcv
        LDB     CHR, #0AH
        BR      continue

clr_rcv:
        CLRB    RCV_FLAG                ; Clear bit-received flag

continue:
        POPF
        RET

        END
```

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Listing 3-11. Using the Serial Port in Mode 1 (Continued)

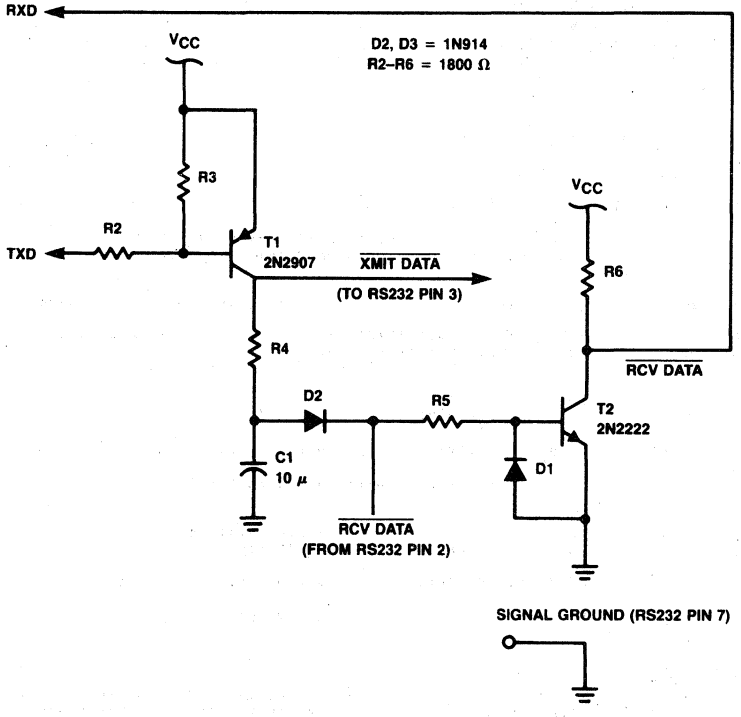

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Figure 3-2. Serial Port Level Conversion

3.2.4. USING THE A TO D

The code in Listing 3-12 makes use of the software flags to implement a non-interrupt driven routine which scans A to D channels 0 through 3 and stores them as words in RAM. An interrupt driven routine is shown in section 4.1. When using the A to D it is important to always read the value using the byte read commands, and to give the converter 8 state times to start converting before reading the status bit.

Since there is no sample and hold on the A to D converter it may be desirable to use an RC filter on each input. A 100Ω resistor in series with a 0.22 uf capacitor to ground has been used successfully in the lab. This circuit gives a time constant of around 22 microseconds which should be long enough to get rid of most noise, without overly slowing the A to D response time.

4.0 ADVANCED SOFTWARE EXAMPLES

Using the 8096 for applications which consist only of the brief examples in the previous section does not really make use of its full capabilities. The following examples use some of the code blocks from the previous section to show how several I/O features can be used together to accomplish a practical task. Three examples will be shown. The first is simply a combination of several of the section 3 examples run under an interrupt system. Next, a software serial port using the HSIO unit is described. The concluding example is one of interfacing the HSI unit to an optical encoder to control a motor.

4.1. Simultaneous I/O Routines under Interrupt Control

A four channel analog to PWM converter can easily be made using the 8096. In the example in Listing 4 analog channels are read and 3 PWM waveforms are generated on the HSO lines and one on the PWM pin. Each analog channel is used to set the duty cycle of its associated output pin. The interrupt system keeps the whole program humming, providing time for a background task which is simply a 32 bit software counter. To show which routines are executing and in which

```
$TITLE('ATOD.APT: SCANNING THE A TO D CHANNELS')

$INCLUDE(DEMO96.INC)

RSEG    at   28H

        BL      EQU     BX:BYTE
        DL      EQU     DX:BYTE

RESULT_TABLE:
        RESULT_1:       dsw     1
        RESULT_2:       dsw     1
        RESULT_3:       dsw     1
        RESULT_4:       dsw     1


cseg    at   2080H


start:  LD      SP, #100H       ; Set Stack Pointer
        CLR     BX

next:   ADDB    AD_COMMAND,BL, #1000B       ; Start conversion on channel
                                            ; indicated by BL register

        NOP             ; Wait for conversion to start
        NOP
check:  JBS     AD_RESULT_LO, 3, check  ; Wait while A to D is busy

        LDB     AL, AD_RESULT_LO        ; Load low order result
        LDB     AH, AD_RESULT_HI        ; Load high order result

        ADDB    DL, BL, BL              ; DL=BL*2
        LDBZE   DX, DL
        ST      AX, RESULT_TABLE[DX]    ; Store result indexed by BL*2

        INCB    BL              ; Increment BL modulo 4
        ANDB    BL, #03H

        BR      next

        END
```

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Listing 3-12. Scanning the A to D Channels

order, Port 1 output pins are used to indicate the current status of each task. The actual code listing is included in Appendix B.

The initialization section, shown in Listing 4-1a, clears a few variables and then loads the first set of on and off times to the HSO unit. Note that 8 state times must be waited between consecutive loads of the HSO. If this is not done it is possible to overwrite the contents of the CAM holding register. An A/D interrupt is forced by setting the bit in the Interrupt Pending register. This causes the first A/D interrupt to occur just after the Interrupt Mask register is set and interrupts are enabled.

Listing 4-1. Using Multiple I/O Devices

```
$TITLE ('8096 EXAMPLE PROGRAM FOR PWM OUTPUTS FROM A TO D INPUTS')
$PAGEWIDTH(130)

; This program will provide 3 PWM outputs on HSO pins 0-2
; and one on the PWM.
;
; The PWM values are determined by the input to the A/D converter.
;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

$INCLUDE(DEMO96.INC)

RSEG AT 28H

        DL      EQU     DX:BYTE

ON_TIME:
        PWM_TIME_1:     DSW     1
        HSO_ON_0:       DSW     1
        HSO_ON_1:       DSW     1
        HSO_ON_2:       DSW     1

RESULT_TABLE:
        RESULT_0:       DSW     1
        RESULT_1:       DSW     1
        RESULT_2:       DSW     1
        RESULT_3:       DSW     1

        NXT_ON_T:       DSW     1
        NXT_OFF_0:      DSW     1
        NXT_OFF_1:      DSW     1
        NXT_OFF_2:      DSW     1
        COUNT:          DSL     1
        AD_NUM:         DSW     1       ; Channel being converted
        TMP:            DSW     1
        HSO_PER:        DSW     1
        LAST_LOAD:      DSB     1

cseg    AT 2000H

        DCW     start           ; Timer_ovf_int
        DCW     Atod_done_int
        DCW     start           ; HSI_data_int
        DCW     HSO_exec_int


cseg    AT 2080H

start:  LD      SP, #100H       ; Set Stack Pointer
        CLR     AX
wait:   DEC     AX              ; wait approx. 0.2 seconds for
        JNE     wait            ; SBE to finish communications

        CLRB    AD_NUM

        LD      PWM_TIME_1, #080H
        LD      HSO_PER, #100H
        LD      HSO_ON_0, #040H
        LD      HSO_ON_1, #080H
        LD      HSO_ON_2, #0C0H

        ADD     NXT_ON_T,  Timer1, #100H
```

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Listing 4-1a. Initializing the A to D to PWM Program

```
            LDB     HSO_COMMAND, #00110110B     ; Set HSO for timer1, set pin 0,1
            LD      HSO_TIME, NXT_ON_T          ; with interrupt
            NOP
            NOP
            LDB     HSO_COMMAND, #00100010B     ; Set HSO for timer1, set pin 2
            ADD     HSO_TIME, NXT_ON_T          ; without interrupt

            ORB     LAST_LOAD, #00000111B   ; Last loaded value was set all pins
            LDB     INT_MASK, #00001010B    ; Enable HSO and A/D interrupts
            LDB     INT_PENDING, #00001010B ; Fake an A/D and HSO interrupt
            EI

 loop:      ORB     Port1, #00000001B       ; set P1.0
            ADD     COUNT, #01
            ADDC    COUNT+2,zero
            ANDB    Port1, #11111110B       ; clear P1.0
            BR      loop
```

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Listing 4-1a. Initializing the A to D to PWM program (Continued)

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;          HSO  EXECUTED  INTERRUPT          ;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

HSO_exec_int:
            PUSHF
            ORB     Port1, #00000010B       ; Set p1.1

            SUB     TMP,TIMER1, NXT_ON_T
            CMP     TMP,ZERO
            JLT     set_off_times

set_on_times:
            ADD     NXT_ON_T, HSO_PER
            LDB     HSO_COMMAND, #00110110B   ; Set HSO for timer1, set pin 0,1
            LD      HSO_TIME, NXT_ON_T
            NOP
            NOP
            LDB     HSO_COMMAND, #00100010B   ; Set HSO for timer1, set pin 2
            LD      HSO_TIME, NXT_ON_T

            ORB     LAST_LOAD, #00000111B     ; Last loaded value was all ones

            LDB     PWM_CONTROL, PWM_TIME_1       ; Now is as good a time as any
                                                  ; to update the PWM reg
            BR      check_done

set_off_times:
            JBC     LAST_LOAD, 0, check_done

            ADD     NXT_OFF_0, NXT_ON_T, HSO_ON_0
            LDB     HSO_COMMAND, #00010000B       ; Set HSO for timer1, clear pin 0
            LD      HSO_TIME, NXT_OFF_0

            NOP
            ADD     NXT_OFF_1, NXT_ON_T, HSO_ON_1
            LDB     HSO_COMMAND, #00010001B       ; Set HSO for timer1, clear pin 1
            LD      HSO_TIME, NXT_OFF_1

            NOP
            ADD     NXT_OFF_2, NXT_ON_T, HSO_ON_2
            LDB     HSO_COMMAND, #00010010B       ; Set HSO for timer1, clear pin 2
            LD      HSO_TIME, NXT_OFF_2

            ANDB    LAST_LOAD, #11111000B   ; Last loaded value was all 0s

check_done:
            ANDB    Port1, #11111101B       ; Clear P1.1
            POPF
            RET
```

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Listing 4-1b. Interrupt Driven HSO Routine

6

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;       A TO D  COMPLETE  INTERRUPT       ;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

ATOD_done_int:
        PUSHF
        ORB     Portl, #00000100B           ; Set P1.2

        ANDB    AL, AD_RESULT_LO,#11000000B      ; Load low order result
        LDB     AH, AD_RESULT_HI                 ; Load high order result
        ADDB    DL, AD_NUM, AD_NUM               ; DL= AD_NUM *2
        LDBZE   DX, DL
        ST      AX, RESULT_TABLE[DX]        ; Store result indexed by DX

        CMPB    AL, #01000000B
        JNH     no_rnd                      ; Round up if needed
        CMPB    AH,#0FFH          ; Don't increment if AH=0FFH
        JE      no_rnd
        INCB    AH

no_rnd: LDB     AL, AH            ; Align byte and change to word
        CLRB    AH
        ST      AX, ON_TIME[DX]

        INCB    AD_NUM
        ANDB    AD_NUM, #03H                ; Keep AD_NUM between 0 and 3

next:   ADDB    AD_COMMAND, AD_NUM, #1000B      ; Start conversion on channel
                                                ; indicated by AD_NUM register
        ANDB    Portl, #11111011B           ; Clear P1.2
        POPF
        RET

        END
```

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Listing 4-1c. Interrupt Driven A to D Routine

The HSO routine shown in Listing 4-1b is slightly different than the one in section 3. All of the HSO lines turn on at the same time, only the turn-off-time is varied between lines. This action is what is most commonly required for multiple PWM outputs and simplifies the software. A comparison is made between Timer1 and the next HSO turn on time at the beginning of the routine. If the next turn on time has passed, then the on-times are loaded into the CAM, otherwise the off times are loaded.

The maximum number of events in the CAM at any given time is 7. This occurs when the first line to turn off does so, causing the off-times for all of the lines to be loaded. For two of the lines there will be an offtime, an on-time, and the just loaded off-time. The other line (the one that just turned off) will have only the on-time and the just loaded off-time.

A/D conversions are performed by the code in Listing 4-1c about every 60 microseconds, 42 for the conversion, the rest for overhead. The A/D routine sets up the HSO and PWM on and off times. Since the A/D has a ten bit output, the most significant 8 bits are rounded up or down based on the least significant two bits.

4.2. Software Serial Port Using the HSIO Unit

There are many systems which require more than one serial port, an example is a system which must communicate with other computers and have an additional port for a local console. If the on-board UART is being used as an inter-processor link, the HSIO unit can be used to interface the 8096 to an additional asynchronous line.

Figure 4-1 shows the format of a standard 10-bit asynchronous frame. The start bit is used to synchronize the receiver to the transmitter; at the leading edge of the START bit the receiver must set up its timing logic to sample the incoming line in the center of each bit. Following the start bit are the eight data bits which are transmitted least significant bit first. The STOP bit is set to the opposite state of the START bit to guar-

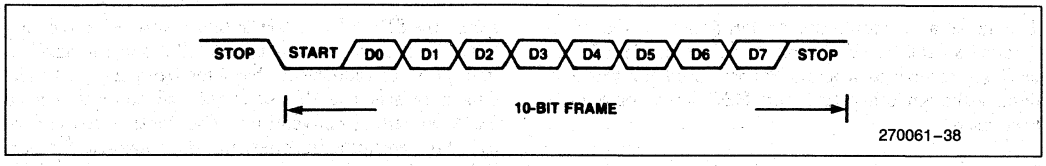

Figure 4-1. 10-bit Asynchronous Frame

antee that the leading edge of the START bit will cause a transition on the line; it also provides for a dead time on the line so that the receiver can maintain its synchronization.

The remainder of this section will show how a full-duplex asynchronous port can be built from the HSIO unit. There are four sections to this code:

1. Interface routines. These routines provide a procedural interface between the interrupt driven core of the software serial port and the remainder of the application software.
2. Initialization routine. This routine is called during the initialization of the overall system and sets up the various variables used by the software port.
3. Transmit ISR. This routine runs as an ISR (interrupt service routine) in response to an HSO interrupt interrupt. Its function is to serialize the data passed to it by the interface routines.
4. Receive ISRs. There are two ISRs involved in the receive process. One of them runs in response to an HSI interrupt and is used to synchronize the receive process at the leading edge of the start bit. The second receive ISR runs in response to an HSO generated software timer interrupt, this routine is scheduled to run at the center of each bit and is used to deserialize the incoming data.

The routines share the set of variables that are shown in Listing 4-2. These variables should be accessed only by the routines which make up the software serial port.

```
;
;       VARIABLES NEEDED BY THE SOFTWARE SERIAL PORT
;       ============================================
;
        rseg

rcve_state:     dsb 1
  rxrdy         equ 1           ; indicates receive done
  rxoverrun     equ 2           ; indicates receive overflow
  rip           equ 4           ; receive in progress flag
rcve_buf:       dsb 1           ; used to double buffer receive data
rcve_reg:       dsb 1           ; used to deserialize receive
sample_time:    dsw 1           ; records last receive sample time

serial_out:     dsw 1           ; Holds the output character+framing (start and
                                ;   stop bits) for transmit process.
baud_count:     dsw 1           ; Holds the period of one bit in units
                                ;   of T1 ticks.
txd_time:       dsw 1           ; Transition time of last Txd bit that was
                                ;   sent to the CAM
char:           dsb 1           ; for test only
;
;       COMMANDS ISSUED TO THE HSO UNIT
;       ===============================
;
mark_command    equ     0110101b        ; timer1,set,interrupt on 5
space_command   equ     0010101b        ; timer1,clr,interrupt on 5
sample_command  equ     0011000b        ; software timer 0

$eject
```

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Listing 4-2. Software Serial Port Declarations

The table also shows the declarations for the commands issued to the HSO unit. In this example HSI.2 is used for receive data and HSO.5 is used for transmit data, although other HSI and HSO lines could have been used.

The interface routines are shown in Listing 4-3. Data is passed to the port by pushing the eight-bit character into the stack and calling *char_out*, which waits for any in-process transmission to complete and stores the character into the variable *serial_out*. As the data is stored the START and STOP bits are added to the data bits. The routine *char—in* is called when the application software requires a character from the port. The data is returned in the *ax* register in conformance to PLM 96 calling conventions. The routine *csts* can be called to determine if a character is available at the port before calling *char_in*. (If no character is available *char_in* will wait indefinitely).

The initialization routine is shown in Listing 4-4. This routine is called with the required baud rate in the

```
;
char_out:
; Output character to the software serial port
;
        pop     cx              ; the return address
        pop     bx              ; the character for output
        ldb     (bx+1),#01h     ; add the start and stop bits
        add     bx,bx           ;   to the char and leave as 16 bit
wait_for_xmit:
        cmp     serial_out,0    ; wait for serial_out=0 (it will be cleared by
        bne     wait_for_xmit   ;   the hso interrupt process)
        st      bx,serial_out   ; put the formatted character in serial_out
        br      [cx]            ; return to caller
;
csts:
; Returns "true" (ax<>0) if char_in has a character.
;
        clr     ax
        bbc     rcve_state,0,csts_exit
        inc     ax
csts_exit:
        ret
;
char_in:
; Get a character from the software serial port
;
                                ; wait for character ready
        bbc     rcve_state,0,char_in
        pushf                   ; set up a critical region
        andb    rcve_state,#not(rxrdy)
        ldbze   al,rcve_buf
        popf                    ; leave the critical region
        ret
```

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Listing 4-3. Software Serial Port Interface Routines

```
;
setup_serial_port:
; Called on system reset to intiate the software serial port.
;
        pop     cx              ; the return address
        pop     bx              ; the baud rate (in decimal)
        ld      dx,#0007h       ; dx:ax:=500,000 (assumes 12 Mhz crystal)
        ld      ax,#0A120h
        divu    ax,bx           ; calculate the baud count (500,000/baudrate)
        st      ax,baud_count
        st      0,serial_out    ; clear serial out
        ldb     ioc1,#01100000b ; Enable HSO.5 and Txd
        bbs     ios0,6,$        ; Wait for room in the HSO CAM
                                ; and issue a MARK command.
        add     txd_time,timer1,20
        ldb     hso_command,#mark_command
        ld      hso_time,txd_time
        clrb    rcve_buf        ; clear out the receive variables
        clrb    rcve_reg
        clrb    rcve_state
        call    init_receive    ; setup to detect a start bit
        br      [cx]            ; return
```

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Listing 4-4. Software Serial Port Initialization Routine

stack; it calculates the bit time from the baud rate and stores it in the variable *baud_count* in units of TIMER1 ticks. An HSO command is issued which will initiate the transmit process and then the remainder of the variables owned by the port are initialized. The routine *init_receive* is called to setup the HSI unit to look for the leading edge of the START bit.

The transmit process is shown in Listing 4-5. The HSO unit is used to generate an output command to the transmit pin once per bit time. If the *serial_out* register is zero a MARK (idle condition) is output. If the *serial_out* register contains data then the least significant bit is output and the register shifted right one place. The framing information (START and STOP bits) are appended to the actual data by the interface routines. Note that this routine will be executed once per bit time whether or not data is being transmitted. It would be possible to use this routine for additional low resolution timing functions with minimal overhead.

The receive process consists of an initialization routine and two interrupt service routines, *hsi_isr* and *software_timer_isr*. The listings of these routines are shown in Listings 4-6a,4-6b, and 4-6c respectively. The

```
;
hso_isr:
; Fields the hso interrupts and performs the serialization of the data.
; Note: this routine would be incorporated into the hso service strategy for an
;       actual system.

        cseg    at 2006h
        dcw     hso_isr             ; Set up vector

        cseg
        pushf
        add     txd_time,baud_count
        cmp     serial_out,0        ; if character is done send a mark
        be      send_mark
        shr     serial_out,#1       ; else send bit 0 of serial_out and shift
        bc      send_mark           ;   serial_out left one place.
send_space:
        ldb     hso_command,#space_command
        ld      hso_time,txd_time
        br      hso_isr_exit
send_mark:
        ldb     hso_command,#mark_command
        ld      hso_time,txd_time

hso_isr_exit:
        popf
        ret
$eject
```

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Listing 4-5. Software Serial Port Transmit Process

Listing 4-6. Receive Process

```
;
init_receive:
; Called to prepare the serial input process to find the leading edge of
; a start bit.
;
        ldb     ioc0,#00000000b         ; disconnect change detector
        ldb     hsi_mode,#00100000b     ; negative edges on HSI.2
flush_fifo:
        orb     iosl_save,iosl
        bbc     iosl_save,7,flush_fifo_done
        ldb     al,hsi_status
        ld      ax,hsi_time             ; trash the fifo entry
        andb    iosl_save,#not(80h)     ; clear bit 7.
        br      flush_fifo
flush_fifo_done:
        ldb     ioc0,#00010000b         ; connect HSI.2 to detector
        ret
```

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Listing 4-6a. Software Serial Port Receive Initialization

```
;
hsi_isr:
; Fields interrupts from the HSI unit, used to detect the leading edge
; of the START bit
; Note: this routine would be incorporated into the HSI strategy of an actual
; system.
;
        cseg at 2004h
        dcw     hsi_isr                 ; setup the interrupt vector

        cseg
        pushf
        push    ax
        ldb     al,hsi_status
        ld      sample_time,hsi_time
        bbc     al,4,exit_hsi
        bbs     ios0,7,$                ; wait for room in HSO holding reg
        ld      ax,baud_count           ; send out sample command in 1/2
        shr     ax,#1                   ; bit time
        add     sample_time,ax
        ldb     hso_command,#sample_command
        st      sample_time,hso_time
        ldb     ioc0,#00000000b         ; disconnect hsi.2 from change detector
exit_hsi:
        pop     ax
        popf
        ret
```

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Listing 4-6b. Software Serial Port Start Bit Detect

```
;
software_timer_isr:
; Fields the software timer interrupt, used to deserialize the incomming data.
; Note: this routine would be incorporated into the software timer stategy
; in an actual system.
;
        cseg at 200ah
        dcw     software_timer_isr      ; setup vector

        cseg
        pushf
        orb     ios1_save,ios1
        andb    ios1_save,#not(01h)     ; clear bit 0
        andb    0,rcve_state,#0fch      ; All bits except rxrdy and overrun=0
        bne     process_data
process_start_bit:
        bbc     hsi_status,5,start_ok
        call    init_receive
        br      software_timer_exit
start_ok:
        orb     rcve_state,#rip ; set receive in progress flag
        br      schedule_sample

process_data:
        bbs     rcve_state,7,check_stopbit
        shrb    rcve_reg,#1
        bbc     hsi_status,5,datazero
        orb     rcve_reg,#80h   ; set the new data bit
datazero:
        addb    rcve_state,#10h ; increment bit count
        br      schedule_sample

check_stopbit:
        bbc     hsi_status,5,$  ; DEBUG ONLY
        ldb     rcve_buf,rcve_reg
        orb     rcve_state,#rxrdy
        andb    rcve_state,#03h ; Clear all but ready and overrun bits
        call    init_receive
        br      software_timer_exit

schedule_sample:
        bbs     ios0,7,$        ; wait for holding reg empty
        ldb     hso_command,#sample_command
        add     sample_time,baud_count
        st      sample_time,hso_time

software_timer_exit:
        popf
        ret
```

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Listing 4-6c. Software Serial Port Data Reception

start is detected by the *hsi__isr* which schedules a software timer interrupt in one-half of a bit time. This first sample is used to verify that the START bit has not ended prematurely (a protection against a noisy line). The software timer service routine uses the variable *rcve__state* to determine whether it should check for a valid START bit, deserialize data, or check for a valid STOP bit. When a complete character has been received it is moved to the receive buffer and *init__receive* is called to set up the receive process for the next character. This routine is also called when an error (e.g., invalid START bit) is detected.

Appendix C contains the complete listing of the routines and the simple loop which was used to initialize them and verify their operation. The test was run for several hours at 9600 baud with no apparent malfunction of the port.

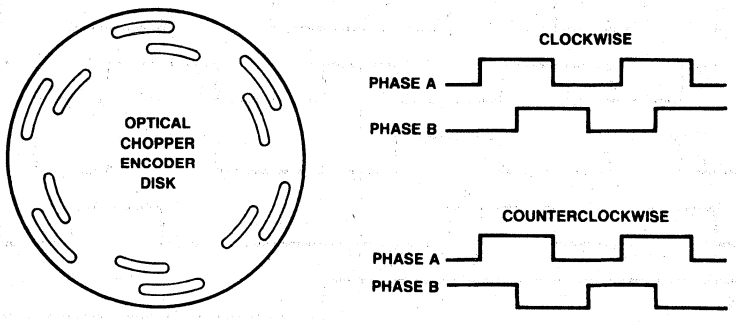
4.3. Interfacing an Optical Encoder to the HSI Unit

Optical encoders are among one of the more popular devices used to determine position of rotating equipment. These devices output two pulse trains with edges that occur from 2 to 4000 times a revolution.

Frequently there is a third line which generates one pulse per revolution for indexing purposes. Figure 4-2 shows a six line encoder and typical waveforms. As can be seen, the two waveforms provide the ability to determine both position and direction. Since a microcontroller can perform real time calculations it is possible to determine velocity and acceleration from the position and time information.

Interfacing to the encoder can be an interesting problem, as it requires connecting mechanically generated electrical signals to the HSI unit. The problems arise because it is difficult to obtain the exact nature of the signals under all conditions.

The equipment used in the lab was a Pittman 9400 series gearmotor with a 600 line optical encoder from Vernitech. The encoder has to be carefully attached to the shaft to minimize any runout or endplay. Fortunately, Pitmann has started marketing their motors with ball bearings and optical encoders already installed. It is recommended that the encoder be mounted to the motor using the exact specifications of the encoder manufacturer and/or a good machine shop.



Inside track generates Phase A. Outside track generates Phase B.

Figure 4-2. Optical Encoder and Waveforms

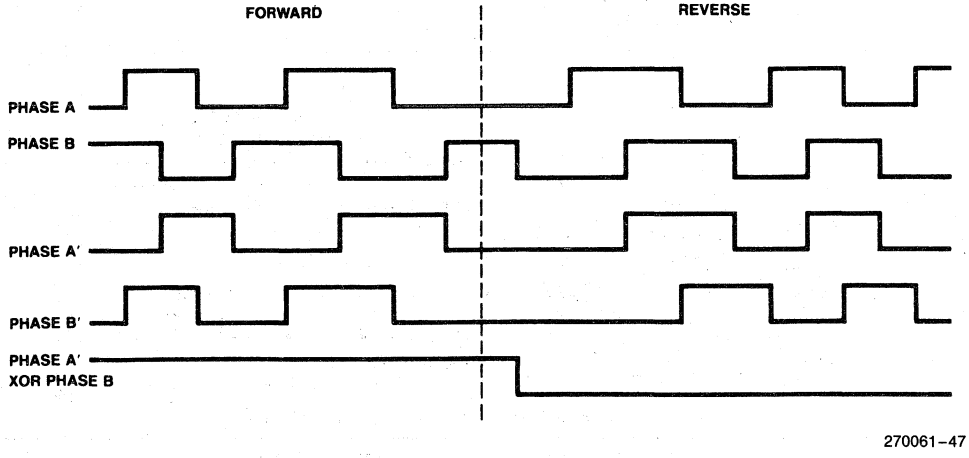
Digital filtering external to the 8096 is used on the encoder signals. The idealized signals coming from the encoder and after the digital filter are shown in Figure 4-3. The circuitry connecting the encoder to the 8096 requires only two chips. A one-shot constructed of XOR gates generates pulses on each edge of each signal. The pulses generated by Phase A are used to clock the signal from Phase B and vice versa. The hardware is shown in Figure 4-4. CMOS parts are used to reduce loading on the encoder so that buffers are not needed. Note that T2CLK is clocked on both edges of both filtered phases.

By using this method repetitive edges on a single phase without an edge on the other phase will not be passed on to the 8096. Repetitive edges on a phase can occur when the motor is stopped and vibrates or when it is changing direction. The digital filtering technique causes a little more delay in the signal at slow speeds than an analog filter would, but the simplicity trade off is worthwhile. The net effect of digital filtering is losing the ability to determine the first edge after a direction change. This does not affect the count since the first edge in both directions is lost.

If it is desired to determine when each edge occurs before filtering, the encoder outputs can be attached directly to the 8096. As these would be input signals, Port 0 is the most likely choice for connection. It would not be required to connect these lines to the HSI unit, as the information on them would only be needed when the motor is going very slowly.

The motor is driven using the PWM output pin for power control and a port pin for direction control. The 8096 drives a 7438 which drives 2 opto-isolators. These in turn drive two VFETs. A MOV (Metal Oxide Varistor, a type of transient absorber) is used to protect the VFETs, and a capacitor filters the PWM to get the best motor performance. Figure 4-5 shows the driver circuitry. To avoid noise getting into the 8096 system, the ±15 volt power supply is isolated from the 8096 logic power supply.

This is the extent of the external circuitry required for this example. All of the counting and direction detection are done by the 8096. There are two sections to the example: driving the motor and interfacing to the encoder. The motor driver uses proportional control with



NOTES:
Phase A' is Phase A clocked by Phase B
Phase B' is Phase B clocked by Phase A

Figure 4-3. Filtered Encoder Waveforms

some modifications and a braking algorithm. Since the main point of this example is I/O interfacing, the motor driver will be briefly described at the end of this section.

In order to interface to the encoder it is necessary to know the types of waveforms that can be expected. The motor was accelerated and decelerated many times using different maximum voltages. It was found that the

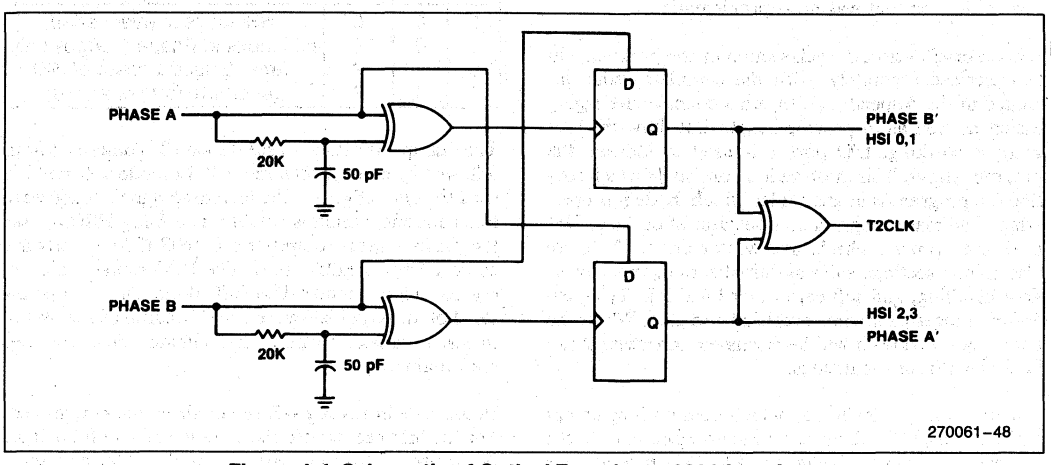


Figure 4-4. Schematic of Optical Encoder to 8096 Interface

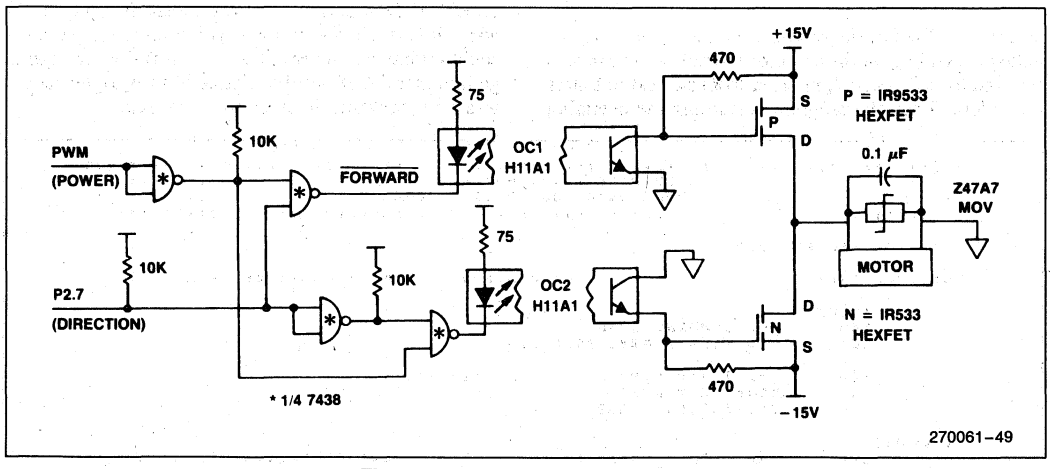


Figure 4-5. Motor Driver Circuitry

motor would decelerate smoothly until the time between encoder edges was around 100 microseconds. At this point the motor would either continue to decelerate slowly, or would suddenly stop and reverse. The latter case is the one that was most problematic.

After a brief overview, each section of the program will be described separately, with the complete listing included in the Appendix D. In order to make debugging easier, as well as to provide insight into how the program is working, I/O port 1 is used to indicate the program status. This information consists of which routine the program is in and under which mode it is operating. The main program sections are: Main loop, HSI interrupt, Timer 2 check, and Motor drive. There are also minor sections such as initialization, timer overflow handling, and software timer handling. Tying everything together is some overhead and glue. Where the glue is not obvious it will be discussed, otherwise it can be derived from the listings.

The program is a main loop which does nothing except serve as a place for the program to go when none of the interrupt routines are being run. All of the processing is done on an interrupt basis.

There are three basic software modes which are invoked depending on the speed of the motor. The modes referred to as 0, 1 and 2, in order from slowest to fastest operation. When the program is running the operating mode is indicated by the lower 2 bits of Port 1, with the following coding:

P1.0	P1.1	Mode	Description
0	0	0	HSI looks at every edge
1	0	1	HSI looks at Phase A edges only
0	1	2	Timer 2 used instead of HSI
1	1	2	(alternate form of above)

The example is easiest to see if mode 2 is described first, followed by mode 1 then mode 0. In mode 2 Timer 2 is used to count edges on the incoming signal. A software timer routine, which is actually run using HSO.0, uses the Timer 2 value to update a LONG (32-bit) software counter labeled *POSITION.* The HSO routine runs every 260 microseconds. The HSO.0 interrupt is used instead of an actual software timer because of the ability to easily unmask it while other software timer routines are running.

In the code in Listing 4-7, the mode is first determined. For the first pass ignore the code starting with the label *in_mode_1.* Starting with *in_mode_2* the counter is incremented or decremented based on bit zero of DIRECT. If DIRECT.0 = 0 the motor is going backward, if it is a 1 the motor is going forward. Next the count difference is checked to see if it is slow enough to go into mode 1. If not the routine returns to the code it was running when the interrupt occurred.

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;                     SOFTWARE TIMER ROUTINE 0                  ;;;;;;;;;;;
;;;;;;                     NOW  USING HSO.0 TO TRIGGER               ;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

        CSEG AT 2280H

hso_exec_int:                       ; Check mode -  Update position in mode 2

        PUSHF
        ldb     HSO_COMMAND,#30H
        add     HSO_TIME,TIMER1,HSO0_dly

        orb     port1,#00100000B        ; set P1.5
        ld      Timer_2,TIMER2
        jbs     Port1,1,in_mode2

in_mode1:
        sub     tmp1,Timer_2,old_t2     ; Check count difference in tmp1
        cmp     tmp1,#2
        jh      end_swt0
set_mode0:
        jbc     Port1,0,end_swt0        ; if already in mode 0
        andb    Port1,#11111100B        ; Clear P1.0, P1.1 (set mode 0)
        ldb     IOC0,#01010101B         ; enable all HSI
        ldb     last_stat,zero
        br      end_swt0
```

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Listing 4-7. Motor Control HSO.0 Timer Routine

```
in_mode2:
        sub     delta_p,timer_2,tmr2_old        ; get timer2 count difference
        ld      tmr2_old,timer_2

        jbc     direct,0,in_rev

in_fwd: add     position,delta_p
        addc    position+2,zero
        br      chk_mode

in_rev: sub     position,delta_p
        subc    position+2,zero

chk_mode:
        sub     tmp1,Timer_2,old_t2     ; Check count difference in tmp1
        cmp     tmp1,#5                 ; set model if count is too low
        jgt     end_swt0                ; count <= 5

set_model:
        andb    Port1,#11111101B        ; Clear P1.1, set P1.0 (set mode 1)
        orb     Port1,#00000001B
        ldb     IOC0,#00000101B         ; enable HSI 0 and 1
        ld      zero, HSI_TIME
        sub     last1_time,Timer1,min_hsi1
                ; set up so (time-last2_time)>min_hsi1 on next HSI
clr_hsi:
        ld      ZERO, HSI_TIME
        andb    iosl_bak,#01111111B             ; clear bit 7
        orb     iosl_bak,iosl
        jbs     iosl_bak,7,clr_hsi      ; If hsi is triggered then clear hsi

end_swt0:
        ld      old_t2,TIMER_2
        andb    port1,#11011111B        ; clear P1.5
        POPF
        ret
```

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Listing 4-7. Motor Control HSO.0 Timer Routine (Continued)

If the pulse rate is slow enough to go to mode 1, the transition is made by enabling HSI.0 and HSI.1. Both of these lines are connected to the same encoder line, with HSI.0 looking for rising edges and HSI.1 looking for falling edges. The *HSI__TIME* register is read to speed up clearing the HSI FIFO and the *LAST1__TIME* value is set up so the mode 1 routine does not immediately put the program into another mode. The HSI FIFO is then cleared, the Timer 2 value used throughout this routine is saved, and the routine returns.

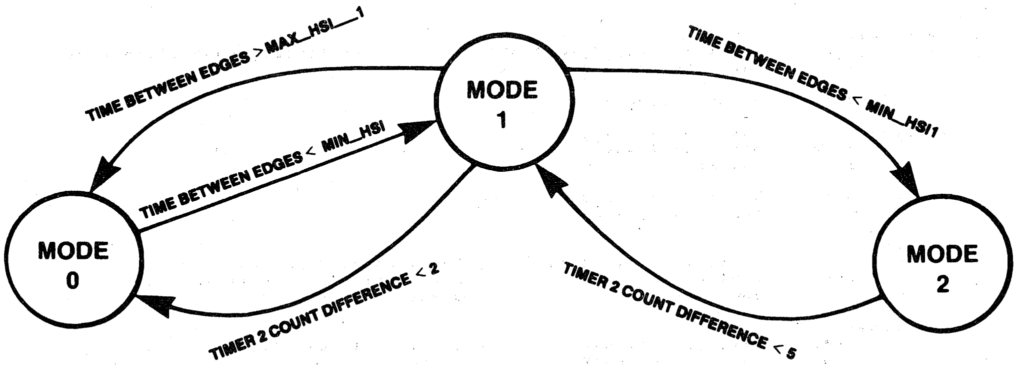
This routine still runs in modes 0 and 1, but in an abbreviated form. The section of code starting with the label *in__mode1* checks to see if the pulses are coming in so slowly that both HSI lines can be checked. If this is the case then all of the HSIs are enabled and the program returns. This routine is the secondary method for going from mode 1 to mode 0, the primary method is by checking the time between edges during the HSI routine, which will be described later.

The HSO routine will enable mode 0 from mode 1 if two edges are not received every 260 microseconds. The primary method, (under the HSI routine), can only enable mode 0 after an edge is received. This could cause a problem if the last 2 edges on Phase A before the encoder stops were too close to enable mode 0. If this happened, mode 0 would not be enabled until after the encoder started again, resulting in missed edges on Phase B. Using the HSO routine to switch from mode 1 to mode 0 eliminates this problem.

Figure 4-6 shows a state diagram of how the mode switching is done. As can be seen, there are two sources for most of the mode decisions. This helps avoid problems such as the one mentioned above.

When either Mode 1 or Mode 0 is enabled the HSI interrupt routine performs the counting of edges, while the HSO routine only ensures that the correct mode is running. The routines for modes 0 and 1 share the same initialization and completion sections, with the main body of code being different.

The initialization routine is similar to many HSI routines. The flags are checked to ensure that the HSI FIFO data is valid, and then the FIFO is read. Next, the main body of code (for either mode 0 or mode 1) is



NOTES:
Mode 0: HSI Examines edges on Phase A and B
Mode 1: HSI Examines edges on Phase A only
Mode 2: TIMER 2 stores edgecount

Figure 4-6. Mode State Diagram

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;               HSI DATA AVAILABLE INTERRUPT ROUTINE           ;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

;   This routine keeps track of the current time and position of the motor.
;   The upper word of information is provided by the timer overflow routine.

        CSEG AT 2400H
now_mode_1:     br      in_mode_1       ; used to save execution time for
no_intl:        br      no_int          ; worst case loop

hsi_data_int:   pushf
        orb     portl,#01000000B        ; set P1.6
        andb    iosl_bak,#01111111B     ; Clear iosl_bak.7
        orb     iosl_bak,iosl
        jbc     iosl_bak,7,no_intl      ; If hsi is not triggered then
                                        ; jump to no_int
get_values:
        ld      timer_2,TIMER2
        andb    hsi_s0,HSI_STATUS,#01010101B
        ld      time, HSI_TIME

        jbs     portl,0,now_mode_1      ; jump if in mode 1

In_mode_0:


;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;                 INSERT  BODY  OF  ROUTINE
;;;;;;;;;;;;;;;;;;;


load_lasts:
        ld      tmr2_old,timer_2
no_cnt: andb    iosl_bak,#01111111B     ; clr bit 7
        orb     iosl_bak,iosl
        jbc     iosl_bak,7,no_int
again:  br      get_values

no_int: andb    portl,#10111111B        ; Clear P1.6
        popf
        ret     ; end of hsi_data interrupt routine
                ; Routine for mode 1 follows and then returns to "load_lasts"
$EJECT
```

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Listing 4-8. Motor Control HSI Data Available Routine

run. At the end time and count values are saved and the holding register is checked for another event. Listing 4-8 contains the initialization and completion sections of the HSI routine.

Listing 4-9 is the main body of the Mode 1 routine. Before any calculations are done in Mode 1, the incoming pulse period is measured to see if it is too fast or too slow for mode 1. The time period between two edges is used so that the duty cycle of the waveform will not affect mode switching. If it is determined that Mode 2 should be set, Port 1.1 is set, all of the HSI lines are disabled, and the HSI fifo is cleared. If Mode 0 is to be set all of the HSI lines are enabled and the variable *LAST_STAT* is cleared. LAST_STAT = 0 is used as a flag to indicate the first HSI interrupt in Mode 0 after Mode 1. After the mode checking and setting are complete the incremental value in Timer 2 is used to update *POSITION*. The program then returns to the completion section of the routine.

There is a lot more code used in Mode 0 than in Mode 1, most of which is due to the multiple jump statements that determine the current and previous state of the HSI pins. In order to save execution time several blocks of code are repeated as can be seen in Listing 4-10. The first determination is that of which edge had occurred. If a Phase A edge was detected the *LAST1_TIME* and *LAST2_TIME* variables are updated so a reference to the pulse frequency will be available. These are the same variables used under Mode 1. A test is also made to see if the edges are coming fast enough to warrant being in Mode 1, if they are, the switch is made. If the last edge detected was on Phase B, the information is used only to determine direction.

```
In_mode_1:                  ; mode 1 HSI routine

          andb      tmp1,hsi_s0,#01010000B
          jne       no_cnt
cmp_time:                                   ; Procedure which sets mode 1 also
                                            ; sets times to pass the tests
          ld        last2_time,last1_time
          ld        last1_time,time

cmp1:     sub       tmp1,time,last2_time
          cmp       tmp1,min_hsi1
          jh        check_max_time

set_mode_2:
          orb       Port1,#00000010B        ; Set P1.1 (in mode 2)
          ldb       IOC0,#00000000B         ; Disable all HSI
mt_hsi:   ld        zero,hsi_time           ; empty the hsi fifo
          andb      ios1_bak,#01111111B             ; clear bit 7
          orb       ios1_bak,ios1
          jbs       ios1_bak,7,mt_hsi       ; If hsi is triggered then clear hsi
          br        done_chk

check_max_time:
          sub       tmp1,time,last2_time
          cmp       tmp1,max_hsi1           ; max_hsi = addition to min_hsi for
                                            ; total time
          jnh       done_chk

set_mode_0:
          andb      Port1,#11111100B        ; clear P1.0,1  set mode 0)
          ldb       IOC0,#01010101B         ; Enable all HSI
          ldb       last_stat,zero

done_chk:
          sub       delta_p,timer_2,tmr2_old        ; get timer2 count difference
          jbc       direct,0,add_rev
add_fwd:
          add       position,delta_p
          addc      position+2,zero
          br        load_lasts
add_rev:
          sub       position,delta_p
          subc      position+2,zero
          br        load_lasts

$eject
```

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Listing 4-9. Motor Control Mode 1 Routines

```
In_mode_0:
        jbs     hsi_s0,0,a_rise
        jbs     hsi_s0,2,a_fall
        jbs     hsi_s0,4,b_rise
        jbs     hsi_s0,6,b_fall
        br      no_cnt

a_rise: ld      last2_time,last1_time
        ld      last1_time,time
        sub     time,last2_time
        cmp     time,min_hsi
        jh      tst_statr
;set model-
        orb     Port1,#00000001B        ; Set P1.0 (in mode 1)
        ldb     IOC0,#00000101B         ; Enable HSI 0 and 1
tst_statr:
        jbs     last_stat,6,going_fwd
        jbs     last_stat,4,going_rev
        jbs     last_stat,2,change_dir
        cmpb    last_stat,zero
        je      first_time              ; first time in mode0
        br      inp_err

a_fall: ld      last2_time,last1_time
        ld      last1_time,time
        sub     time,last2_time
        cmp     time,min_hsi
        jh      tst_statf
;set model-
        orb     Port1,#00000001B        ; Set P1.0 (in mode 1)
        ldb     IOC0,#00000101B         ; Enable HSI 0 and 1
tst_statf:
        jbs     last_stat,4,going_fwd
        jbs     last_stat,6,going_rev
        jbs     last_stat,0,change_dir
        cmpb    last_stat,zero
        je      first_time              ; first time in mode0
        br      inp_err

b_rise: jbs     last_stat,0,going_fwd
        jbs     last_stat,2,going_rev
        jbs     last_stat,6,change_dir
        cmpb    last_stat,zero
        je      first_time              ; first time in mode0
        br      inp_err

b_fall: jbs     last_stat,2,going_fwd
        jbs     last_stat,0,going_rev
        jbs     last_stat,4,change_dir
        cmpb    last_stat,zero
        je      first_time              ; first time in mode0
        br      inp_err

first_time:
        stb     hsi_s0,last_stat
        br      done_chk        ; add delta position
inp_err:
        br      no_int


change_dir:
        notb    direct
no_inc: jbc     direct,0,going_rev

going_fwd:
        orb     PORT2,#01000000B        ; set P2.6
        ldb     direct,#01              ; direction = forward
        add     position,#01
        addc    position+2,zero
        br      st_stat
going_rev:
        andb    PORT2,#10111111B        ; clear P2.6
        ldb     direct,#00              ; direction = reverse
        sub     position,#01
        subc    position+2,zero

st_stat:
        stb     hsi_s0,last_stat
```

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Listing 4-10. Motor Control Mode 0 Routines

After mode correctness is confirmed and the *LASTx_TIME* values are updated the *LAST_STAT* (Last Status) variable is used to determine the current direction of travel. The POSITION value is then updated in the direction specified by the last two edges and the status is stored. Note that the first time in Mode 0 after being in Mode 1, the Mode 1 *done_chk* routine is used to update POSITION, instead of the routines *going_fwd* and *going_rev* from the Mode 0 section of code. The completion section of code is then executed.

Providing the PWM value to drive the motor is done by a routine running under Software Timer 1. The first section of code, shown in Listing 4-11a, has to do with calculating the position and timer errors. Listing 4-11b shows the next section of code where the power to be supplied to the motor is calculated. First the direction is checked and if the direction is reverse the absolute value of the error is taken. If the error is greater than 64K counts, the PWM routine is loaded with the maximum value. The next check is made to see if the motor is close enough to the desired location that the power to it should be reversed, (i.e., enter the Braking mode). If the motor is very close to the position or has slowed to the point that is likely to turn around, the *Hold_Position mode is entered.*

The determination of which modes are selected under what conditions was done empirically. All of the parameters used to determine the mode are kept in RAM so they can be easily changed on the fly instead of by re-assembling the program. The parameters in the listing have been selected to make the motor run, but have not been optimized for speed or stability. A diagram of the modes is shown in Figure 4-7.

In the *Hold_Position* mode power is eased onto the motor to lock it into position. Since the motor could be stopped in this mode, some integral control is needed, as proportional control alone does not work well when the error is small and the load is large. The BOOST variable provides this integral control by increasing the output a fixed amount every time period in which the

Listing 4-11. Motor Control Software Timer 1 Routine

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;                    SOFTWARE TIMER ROUTINE 1              ;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

CSEG AT 2600H

swtl_expired:

        pushf
        orb     portl,#10000000B          ; set portl.7

        ldb     int_mask,#00001101B       ; enable HSI, Tovf, HSO

        ldb     HSO_COMMAND,#39H
        add     HSO_TIME,TIMER1,swtl_dly

        ld      time_err+2,des_time+2     ; Calculate time & position error
        ld      pos_err+2,des_pos+2
        sub     time_err,des_time,time            ; values are set
        subc    time_err+2,time+2
        sub     pos_err,des_pos,position
        subc    pos_err+2,position+2

        EI

        sub     time_delta,last_time_err,time_err
        ld      last_time_err,time_err

        sub     pos_delta,last_pos_err,pos_err
        ld      last_pos_err,pos_err

;;;;;           Time_err  = Desired time to finish - current time
;;;;;           Pos_err   = Desired position to finish - current position
;;;;;           Pos_delta  = Last position error - Curent position error
;;;;;           Time_delta = Last time error - Current time error
;;;;;              note that errors should get smaller so deltas will be
;;;;;              positive for forward motion (time is always forward)
```

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Listing 4-11a. Motor Control Software Position Counter

```
chk_dir:
        cmp     pos_err+2,zero
        jge     go_forward

go_backward:
        neg     pos_err         ; Pos_err = ABS VAL (pos_err)
        ldb     pwm_dir,#00h
        cmp     pos_err+2,#0ffffH
        jne     ld_max
        br      chk_brk

go_forward:
        ldb     pwm_dir,#01H
        cmp     pos_err+2,zero
        je      chk_brk

ld_max: ldb     pwm_pwr,max_pwr
        br      chk_sanity

Chk_brk:                        ;  Position_Error now = ABS(pos_err)
        cmp     pos_err,pos_pnt
        jnh     hold_position   ; position_error<position_control_point
        cmp     pos_err,brk_pnt
        jh      ld_max          ; position_error>brake_point

braking:
        cmp     pos_delta,zero
        jge     chk_delta
        neg     pos_delta
chk_delta:
        cmp     pos_delta,vel_pnt       ; velocity = pos_delta/sample_time
        jnh     hold_position           ; jmp if  ABS(velocity) < vel_pnt

brake:  ldb     pwm_pwr,max_brk
        ldb     tmp,direct              ; If braking apply power in opposite
        notb    tmp                     ; direction of current motion
        ldb     pwm_dir,tmp

        br      ld_pwr

Hold_position:                  ; position hold mode
        cmp     pos_err,#02
        jh      calc_out        ; if position error < 2 then turn off power
        clr     tmp+2
        clr     boost
        BR      output

calc_out:
        mulub   tmp,max_hold,#255
        mulu    tmp,pos_err             ; Tmp = pos_err * max_hold
        cmp     pos_delta,zero
        jne     no_bst
        add     boost,#04               ; Boost is integral control
        add     tmp+2,boost             ; TMP+2 = MSB(pos_err*max_hold)
        br      ck_max
no_bst: clr     boost
ck_max: cmp     tmp+2,max_hold
        jnh     output
maxed:  ld      tmp+2,max_hold
output: ldb     pwm_pwr,tmp+2

chk_sanity:
        br      ld_pwr

ld_pwr:
        ldb     rpwr,pwm_pwr
        notb    rpwr
        jbs     pwm_dir,0,p2fwd

p2bkwd: DI
        andb    port2,#01111111B        ; clear P2.7
        ldb     pwm_control,rpwr
        EI
        br      pwrset
p2fwd:  DI
        orb     port2,#10000000B        ; set P2.7
        ldb     pwm_control,rpwr
        EI
```

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Listing 4-11b: Motor Control Power Algorithm

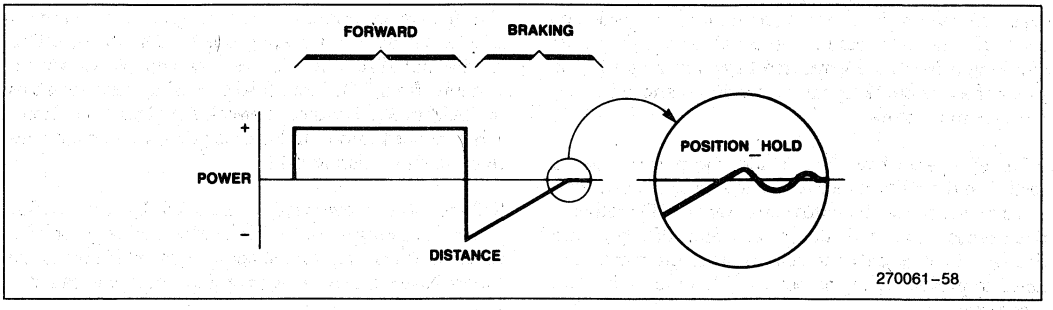

Figure 4-7. Motor Control Modes

error does not get smaller. Once the error does get smaller, usually because the motor starts moving, BOOST is cleared.

A sanity check can be performed at this point to double check that the 8096 has proper control of the motor. In the example the worst that can happen is the proto-

```
pwrset:
        cmp     time_err+2,zero  ; do pos_table when err is negative
        jgt     end_p
;;;     br      end_p

        cmp     nxt_pos,#(32+pos_table)
        jlt     get_vals                ; jump if lower
        ld      nxt_pos,#pos_table
        clr     time+2
get_vals:

        ld      des_pos,[nxt_pos]+
        ld      des_pos+2,[nxt_pos]+
        ld      des_time+2,[nxt_pos]+
        ld      max_pwr,[nxt_pos]+
        ld      max_brk,max_pwr
        add     des_pos,offset
        addc    des_pos+2,zero
        sub     last_pos_err,des_pos,position

end_p:  andb    portl,#01111111B        ; clear P1.7

        popf
        ret

pos_table:

        dcl     00000000H       ; position 0
        dcw     0020H, 0080H    ; next time, power
        dcl     0000c000H       ; position 1
        dcw     0040H, 0040H    ; next time, power
        dcl     00000000H       ; position 2
        dcw     0060H, 00c0H    ; next time, power
        dcl     0FFFF8000H      ; position 3
        dcw     0080H, 0080H    ; next time, power

        dcl     00000800H       ; position 4
        dcw     0058H, 0080H    ; next time, power
        dcl     00003000H       ; position 5
        dcw     0070H, 00ffH    ; next time, power
        dcl     00000000H       ; position 6
        dcw     0090H, 00f0H    ; next time, power
        dcl     00000000H       ; position 7
        dcw     0091H, 00f0H    ; next time, power
```

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Listing 4-12. Motor Control Next Position Lookup

type will need to be reset, so the sanity check was not used. If one were desired, it could be as simple as checking a hardware generated direction indicator, or as complex as checking motor condition and other environmental factors.

After all checks have been made, the power value is loaded to the RPWR register using a software inversion to compensate for the hardware inversion. Direction is determined next and the power and direction are changed in adjacent instructions with interrupts disabled to prevent changing power without direction and vice versa.

To exercise the program logic the desired position is changed based on the time value using the code and lookup table shown in Listing 4-12.

The remaining sections of the program are relatively simple, but worth discussing briefly. The initialization routine initializes the I/O features and places several variables from ROM into RAM. Having these variables in RAM makes it easier to tweak the algorithm. Timer 1 is expanded into a 32-bit timer by the interrupt routine shown in Listing 4-13.

Software timer overhead is handled by the routine shown in Listing 4-14. In this routine the status of each timer bit is checked in a shadow register. If any of the timers have expired the appropriate routine is called.

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;                         TIMER  INTERRUPT  SERVICE              ;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                CSEG AT  2200H

timer_ovf_int:
                pushf

                orb     iosl_bak,IOS1
chk_tl:         jbc     iosl_bak,5,tmr_int_done
                inc     time+2
                andb    iosl_bak,#11011111B       ; clear bit 5
tmr_int_done:
                popf
                ret                 ; End of timer interrupt routine
```

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Listing 4-13. Motor Control Timer Interrupt Routine

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;           SOFTWARE TIMER INTERRUPT SERVICE ROUTINE            ;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                CSEG AT  2220H


soft_tmr_int:
                pushf
                orb     iosl_bak,IOS1
chk_swt0:
                jbc     iosl_bak,0,chk_swt1
                andb    iosl_bak,#11111110B      ; Clear bit 0 - end swt0
                call    swt0_expired
chk_swt1:
                jbc     iosl_bak,1,chk_swt2
                andb    iosl_bak,#11111101B      ; Clear bit 1
                call    swt1_expired
chk_swt2:
                jbc     iosl_bak,2,chk_swt3
                andb    iosl_bak,#11111011B      ; Clear bit 2
                call    swt2_expired
chk_swt3:
                jbc     iosl_bak,4,swt_int_done
                andb    iosl_bak,#11110111B      ; Clear bit 3
;               call    swt3_expired

swt_int_done:
                popf
                ret     ; END OF SOFTWARE TIMER INTERRUPT ROUTINE

$eject
```

270061-B2

Listing 4-14. Motor Control Software Timer Interrupt Handler

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;                  SOFTWARE TIMER ROUTINE 2                      ;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

        CSEG AT 2380H

swt2_expired:
        pushf
        ldb     hso_command,#3AH           ; set swt_2
        add     hso_time,timer1,swt2_dly

        orb     port1,#00000100B           ; set port 1.2
        cmp     out_ptr,#7ffH
        bnh     pulsing
        ld      out_ptr,#1f0H

pulsing:
        jbc     tr_col,0,swt2_done

        st      position+2,[out_ptr]+      ;  position high, position low
        st      position,[out_ptr]+

        st      direct,[out_ptr]+
        st      pwm_pwr,[out_ptr]+

                                           ; store 8 bytes externally

swt2_done:
        sub     tmp1,timer1,last1_time
        cmp     tmp1,#1800H
        jnh     swt2_ret        ; keep (time_last4_time)<7000H

        add     last1_time,#1000H
swt2_ret:
        andb    port1,#11111011B           ; clear port1.2
        popf
        ret
```

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Listing 4-15: Motor Control Software Timer 2 Routine

The last routine, shown in Listing 4-15, is the Software Timer 2 routine which outputs some variables to external RAM. It also keeps LAST1__Time within 1800H of Timer1 to prevent overflows from occurring when the Mode 0 and Mode 1 software check this variable.

A complete listing of the program as it is used in our lab can be found in Appendix D. For a given motor or encoder it will probably be necessary to change some of the time constants on the first page of the listing. With the motor used in our experimentation, pulses are missed from time to time when direction changes quickly. If the motor were not as fast to turn around or the encoder were mounted better these problems should disappear. The missing pulses occur when switching from Mode 1 to Mode 0, other than that no anomalies were found in the lab.

Prior to the version of code just discussed, several attempts were made, one of which could be used under certain constraints. It is possible to use only modes 2 and 0 to monitor the encoder, provided the encoder always operates smoothly and provides at least 200 microseconds between the last several edges of Phase A before reversing. This idea was originally tried because the motor was not characterized thoroughly at first, and caused problems because of the motors tendency to stop suddenly when its speed was low.

If an encoder has a lower line count and therefore more time between output pulses the two mode solution can be used. The software for the two mode version can be easily extracted form the three mode version, so it will not be presented.

5.0 HARDWARE EXAMPLE

5.1. EPROM Only Minimum System

The diagram in Figure 5-1 illustrates how to connect an 8096 in a minimum configuration system. Either 2764s or 27128s can be used in the system. Note that the lower EPROM contains the even bytes while the upper

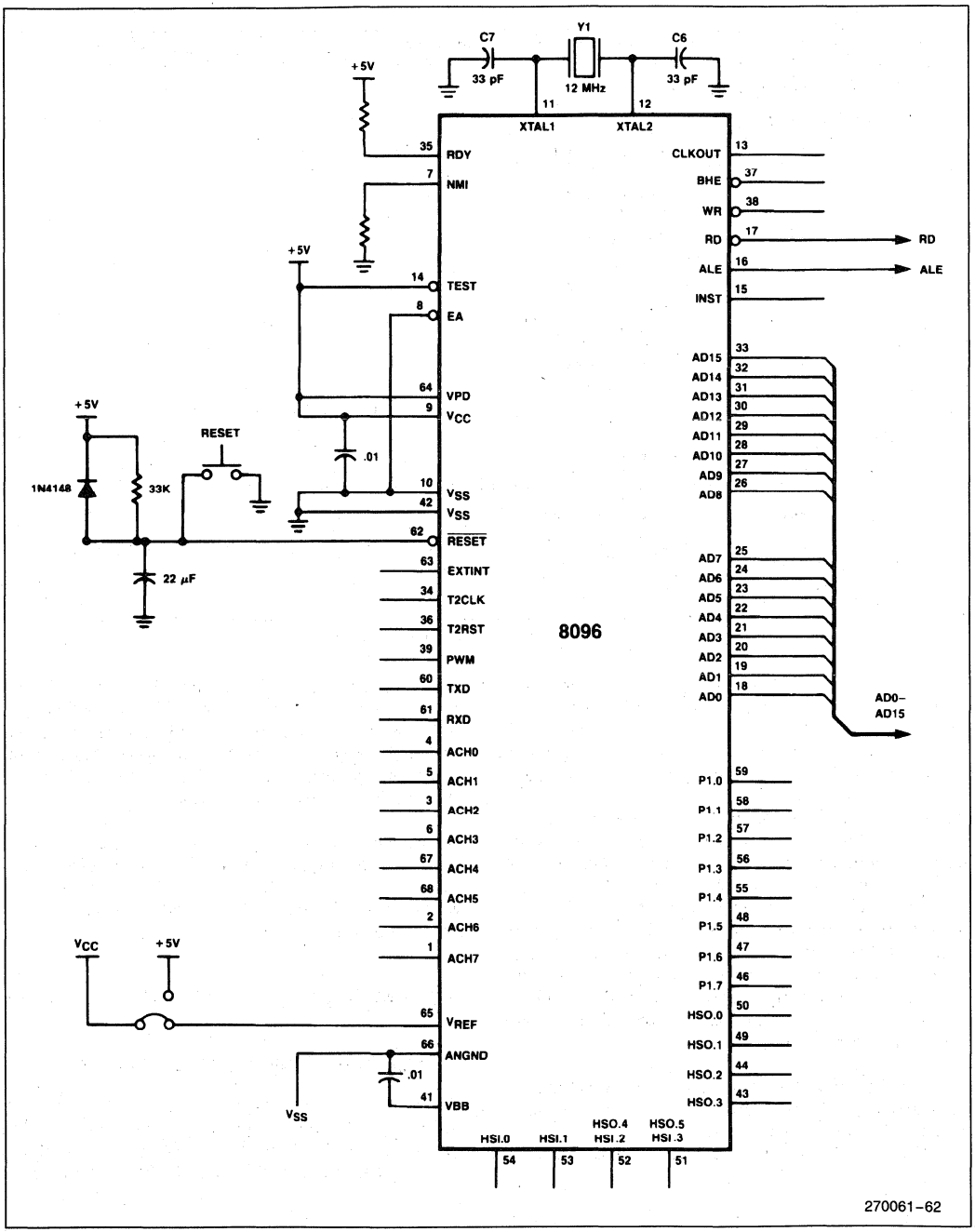

Figure 5-1 (1 of 2).

one contains the odd bytes, and the addressing is not fully decoded. This means that the addressing on a 2764 will be such that the lower 4K of each EPROM is mapped at 0000H and 4000H while the upper 4K is mapped at 2000H. If the program being loaded is 16 Kbytes long the first half is loaded into the second half of the 2764s and vice versa. A similar situation exists when using 27128s.

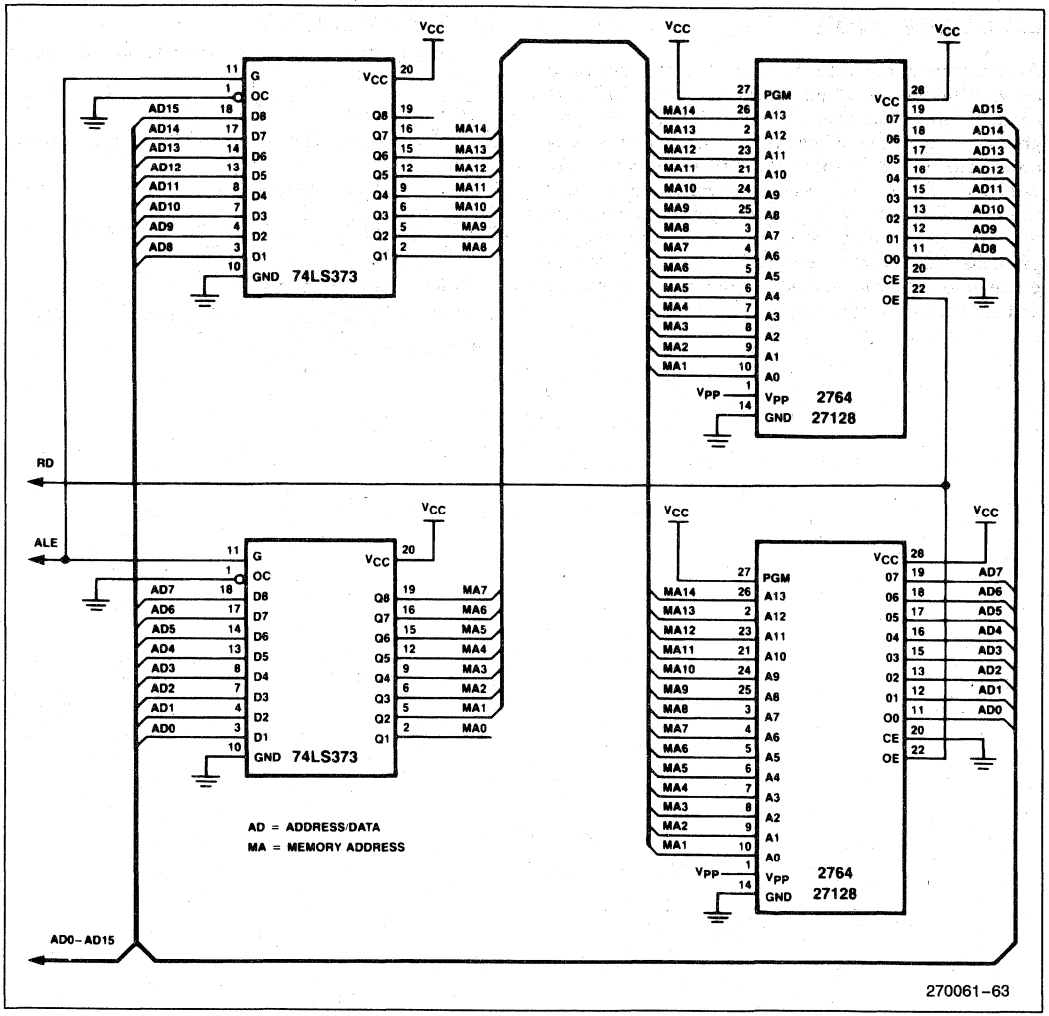

Figure 5-1 (2 of 2).

This circuit will allow most of the software presented in this ap-note to be run. In a system designed for prototyping in the lab it may be desirable to buffer the I/O ports to reduce the risk of burning out the chip during experimentation. One may also want to enhance the system by providing RC filters on the A to D inputs, a precision VREF power supply, and additional RAM.

5.2. Port Reconstruction

If it is desired to fully emulate a 8396 then I/O ports 3 and 4 must be reconstructed. It is easiest to do this if the usage of the lines can be restricted to inputs or outputs on a port by port rather than line by line basis. The ports are reconstructed by using standard memory-mapped I/O techniques, (i.e., address decoders and latches), at the appropriate addresses. If no external RAM is being used in the system then the address decoding can be partial, resulting in less complex logic.

The reconstructed I/O ports will work with the same code as the on chip ports. The only difference will be the propagation delay in the external circuitry.

6.0 CONCLUSION

An overview of the MCS-96 family has been presented along with several simple examples and a few more complex ones. The source code for all of these programs are available in the Insite Users Library using order code AE-16. Additional information on the 8096 can be found in the Microcontroller Handbook and it is recommended that this book be in your possession before attempting any work with the MCS-96 family of products. Your local Intel sales office can assist you in getting more information on the 8096 and its hardware and software development tools.

7.0 BIBLOGRAPHY

1. MSC-96 Macro Assembler User's Guide, Intel Corporation, 1983.

   Order number 122048-001.

2. Microcontroller Handbook (1985), Intel Corporation, 1984.

   Order number 210918-002.

3. MSC-96 Utilities User's Guide, Intel Corporation, 1983.

   Order number 122049-001.

4. PL/M-96 User's Guide, Intel Corporation, 1983.

   Order number 122134-001.

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:  F3:INTER1.A96
OBJECT FILE:  F3:INTER1.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT                  LINE      SOURCE STATEMENT
                                    1  $TITLE('INTER1.A96:  Interpolation routine 1')
                                    2  ;;;;;;;    8096 Assembly code for table lookup and interpolation
                                    3
                                    4  $INCLUDE(:F0:DEMO96.INC)       ; Include demo definitions
                               =1   5  $nolist  ;  Turn listing off for include file
                               =1  53           ;  End of include file
                                   54
    0022                           55  RSEG  at 22H
                                   56
    0022                           57          IN_VAL:         dsb     1               ; Actual Input Value
    0024                           58          TABLE_LOW:      dsw     1
    0026                           59          TABLE_HIGH:     dsw     1
    0028                           60          IN_DIF:         dsw     1               ; Upper Input - Lower Input
      0028                         61          IN_DIFB         equ     IN_DIF  :byte
    002A                           62          TAB_DIF:        dsw     1               ; Upper Output - Lower Output
    002C                           63          OUT:            dsw     1
    002E                           64          RESULT:         dsw     1
    0030                           65          OUT_DIF:        dsl     1               ; Delta Out
                                   66
                                   67
    2080                           68  CSEG at 2080H
                                   69
    2080 A1000118                  70          LD      SP, #100H
                                   71
    2084 B0221C                    72  look:   LDB     AL, IN_VAL      ; Load temp with Actual Value
    2087 18031C                    73          SHRB    AL, #3          ; Divide the byte by 8
    208A 71FE1C                    74          ANDB    AL, #11111110B  ; Insure AL is a word address
                                   75                                  ;  This effectively divides AL by 2
                                   76                                  ;  so AL = IN_VAL/16
                                   77
    208D AC1C1C                    78          LDBZE   AX, AL          ; Load byte AL to word AX
    2090 A31D002124                79          LD      TABLE_LOW, TABLE [AX]   ; TABLE_LOW is loaded with the value
                                   80                                          ;  in the table at table location AX
                                   81
```

270061-64

```
2095 A31D022126          82          LD      TABLE_HIGH, (TABLE+2)[AX]  ; TABLE_HIGH is loaded with the
                         83                                             ; value in the table at table
                         84                                             ; location AX+2
                         85                                             ; (The next value in the table)
                         86
209A 4824262A            87          SUB     TAB_DIF, TABLE_HIGH, TABLE_LOW
                         88                                             ; TAB_DIF=TABLE_HIGH-TABLE_LOW
                         89
209E 510F2228            90          ANDB    IN_DIFB, IN_VAL, #0FH      ; IN_DIFB=least significant 4 bits
                         91                                             ;  of IN_VAL
20A2 AC2828              92          LDBZE   IN_DIF, IN_DIFB            ; Load byte IN_DIFB to word IN_DIF
                         93
20A5 FE4C2A2830          94          MUL     OUT_DIF, IN_DIF, TAB_DIF
                         95                                             ; Output_difference =
                         96                                             ;  Input_difference*Table_difference
20AA 0E0430              97          SHRAL   OUT_DIF, #4                ; Divide by 16 (2**4)
                         98
20AD 4424302C            99          ADD     OUT, OUT_DIF, TABLE_LOW    ; Add output difference to output
                        100                                             ;  generated with truncated IN_VAL
                        101                                             ;  as input
20B1 0A042C             102          SHRA    OUT, #4                    ; Round to 12-bit answer
20B4 A4002C             103          ADDC    OUT, zero                  ; Round up if Carry = 1
                        104
20B7 C02E2C             105  no_inc: ST      OUT, RESULT                ; Store OUT to RESULT
                        106
20BA 27C8               107          BR      look                       ; Branch to "look:"
                        108
                        109
2100                    110  cseg    AT 2100H
                        111
2100 000000200034004C   112  table:  DCW     0000H, 2000H, 3400H, 4C00H  ; A random function
2108 005D006A00720078   113          DCW     5D00H, 6A00H, 7200H, 7800H
2110 007B007D0076006D   114          DCW     7B00H, 7D00H, 7600H, 6D00H
2118 005D004B00340022   115          DCW     5D00H, 4B00H, 3400H, 2200H
2120 0010               116          DCW     1000H
                        117
2122                    118  END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

270061-65

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:   F3:INTER2.A96
OBJECT FILE:   F3:INTER2.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT                  LINE        SOURCE STATEMENT
                                    1   $TITLE('INTER2.A96:  Interpolation routine 2')
                                    2
                                    3   ;;;;;;;    8096 Assembly code for table lookup and interpolation
                                    4   ;;;;;;;    Using tabled values in place of division
                                    5
                                    6   $INCLUDE(:F0:DEMO96.INC) ; Include demo definitions
                               =1   7   $nolist  ;  Turn listing off for include file
                               =1  55            ;  End of include file
                                   56
    0024                           57   RSEG  at 24H
                                   58
    0024                           59           IN_VAL:          dsb     1            ; Actual Input Value
    0026                           60           TABLE_LOW:       dsw     1            ; Table value for function
    0028                           61           TABLE_INC:       dsw     1            ; Incremental change in function
    002A                           62           IN_DIF:          dsw     1            ; Upper Input - Lower Input
      002A                         63           IN_DIFB          equ     IN_DIF  :byte
    002C                           64           OUT:             dsw     1
    002E                           65           RESULT:          dsw     1
    0030                           66           OUT_DIF:         dsl     1            ; Delta Out
                                   67
                                   68
    2080                           69   CSEG at 2080H
                                   70
    2080 A1000118                  71           LD      SP, #100H       ; Initialize SP to top of reg  file
                                   72
    2084 B0241C                    73   look:   LDB     AL, IN_VAL      ; Load temp with Actual Value
    2087 18031C                    74           SHRB    AL, #3          ; Divide the byte by 8
    208A 71FE1C                    75           ANDB    AL, #11111110B  ; Insure AL is a word address
                                   76                                   ;  This effectively divides AL by 2
                                   77                                   ;  so AL = IN_VAL/16
    208D AC1C1C                    78           LDBZE   AX, AL          ; Load byte AL to word AX
                                   79
    2090 A31D002126                80           LD      TABLE_LOW, VAL_TABLE[AX] ; TABLE_LOW is loaded with the value
                                   81                                            ;  in the value table at location AX
                                   82
    2095 A31D222128                83           LD      TABLE_INC, INC_TABLE[AX] ; TABLE_INC is loaded with the value
                                   84                                            ; in the increment table at
                                   85                                            ; location AX+2
                                   86
```

270061-66

```
209A 510F242A            87          ANDB    IN_DIFB, IN_VAL, #0FH   ; IN_DIFB=least significant 4 bits
                         88                                          ;  of IN_VAL
209E AC2A2A              89          LDBZE   IN_DIF, IN_DIFB         ; Load byte IN_DIFB to word IN_DIF
                         90
20A1 FE4C282A30          91          MUL     OUT_DIF, IN_DIF, TABLE_INC
                         92                                          ; Output_difference =
                         93                                          ;  Input_difference*Incremental_change
                         94
20A6 4426302C            95          ADD     OUT, OUT_DIF, TABLE_LOW ; Add output difference to output
                         96                                          ;  generated with truncated IN_VAL
                         97                                          ;  as input
20AA 08042C              98          SHR     OUT, #4                 ; Round to 12-bit answer
20AD A4002C              99          ADDC    OUT, zero               ; Round up if Carry = 1
                        100
20B0 C02E2C             101  no_inc: ST      OUT, RESULT             ; Store OUT to RESULT
20B3 27CF               102          BR      look                    ; Branch to "look:"
                        103
                        104
2100                    105  cseg    AT 2100H
                        106
2100                    107  val_table:
2100 0000002000034004C  108          DCW     0000H, 2000H, 3400H, 4C00H  ; A random function
2108 005D006A00720078   109          DCW     5D00H, 6A00H, 7200H, 7800H
2110 007B007D0076006D   110          DCW     7B00H, 7D00H, 7600H, 6D00H
2118 005D004B00340022   111          DCW     5D00H, 4B00H, 3400H, 2200H
2120 0010               112          DCW     1000H
2122                    113  inc_table:
2122 0002400180011001   114          DCW      0200H,  0140H,  0180H,  0110H   ; Table of incremental
212A D000800060003000   115          DCW      00D0H,  0080H,  0060H,  0030H   ; differences
2132 200090FF70FF00FF   116          DCW     00020H, 0FF90H, 0FF70H, 0FF00H
213A E0FE90FEE0FEE0FE   117          DCW     0FEE0H, 0FE90H, 0FEE0H, 0FEE0H
                        118
2142                    119  END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

270061-67

```
SERIES-III PL/M-96 V1.0 COMPILATION OF MODULE PLMEX
OBJECT MODULE PLACED IN :F3:PLMEX1.OBJ
COMPILER INVOKED BY:  PLM96.86 :F3:PLMEX1.P96 CODE


              $TITLE('PLMEX1:  PLM-96 Example Code for Table Lookup')

              /* PLM-96 CODE FOR TABLE LOOK-UP AND INTERPOLATION */

   1          PLMEX:    DO;

   2    1     DECLARE IN_VAL           WORD        PUBLIC;
   3    1     DECLARE TABLE_LOW        INTEGER     PUBLIC;
   4    1     DECLARE TABLE_HIGH       INTEGER     PUBLIC;
   5    1     DECLARE TABLE_DIF        INTEGER     PUBLIC;
   6    1     DECLARE OUT              INTEGER     PUBLIC;
   7    1     DECLARE RESULT           INTEGER     PUBLIC;
   8    1     DECLARE OUT_DIF          LONGINT     PUBLIC;
   9    1     DECLARE TEMP             WORD        PUBLIC;

  10    1     DECLARE TABLE(17)        INTEGER DATA (
                        0000H, 2000H, 3400H, 4C00H,       /* A random function */
                        5D00H, 6A00H, 7200H, 7800H,
                        7B00H, 7D00H, 7600H, 6D00H,
                        5D00H, 4B00H, 3400H, 2200H,
                        1000H);

  11    1     DMPY:     PROCEDURE (A,B) LONGINT EXTERNAL;
  12    2               DECLARE (A,B) INTEGER;
  13    2     END DMPY;

  14    1     LOOP:
                  TEMP=SHR(IN_VAL,4);      /* TEMP is the most significant 4 bits of IN_VAL */

  15    1           TABLE_LOW=TABLE(TEMP);      /* If "TEMP" was replaced by "SHR(IN_VAL,4)"  */
  16    1           TABLE_HIGH=TABLE(TEMP+1);   /* The code would work but the 8096 would     */
                                                  /* do two shifts                              */

  17    1           TABLE_DIF=TABLE_HIGH-TABLE_LOW;

  18    1           OUT_DIF=DMPY(TABLE_DIF,SIGNED(IN_VAL AND 0FH)) /16;

  19    1           OUT=SAR((TABLE_LOW+OUT_DIF),4); /* SAR performs an arithmetic right shift,
                                                       in this case 4 places are shifted     */
```

270061-68

```
20   1          IF CARRY=0 THEN RESULT=OUT;  /* Using the hardware flags must be done   */
22   1            ELSE  RESULT=OUT+1;        /* with care to ensure the flag is tested  */
                                              /* in the desired instruction sequence     */
23   1       GOTO LOOP;

            /* END OF PLM-96 CODE  */

24   1       END;
```

270061-69

```
PL/M-96 COMPILER     PLMEX1:  PLM-96 Example Code for Table Lookup
                     ASSEMBLY LISTING OF OBJECT CODE


                                          ;    STATEMENT     14
         0022                          PLMEX:
         0022  A1000018          R            LD     SP, #STACK
         0026                          LOOP:
         0026  A00010            R            LD     TEMP, IN_VAL
         0029  080410            R            SHR    TEMP, #4H
                                      ;    STATEMENT     15
         002C  4410101C          R            ADD    TMP0, TEMP, TEMP
         0030  A31D000002        R            LD     TABLE_LOW, TABLE[TMP0]
                                      ;    STATEMENT     16
         0035  A31D020004        R            LD     TABLE_HIGH, TABLE+2H[TMP0]
                                      ;    STATEMENT     17
         003A  48020406          R            SUB    TABLE_DIF, TABLE_HIGH, TABLE_LOW
                                      ;    STATEMENT     18
         003E  C806              R            PUSH   TABLE_DIF
         0040  410F00001C        R            AND    TMP0, IN_VAL, #0FH
         0045  C81C                           PUSH   TMP0
         0047  EF0000            E            CALL   DMPY
         004A  0E041C                         SHRAL  TMP0, #4H
         004D  A01E0E            R            LD     OUT_DIF+2H, TMP2
         0050  A01C0C            R            LD     OUT_DIF, TMP0
                                      ;    STATEMENT     19
         0053  A00220            R            LD     TMP4, TABLE_LOW
         0056  0620                           EXT    TMP4
         0058  641C20                         ADD    TMP4, TMP0
         005B  A41E22                         ADDC   TMP6, TMP2
         005E  0E0420                         SHRAL  TMP4, #4H
         0061  A02008            R            LD     OUT, TMP4
                                      ;    STATEMENT     20
         0064  B1FF1C                         LDB    TMP0, #0FFH
         0067  DB02                           BC     @0003
         0069  111C                           CLRB   TMP0
         006B                          @0003:
```

270061-70

```
0068  981C00                        CMPB  R0,TMP0
006E  D705                          BNE   @0001
                                    ;   STATEMENT     21
0070  A0200A            R           LD    RESULT,TMP4
0073  2005                          BR    @0002
                                    ;   STATEMENT     22
0075                        @0001:
0075  A0080A            R           LD    RESULT,OUT
0078  070A              R           INC   RESULT
                                    ;   STATEMENT     23
007A                        @0002:
007A  27AA                          BR    LOOP
                                    ;   STATEMENT     24
                                    END


MODULE INFORMATION:

     CODE AREA SIZE              = 005AH     90D
     CONSTANT AREA SIZE          = 0022H     34D
     DATA AREA SIZE              = 0000H      0D
     STATIC REGS AREA SIZE       = 0012H     18D


PL/M-96 COMPILER     PLMEX1   PLM-96 Example Code for Table Lookup
                     ASSEMBLY LISTING OF OBJECT CODE


     OVERLAYABLE REGS AREA SIZE = 0000H      0D
     MAXIMUM STACK SIZE         = 0006H      6D
     48 LINES READ

PL/M-96 COMPILATION COMPLETE.       0 WARNINGS,     0 ERRORS
```

270061-71

A.3. PLM-96 Code with Expansion (Continued)

```
MCS-96 MACRO ASSEMBLER    MULT.APT:  16*16 multiply procedure for PLM-96

SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:  :F3:MULT.A96
OBJECT FILE:  :F3:MULT.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT                  LINE        SOURCE STATEMENT
                                    1   $TITLE('MULT.APT:  16*16 multiply procedure for PLM-96')
                                    2
                                    3
     0018                           4           SP      EQU     18H:word
                                    5
     0000                           6   rseg
                                    7           EXTRN   PLMREG  :long
                                    8
     0000                           9   cseg
                                   10
                                   11           PUBLIC  DMPY        ; Multiply two integers and return a
                                   12                               ; longint result in AX, DX registers
                                   13
     0000 CC04             E     14   DMPY:   POP     PLMREG+4            ; Load return address
     0002 CC00             E     15           POP     PLMREG              ; Load one operand
     0004 FE6E1900         E     16           MUL     PLMREG,[SP]+    ; Load second operand and increment SP
                                   17
     0008 E304             E     18           BR      [PLMREG+4]      ; Return to PLM code.
     000A                        19   END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

270061-72

```
SERIES-III MCS-96 RELOCATOR AND LINKER, V2.0
Copyright 1983 Intel Corporation

INPUT FILES:  :F3:PLMEX1.OBJ, :F3:MULT.OBJ, PLM96.LIB
OUTPUT FILE:  :F3:PLMOUT.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:
   ROM(2080H-3FFFH)

INPUT MODULES INCLUDED:
   :F3:PLMEX1.OBJ(PLMEX)   12/25/84
   :F3:MULT.OBJ(MULT)   12/25/84
   PLM96.LIB(PLMREG)   11/02/83

SEGMENT MAP FOR :F3:PLMOUT.OBJ(PLMEX):

             TYPE     BASE      LENGTH    ALIGNMENT     MODULE NAME
             ----     ----      ------    ---------     -----------

**RESERVED*           0000H     001AH
*** GAP ***           001AH     0002H
             REG      001CH     0008H     ABSOLUTE      PLMREG
             REG      0024H     0012H     WORD          PLMEX
             STACK    0036H     0006H     WORD
*** GAP ***           003CH     2044H
             CODE     2080H     0003H     ABSOLUTE      PLMEX
*** GAP ***           2083H     0001H
             CODE     2084H     007CH     WORD          PLMEX
             CODE     2100H     000AH     BYTE          MULT
*** GAP ***           210AH     DEF6H
```

270061-73

A.3. PLM-96 Code with Expansion (Continued)

```
SYMBOL TABLE FOR :F3:PLMOUT.OBJ(PLMEX).

ATTRIBUTES              VALUE     NAME
----------              -----     ----

                                  PUBLICS:
REG     WORD            0024H       IN_VAL
REG     INTEGER         0026H       TABLE_LOW
REG     INTEGER         0028H       TABLE_HIGH
REG     INTEGER         002AH       TABLE_DIF
REG     INTEGER         002CH       OUT
REG     INTEGER         002EH       RESULT
REG     LONGINT         0030H       OUT_DIF
REG     WORD            0034H       TEMP
CODE    ENTRY           2100H       DMPY
REG     LONG            001CH       PLMREG
NULL    NULL            003CH       MEMORY
NULL    NULL            1FC4H       ?MEMORY_SIZE

                                  MODULE:  PLMEX

                                  MODULE:  MULT

                                  MODULE:  PLMREG

RL96 COMPLETED,   0 WARNING(S),   0 ERROR(S)
```

270061-74

A.3. PLM-96 Code with Expansion (Continued)

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:  F3:PULSE.A96
OBJECT FILE:  F3:PULSE.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT                  LINE       SOURCE STATEMENT
                                    1   $TITLE('PULSE.A96: Measuring pulses using the HSI unit')
                                    2
                                    3   $INCLUDE(DEMO96.INC)
                                =1  4   $nolist  ;  Turn listing off for include file
                                =1  52          ;  End of include file
                                    53
    0028                            54  rseg    at  28H
                                    55
    0028                            56          HIGH_TIME:      dsw     1
    002A                            57          LOW_TIME:       dsw     1
    002C                            58          PERIOD:         dsw     1
    002E                            59          HI_EDGE:        dsw     1
    0030                            60          LO_EDGE:        dsw     1
                                    61
                                    62
                                    63
    2080                            64  cseg    at  2080H
                                    65
                                    66
    2080 A1000118                   67          LD      SP, #100H
    2084 B10115                     68          LDB     IOC0, #00000001B        ; Enable HSI 0
    2087 B10F03                     69          LDB     HSI_MODE, #00001111B    ; HSI 0 look for either edge
                                    70
    208A 442A282C                   71  wait:   ADD     PERIOD, HIGH_TIME, LOW_TIME
    208E 3E1603                     72          JBS     IOS1, 6, contin         ; If FIFO is full
    2091 3716F6                     73          JBC     IOS1, 7, wait   ; Wait while no pulse is entered
                                    74
    2094 B0061C                     75  contin: LDB     AL, HSI_STATUS          ; Load status; Note that reading
                                    76                                          ;   HSI_TIME clears HSI_STATUS
                                    77
    2097 A00420                     78          LD      BX, HSI_TIME            ; Load the HSI_TIME
                                    79
    209A 391C09                     80          JBS     AL, 1, hsi_hi           ; Jump if HSI.0 is high
                                    81
    209D C03020                     82  hsi_lo: ST      BX, LO_EDGE
    20A0 482E3028                   83          SUB     HIGH_TIME, LO_EDGE, HI_EDGE
    20A4 27E4                       84          BR      wait
                                    85
                                    86
    20A6 C02E20                     87  hsi_hi: ST      BX, HI_EDGE
```

270061-75

```
20A9 48302E2A          88          SUB     LOW_TIME, HI_EDGE, LO_EDGE
20AD 27DB              89          BR      wait
                       90
20AF                   91          END

ASSEMBLY COMPLETED,  NO ERROR(S) FOUND.
```

270061-76

A.4. Pulse Measurement (Continued)

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:   F3:ENHSI.A96
OBJECT FILE:   F3:ENHSI.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT                  LINE       SOURCE STATEMENT
                                    1   $TITLE ('ENHSI.A96  ENHANCED HSI PULSE ROUTINE')
                                    2
                                    3   $INCLUDE(DEMO96.INC)
                                =1  4   $nolist  ,  Turn listing off for include file
                                =1  52          ;  End of include file
                                    53
    0028                            54  RSEG AT 28H
                                    55
    0028                            56          TIME:           DSW 1
    002A                            57          LAST_RISE:      DSW 1
    002C                            58          LAST_FALL:      DSW 1
    002E                            59          HSI_SO:         DSB 1
    002F                            60          IOS1_BAK:       DSB 1
    0030                            61          PERIOD:         DSW 1
    0032                            62          LOW_TIME:       DSW 1
    0034                            63          HIGH_TIME:      DSW 1
    0036                            64          COUNT:          DSW 1
                                    65
    2080                            66  cseg    at      2080H
                                    67
    2080 A1000118                   68  init:   LD      SP,#100H
                                    69
    2084 B12516                     70          LDB     IOC1,#00100101B ; Disable HSO.4,HSO.5, HSI_INT=first,
                                    71                                  ; Enable PWM,TXD,TIMER1_OVRFLOW_INT
                                    72
    2087 B19903                     73          LDB     HSI_MODE,#10011001B     ; set hsi.1 -, hsi.0 +
    208A B10715                     74          LDB     IOC0,#00000111B         ; Enable  hsi 0,1
                                    75                                          ; T2 CLOCK=T2CLK,  T2RST=T2RST
                                    76                                          ; Clear timer2
                                    77
                                    78
    208D 717F2F                     79  wait:   ANDB    IOS1_BAK,#01111111B     ; Clear IOS1_BAK.7
    2090 90162F                     80          ORB     IOS1_BAK,IOS1           ; Store into temp to avoid clearing
                                    81                                          ; other flags which may be needed
    2093 372FF7                     82          JBC     IOS1_BAK,7,wait         ; If hsi is not triggered then
                                    83                                          ; jump to wait
                                    84
    2096 5155062E                   85          ANDB    HSI_SO,HSI_STATUS,#01010101B
    209A A00428                     86          LD      TIME, HSI_TIME
                                    87
```

270061-77

```
209D 382E05                88            JBS     HSI_SO,0,a_rise
20A0 3A2E0F                89            JBS     HSI_SO,2,a_fall
20A3 201A                  90            BR      no_cnt
                           91
20A5 482C2832              92    a_rise: SUB     LOW_TIME, TIME, LAST_FALL
20A9 482A2830              93            SUB     PERIOD, TIME,LAST_RISE
20AD A0282A                94            LD      LAST_RISE, TIME
20B0 200B                  95            BR      increment
                           96
20B2 482A2834              97    a_fall: SUB     HIGH_TIME, TIME, LAST_RISE
20B6 482C2830              98            SUB     PERIOD, TIME,LAST_FALL
20BA A0282C                99            LD      LAST_FALL, TIME
                          100
20BD                      101    increment:
20BD 0736                 102            INC     COUNT
20BF 27CC                 103    no_cnt: BR      wait
                          104
20C1                      105            END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

270061-78

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:  :F3:HSODRV.A96
OBJECT FILE:  :F3:HSODRV.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT                  LINE       SOURCE STATEMENT
                                    1   $TITLE('HSODRV.A96: Driver module for HSO PWM program')
                                    2
                                    3   HSODRV          MODULE  MAIN, STACKSIZE(8)
                                    4
                                    5
                                    6           PUBLIC  HSO_ON_0 , HSO_OFF_0
                                    7           PUBLIC  HSO_ON_1 , HSO_OFF_1
                                    8           PUBLIC  HSO_TIME , HSO_COMMAND
                                    9           PUBLIC  SP , TIMER1 , IOS0
                                   10
                                   11   $INCLUDE(DEMO96.INC)
                              =1   12   $nolist  ;  Turn listing off for include file
                              =1   60             ;  End of include file
                                   61
    0028                           62   rseg at 28H
                                   63
                                   64           EXTRN   OLD_STAT        :byte
                                   65
    0028                           66           HSO_ON_0:       dsw     1
    002A                           67           HSO_OFF_0:      dsw     1
    002C                           68           HSO_ON_1:       dsw     1
    002E                           69           HSO_OFF_1:      dsw     1
    0030                           70           count:          dsb     1
                                   71
    2080                           72   cseg  at 2080H
                                   73
                                   74           EXTRN   wait    :entry
                                   75
    2080 FA                        76   strt:   DI
    2081 A1000118                  77           LD      SP, #100H
    2085 510F1500             E    78           ANDB    OLD_STAT, IOS0, #0FH
    2089 950F00               E    79           XORB    OLD_STAT, #0FH
                                   80
    208C                           81   initial:
    208C A1000122                  82           LD      CX, #0100H
                                   83
    2090 A100101C                  84   loop:   LD      AX, #1000H
    2094 48221C20                  85           SUB     BX, AX, CX
    2098 A0221C                    86           LD      AX, CX
                                   87
```

270061-79

```
209B C0281C                88          ST      AX, HSO_ON_0
209E C02A20                89          ST      BX, HSO_OFF_0
                           90
20A1 08011C                91          SHR     AX,#1
20A4 080120                92          SHR     BX,#1
20A7 C02C1C                93          ST      AX, HSO_ON_1
20AA C02E20                94          ST      BX, HSO_OFF_1
                           95
20AD EF0000           E    96          CALL    wait
                           97
20B0 0722                  98          INC     CX
20B2 89000F22              99          CMP     CX, #00F00H
20B6 D7D8                 100          BNE     loop
                          101
20B8 27D2                 102          BR      initial
                          103
20BA                      104          END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND
```

270061-80

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:  :F3:HSOMOD.A96
OBJECT FILE:  :F3:HSOMOD.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT            LINE        SOURCE STATEMENT
                              1   $TITLE('HSOMOD.A96:  8096 PWM PROGRAM MODIFIED FOR DRIVER')
                              2   $PAGEWIDTH(130)
                              3
                              4   ; This program will provide 3 PWM outputs on HSO pins 0-2
                              5   ; The input parameters passed to the program are:
                              6   ;
                              7   ;                 HSO_ON_N     HSO on time for pin N
                              8   ;                 HSO_OFF_N    HSO off time for pin N
                              9
                             10   ;       Where:   Times are in timer1 cycles
                             11   ;                N takes values from 0 to 3
                             12
                             13   ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                             14
                             15
                             16   ;     NOTE: Use this file to replace the declaration section of
                             17   ;           the HSO PWM program from "$INCLUDE(DEMO96.INC)" through
                             18   ;           the line prior to the label "wait".  Also change the last
                             19   ;           branch in the program to a "RET".
                             20
    0000                     21   RSEG
                             22
    0000                     23           D_STAT:          DSB     1
                             24           extrn   HSO_ON_0  :word , HSO_OFF_0  :word
                             25           extrn   HSO_ON_1  :word , HSO_OFF_1  :word
                             26           extrn   HSO_TIME  :word , HSO_COMMAND :byte
                             27           extrn   TIMER1    :word , IOSO        :byte
                             28           extrn   SP        :word
                             29
                             30           public  OLD_STAT
    0001                     31           OLD_STAT:        dsb     1
    0002                     32           NEW_STAT:        dsb     1
                             33
                             34
    0000                     35   cseg
                             36           PUBLIC  wait
                             37
    0000 3E00FD       E      38   wait:   JBS     IOSO, 6, wait          ; Loop until HSO holding register
    0003 FD                  39           NOP                            ; is empty
                             40
                             41                   ; For opperation with interrupts 'store_stat:' would be the
                             42                   ; entry point of the routine.
                             43                   ; Note that a DI or PUSHF might have to be added.
                             44
```

270061-81

A.6. PWM Using the HSO (Continued)

```
0004                            45  store_stat:
0004 510F0002           E       46          ANDB NEW_STAT, IOSO, #0FH       ; Store new status of HSO
0008 980201             R       47          CMPB OLD_STAT, NEW_STAT
000B DFF3                       48          JE   wait
000D 940201             R       49          XORB OLD_STAT, NEW_STAT
                                50
                                51
0010                            52  check_0:
0010 300113             R       53          JBC  OLD_STAT, 0, check_1       ; Jump if OLD_STAT(0)=NEW_STAT(0)
0013 380209             R       54          JBS  NEW_STAT, 0, set_off_0
                                55
0016                            56  set_on_0:
0016 B13000             E       57          LDB  HSO_COMMAND, #00110000B    ; Set HSO for timer1, set pin 0
0019 44000000           E       58          ADD  HSO_TIME, TIMER1, HSO_OFF_0 ; Time to set pin = Timer1 value
001D 2007                       59          BR   check_1                    ;  + Time for pin to be low
                                60
001F                            61  set_off_0:
001F B11000             E       62          LDB  HSO_COMMAND, #00010000B    ; Set HSO for timer1, clear pin 0
0022 44000000           E       63          ADD  HSO_TIME, TIMER1, HSO_ON_0 ; Time to clear pin = Timer1 value
                                64                                          ;  + Time for pin to be high
0026                            65  check_1:
0026 310113             R       66          JBC  OLD_STAT, 1, check_done    ; Jump if OLD_STAT(1)=NEW_STAT(1)
0029 390209             R       67          JBS  NEW_STAT, 1, set_off_1
                                68
002C                            69  set_on_1:
002C B13100             E       70          LDB  HSO_COMMAND, #00110001B    ; Set HSO for timer1, set pin 1
002F 44000000           E       71          ADD  HSO_TIME, TIMER1, HSO_OFF_1 ; Time to set pin = Timer1 value
0033 2007                       72          BR   check_done
                                73
0035                            74  set_off_1:
0035 B11100             E       75          LDB  HSO_COMMAND, #00010001B    ; Set HSO for timer1, clear pin 1
0038 44000000           E       76          ADD  HSO_TIME, TIMER1, HSO_ON_1 ; Time to clear pin = Timer1 value
                                77                                          ;  + Time for pin to be high
003C                            78  check_done:
003C B00201             R       79          LDB  OLD_STAT, NEW_STAT         ; Store current status and
                                80                                          ; wait for interrupt flag
                                81
003F F0                         82          RET
                                83              use "BR  wait" if this routine is used with the driver
                                84
0040                            85          END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

270061-82

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:   F3_SP.A96
OBJECT FILE:   F3_SP.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT                  LINE        SOURCE STATEMENT
                                    1
                                    2   $TITLE('SP.A96:  SERIAL PORT DEMO PROGRAM')
                                    3
                                    4   $INCLUDE(DEMO96.INC)
                               =1   5   $nolist  ;  Turn listing off for include file
                               =1  53            ;  End of include file
                                   54
    0028                           55   rseg     at 28H
                                   56
    0028                           57            CHR:     dsb      1
    0029                           58            SPTEMP:  dsb      1
    002A                           59            TEMP0:   dsb      1
    002B                           60            TEMP1:   dsb      1
    002C                           61            RCV_FLAG:        dsb      1
                                   62
    200C                           63   cseg     at 200CH
                                   64
    200C 9C20                      65            DCW      ser_port_int
                                   66
    2080                           67   cseg     at 2080H
                                   68
    2080 A1000118                  69            LD       SP, #100H
                                   70
    2084 B12016                    71            LDB      IOC1, #00100000B                ; Set P2.0 to TXD
                                   72
                                   73                     ; Baud rate = input frequency / (64*baud_val)
                                   74                     ; baud_val  = (input frequency/64) / baud rate
                                   75
                                   76
      0027                         77   baud_val         equ      39              ; 39 = (12,000,000/64)/4800 baud
                                   78
      0080                         79   BAUD_HIGH        equ      ((baud_val-1)/256) OR 80H       ; Set MSB to 1
      0026                         80   BAUD_LOW         equ      (baud_val-1) MOD 256
                                   81
                                   82
    2087 B1260E                    83            LDB      BAUD_REG, #BAUD_LOW
    208A B1800E                    84            LDB      BAUD_REG, #BAUD_HIGH
                                   85
```

270061-83

```
20BD B14911              86            LDB     SPCON, #01001001B       ; Enable receiver, Mode 1
                         87
                         88                    ; The serial port is now initialized
                         89
                         90
2090 C42807              91            STB     SBUF, CHR               ; Clear serial Port
2093 B1202A              92            LDB     TEMPO, #00100000B       ; Set TI-temp
                         93
2096 B14008              94            LDB     INT_MASK, #01000000B    ; Enable Serial Port Interrupt
2099 FB                  95            EI
209A 27FE                96    loop:   BR      loop            ; Wait for serial port interrupt
                         97
                         98
209C                     99    ser_port_int:
209C F2                 100            PUSHF
209D                    101    rd_again:                               ; This section of code can be replaced
209D B01129             102            LDB     SPTEMP, SPSTAT          ; with "ORB  TEMPO, SP_STAT" when the
20A0 90292A             103            ORB     TEMPO, SPTEMP           ; serial port TI and RI bugs are fixed
20A3 716029             104            ANDB    SPTEMP,#01100000B
20A6 D7F5               105            JNE     rd_again        ; Repeat until TI and RI are properly cleared
                        106
20A8                    107    get_byte:
20A8 362A09             108            JBC     TEMPO, 6, put_byte      ; If RI-temp is not set
20AB C42807             109            STB     SBUF, CHR               ; Store byte
20AE 71BF2A             110            ANDB    TEMPO, #10111111B       ; CLR RI-temp
20B1 B1FF2C             111            LDB     RCV_FLAG, #0FFH         ; Set bit-received flag
                        112
20B4                    113    put_byte:
20B4 302C18             114            JBC     RCV_FLAG, 0, continue   ; If receive flag is cleared
20B7 352A15             115            JBC     TEMPO, 5, continue      ; If TI was not set
20BA B02807             116            LDB     SBUF, CHR               ; Send byte
20BD 71DF2A             117            ANDB    TEMPO, #11011111B       ; CLR TI-temp
                        118
20C0 717F28             119            ANDB    CHR, #01111111B         ; This section of code appends
20C3 990D28             120            CMPB    CHR,#0DH                ; an LF after a CR is sent
20C6 D705               121            JNE     clr_rcv
20C8 B10A28             122            LDB     CHR, #0AH
20CB 2002               123            BR      continue
                        124
20CD                    125    clr_rcv:
20CD 112C               126            CLRB    RCV_FLAG                ; Clear bit-received flag
                        127
20CF                    128    continue:
20CF F3                 129            POPF
20D0 F0                 130            RET
                        131
20D1                    132            END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

270061-84

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:  :F3:ATOD.A96
OBJECT FILE:  :F3:ATOD.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT                  LINE       SOURCE STATEMENT
                                    1   $TITLE('ATOD.A96:  SCANNING THE A TO D CHANNELS')
                                    2
                                    3   $INCLUDE(DEMO96.INC)
                               =1   4   $nolist  ;  Turn listing off for include file
                               =1  52            ;  End of include file
                                   53
    0028                           54   RSEG    at  28H
                                   55
      0020                         56           BL      EQU     BX:BYTE
      001E                         57           DL      EQU     DX:BYTE
                                   58
    0028                           59   RESULT_TABLE:
    0028                           60           RESULT_1:       dsw     1
    002A                           61           RESULT_2:       dsw     1
    002C                           62           RESULT_3:       dsw     1
    002E                           63           RESULT_4:       dsw     1
                                   64
                                   65
    2080                           66   cseg    at  2080H
                                   67
                                   68
    2080 A1000118                  69   start:  LD      SP, #100H       ; Set Stack Pointer
    2084 0120                      70           CLR     BX
                                   71
    2086 55082002                  72   next:   ADDB    AD_COMMAND,BL, #1000B       ; Start conversion on channel
                                   73                                               ; indicated by BL register
                                   74
    208A FD                        75           NOP             ; Wait for conversion to start
    208B FD                        76           NOP
    208C 3B02FD                    77   check:  JBS     AD_RESULT_LO, 3, check  ; Wait while A to D is busy
                                   78
    208F B0021C                    79           LDB     AL, AD_RESULT_LO        ; Load low order result
    2092 B0031D                    80           LDB     AH, AD_RESULT_HI        ; Load high order result
                                   81
    2095 5420201E                  82           ADDB    DL, BL, BL              ; DL=BL*2
    2099 AC1E1E                    83           LDBZE   DX, DL
    209C C31E281C                  84           ST      AX, RESULT_TABLE[DX]    ; Store result indexed by BL*2
                                   85
    20A0 1720                      86           INCB    BL              ; Increment BL modulo 4
```

270061-85

```
20A2 710320          87          ANDB    BL, #03H
                     88
20A5 27DF            89          BR      next
                     90
20A7                 91          END

ASSEMBLY COMPLETED,  NO ERROR(S) FOUND.
```

270061-86

A.8. A to D Converter (Continued)

APPENDIX B
HSO AND A TO D UNDER INTERRUPT CONTROL

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE: :F3:A2DHSO.A96
OBJECT FILE: :F3:A2DHSO.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: NOSB

ERR LOC  OBJECT          SOURCE STATEMENT
                 $TITLE ('A2DHSO.A96: GENERATING PWM OUTPUTS FROM A TO D INPUTS')

                 ; This program will provide 3 PWM outputs on HSO pins 0-2
                 ; and one on the PWM.
                 ;
                 ; The PWM values are determined by the input to the A/D converter.
                 ;
                 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                 $INCLUDE(DEMO96.INC)
            =1   $nolist  ;  Turn listing off for include file
            =1            ;  End of include file

    0028         RSEG AT 28H

      001E               DL        EQU      DX:BYTE

    0028         ON_TIME:
    0028                 PWM_TIME_1:        DSW      1
    002A                 HSO_ON_0:          DSW      1
    002C                 HSO_ON_1:          DSW      1
    002E                 HSO_ON_2:          DSW      1

    0030         RESULT_TABLE:
    0030                 RESULT_0:          DSW      1
    0032                 RESULT_1:          DSW      1
    0034                 RESULT_2:          DSW      1
    0036                 RESULT_3:          DSW      1

    0038                 NXT_ON_T:          DSW      1
    003A                 NXT_OFF_0:         DSW      1
    003C                 NXT_OFF_1:         DSW      1
    003E                 NXT_OFF_2:         DSW      1
    0040                 COUNT:             DSL      1
    0044                 AD_NUM:            DSW      1          Channel being converted
    0046                 TMP:               DSW      1
    0048                 HSO_PER:           DSW      1
    004A                 LAST_LOAD:         DSB      1
```

270061-87

6

```
2000                        87  cseg    AT 2000H
                            88
2000 8020                   89          DCW     start           ; Timer_ovf_int
2002 1D21                   90          DCW     Atod_done_int
2004 8020                   91          DCW     start           ; HSI_data_int
2006 CC20                   92          DCW     HSO_exec_int
                            93
                            94  $EJECT
                            95
2080                        96  cseg    AT 2080H
                            97
2080 A1000118               98  start:  LD      SP, #100H       ; Set Stack Pointer
2084 011C                   99          CLR     AX
2086 051C                  100  wait:   DEC     AX              ; wait approx. 0.2 seconds for
2088 D7FC                  101          JNE     wait            ; SBE to finish communications
                           102
208A 1144                  103          CLRB    AD_NUM
                           104
208C A1800028              105          LD      PWM_TIME_1, #080H
2090 A1000148              106          LD      HSO_PER, #100H
2094 A140002A              107          LD      HSO_ON_0, #040H
2098 A180002C              108          LD      HSO_ON_1, #080H
209C A1C0002E              109          LD      HSO_ON_2, #0C0H
                           110
20A0 4500010A38            111          ADD     NXT_ON_T,  Timer1, #100H
                           112
20A5 B13606                113          LDB     HSO_COMMAND, #00110110B     ; Set HSO for timer1, set pin 0,1
20A8 A03804                114          LD      HSO_TIME, NXT_ON_T          ; with interrupt
20AB FD                    115          NOP
20AC FD                    116          NOP
20AD B12206                117          LDB     HSO_COMMAND, #00100010B     ; Set HSO for timer1, set pin 2
20B0 643804                118          ADD     HSO_TIME, NXT_ON_T          ; without interrupt
                           119
20B3 91074A                120          ORB     LAST_LOAD, #00000111B   ; Last loaded value was set all pins
20B6 B10A08                121          LDB     INT_MASK, #00001010B    ; Enable HSO and A/D interrupts
20B9 B10A09                122          LDB     INT_PENDING, #00001010B ; Fake an A/D and HSO interrupt
20BC FB                    123          EI
                           124
20BD 91010F                125  loop:   ORB     Port1, #00000001B       ; set P1.0
20C0 65010040              126          ADD     COUNT, #01
20C4 A40042                127          ADDC    COUNT+2, zero
20C7 71FE0F                128          ANDB    Port1, #11111110B       ; clear P1.0
20CA 27F1                  129          BR      loop
                           130
                           131  $EJECT
```

270061-88

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;        HSO  EXECUTED  INTERRUPT        ;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

20CC                 HSO_exec_int:
20CC F2                       PUSHF
20CD 91020F                   ORB     Port1, #00000010B       ; Set p1.1

20D0 48380A46                 SUB     TMP,TIMER1, NXT_ON_T
20D4 880046                   CMP     TMP,ZERO
20D7 DE19                     JLT     set_off_times

20D9                 set_on_times:
20D9 644838                   ADD     NXT_ON_T, HSO_PER
20DC B13606                   LDB     HSO_COMMAND, #00110110B   ; Set HSO for timer1, set pin 0,1
20DF A03804                   LD      HSO_TIME, NXT_ON_T
20E2 FD                       NOP
20E3 FD                       NOP
20E4 B12206                   LDB     HSO_COMMAND, #00100010B   ; Set HSO for timer1, set pin 2
20E7 A03804                   LD      HSO_TIME, NXT_ON_T

20EA 91074A                   ORB     LAST_LOAD, #00000111B     ; Last loaded value was all ones

20ED B02817                   LDB     PWM_CONTROL, PWM_TIME_1      ; Now is as good a time as any
                                                                   ; to update the PWM reg
20F0 2026                     BR      check_done


20F2                 set_off_times:
20F2 304A23                   JBC     LAST_LOAD, 0, check_done

20F5 442A383A                 ADD     NXT_OFF_0, NXT_ON_T, HSO_ON_0
20F9 B11006                   LDB     HSO_COMMAND, #00010000B      ; Set HSO for timer1, clear pin 0
20FC A03A04                   LD      HSO_TIME, NXT_OFF_0

20FF FD                       NOP
2100 442C383C                 ADD     NXT_OFF_1, NXT_ON_T, HSO_ON_1
2104 B11106                   LDB     HSO_COMMAND, #00010001B      ; Set HSO for timer1, clear pin 1
2107 A03C04                   LD      HSO_TIME, NXT_OFF_1

210A FD                       NOP
210B 442E383E                 ADD     NXT_OFF_2, NXT_ON_T, HSO_ON_2
210F B11206                   LDB     HSO_COMMAND, #00010010B       ; Set HSO for timer1, clear pin 2
2112 A03E04                   LD      HSO_TIME, NXT_OFF_2

2115 71F84A                   ANDB    LAST_LOAD, #11111000B    ; Last loaded value was all 0s

2118                 check_done:
2118 71FD0F                   ANDB    Port1, #11111101B       ; Clear P1.1
```

270061-89

6

```
211B F3                    POPF
211C F0                    RET

                     $EJECT

                     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                     ;;;;;;;;;;;;;;;;;        A TO D  COMPLETE  INTERRUPT        ;;;;;;;;;;;;;;;;;;;;
                     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

211D                 ATOD_done_int:
211D F2                    PUSHF
211E 91040F                ORB     Port1, #00000100B          ; Set P1.2

2121 51C0021C              ANDB    AL, AD_RESULT_LO,#11000000B     ; Load low order result
2125 B0031D                LDB     AH, AD_RESULT_HI                ; Load high order result
2128 5444441E              ADDB    DL, AD_NUM, AD_NUM              ; DL= AD_NUM *2
212C AC1E1E                LDBZE   DX, DL
212F C31E301C              ST      AX, RESULT_TABLE[DX]       ; Store result indexed by DX

2133 99401C                CMPB    AL, #01000000B
2136 D107                  JNH     no_rnd                     ; Round up if needed
2138 99FF1D                CMPB    AH,#0FFH          ; Don't increment if AH=0FFH
213B DF02                  JE      no_rnd
213D 171D                  INCB    AH

213F B01D1C          no_rnd: LDB   AL, AH            ; Align byte and change to word
2142 111D                  CLRB    AH
2144 C31E281C              ST      AX, ON_TIME[DX]

2148 1744                  INCB    AD_NUM
214A 710344                ANDB    AD_NUM, #03H               ; Keep AD_NUM between 0 and 3

214D 55084402        next:  ADDB   AD_COMMAND, AD_NUM, #1000B      ; Start conversion on channel
                                                               ; indicated by AD_NUM register
2151 71FB0F                ANDB    Port1, #11111011B          ; Clear P1.2
2154 F3                    POPF
2155 F0                    RET


2156                       END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

270061-90

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:  :F3:SWPORT.A96
OBJECT FILE:  :F3:SWPORT.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT                  LINE        SOURCE STATEMENT
                                    1   $TITLE('SWPORT.A96 : SOFTWARE IMPLEMENTED ASYNCHRONOUS SERIAL PORT')
                                    2
                                    3   ; This module provides a software implemented asynchronous serial port
                                    4   ; for the 8096.  HSO.5 is used for transmit data.  HSI.2 is used for
                                    5   ; receive data. Note: the choice of HSO.5 and HSI.2 is arbitrary).
                                    6
                                    7   $INCLUDE(DEMO96.INC)
                               =1   8   $nolist  ;  Turn listing off for include file
                               =1  56            ;  End of include file.
                                   57
                                   58   ;       VARIABLES NEEDED BY THE SOFTWARE SERIAL PORT
                                   59   ;       ===========================================
                                   60   ;
    0000                           61            rseg
                                   62
    0000                           63   ios1_save:       dsb 1     ; Used to save contents of ios1
    0001                           64   rcve_state:      dsb 1
      0001                         65     rxrdy          equ 1     ; indicates receive done
      0002                         66     rxoverrun      equ 2     ; indicates receive overflow
      0004                         67     rip            equ 4     ; receive in progress flag
    0002                           68   rcve_buf:        dsb 1     ; used to double buffer receive data
    0003                           69   rcve_reg:        dsb 1     ; used to deserialize receive
    0004                           70   sample_time:     dsw 1     ; records last receive sample time
                                   71
    0006                           72   serial_out:      dsw 1     ; Holds the output character+framing (start and
                                   73                             ;   stop bits) for transmit process.
    0008                           74   baud_count:      dsw 1     ; Holds the period of one bit in units
                                   75                             ;   of T1 ticks.
    000A                           76   txd_time:        dsw 1     ; Transition time of last Txd bit that was
                                   77                             ;   sent to the CAM
    000C                           78   char:            dsb 1     ; for test only
                                   79   ;
                                   80   ;       COMMANDS ISSUED TO THE HSO UNIT
                                   81   ;       ==============================
                                   82   ;
      0035                         83   mark_command     equ     0110101b        ; timer1,set,interrupt on 5
      0015                         84   space_command    equ     0010101b        ; timer1,clr,interrupt on 5
      0018                         85   sample_command   equ     0011000b        ; software timer 0
                                   86
                                   87   $eject
```

270061-91

```
2080                            88          cseg at 2080h
                                89  ;
2080                            90  reset_loc:
                                91  ; The 8096 starts executing here on reset, the program will initialize the
                                92  ; the software serial port and run a simple test to excercize it.
                                93  ;
2080 FA                         94          di
2081 A1F00018                   95          ld      sp,#0f0h
2085 C9C012                     96          push    #4800
2088 EF0000             R       97          call    setup_serial_port
208B B16C08                     98          ldb     int_mask,#01101100b     ; serial, swt,hso,hsi
208E FB                         99          ei
                               100
                               101  ;
208F                           102  test1:
                               103  ; A simple test of the serial port routines.
                               104  ; While no characters are received an incrementing pattern is sent to the
                               105  ; serial output.  When a character is received the incrementing pattern
                               106  ; "jumps" to the character receved and proceeds from there.
                               107  ;
  000D                         108          CR      equ     0DH                     ; Carriage return
208F B10D0C             R      109          ldb     char,#CR
2092                           110  test1loop:
2092 AC0C1C             R      111          ldbze   ax,char
2095 C81C                      112          push    ax
2097 EF3000             R      113          call    char_out
                               114
209A 990D0C             R      115          cmpb    char,#CR                ; Pause on Carriage return
209D D706                      116          bne     nopause
209F 011C                      117          clr     ax
20A1                           118  pause:
20A1 071C                      119          inc     ax
20A3 D7FC                      120          bne     pause
20A5                           121  nopause:
                               122
20A5 170C               R      123          incb    char
20A7                           124  test2:
20A7 EF4400             R      125          call    csts                    ; char ready?
20AA 98001C                    126          cmpb    al,0
20AD DFE3                      127          be      test1loop               ;   loop if not
20AF EF4C00             R      128          call    char_in
20B2 B01C0C             R      129          ldb     char,al
20B5 27DB                      130          br      test1loop
                               131  $eject
```

270061-92

```
                                132
0000                            133             cseg
                                134     ;
0000                            135     setup_serial_port:
                                136     ; Called on system reset to intiate the software serial port.
                                137     ;
0000 CC22                       138             pop     cx                      ; the return address
0002 CC20                       139             pop     bx                      ; the baud rate (in decimal)
0004 A107001E                   140             ld      dx,#0007h               ; dx:ax:=500,000 (assumes 12 Mhz crystal)
0008 A120A11C                   141             ld      ax,#0A120h
000C 8C201C                     142             divu    ax,bx                   ; calculate the baud count (500,000/baudrate)
000F C0081C             R       143             st      ax,baud_count
0012 C00600             R       144             st      0,serial_out            ; clear serial out
0015 B16016                     145             ldb     ioc1,#01100000b         ; Enable HSO.5 and Txd
0018 3E15FD                     146             bbs     ios0,6,$                ; Wait for room in the HSO CAM
                                147                                             ; and issue a MARK command.
001B 44140A0A           R       148             add     txd_time,timer1,20
001F B13506                     149             ldb     hso_command,#mark_command
0022 A00A04             R       150             ld      hso_time,txd_time
0025 1102               R       151             clrb    rcve_buf                ; clear out the receive variables
0027 1103               R       152             clrb    rcve_reg
0029 1101               R       153             clrb    rcve_state
002B EF4B00                     154             call    init_receive            ; setup to detect a start bit
002E E322                       155             br      [cx]                    ; return
                                156     $eject
                                157     ;
0030                            158     char_out:
                                159     ; Output character to the software serial port
                                160     ;
0030 CC22                       161             pop     cx                      ; the return address
0032 CC20                       162             pop     bx                      ; the character for output
0034 B10121                     163             ldb     (bx+1),#01h             ; add the start and stop bits
0037 642020                     164             add     bx,bx                   ;   to the char and leave as 16 bit
003A                            165     wait_for_xmit:
003A 880006             R       166             cmp     serial_out,0            ; wait for serial_out=0 (it will be cleared by
003D D7FB                       167             bne     wait_for_xmit           ;   the hso interrupt process)
003F C00620             R       168             st      bx,serial_out           ; put the formatted character in serial_out
0042 E322                       169             br      [cx]                    ; return to caller
                                170     ;
0044                            171     csts:
                                172     ; Returns "true" (ax<>0) if char_in has a character.
                                173     ;
0044 011C                       174             clr     ax
0046 300102             R       175             bbc     rcve_state,0,csts_exit
0049 071C                       176             inc     ax
004B                            177     csts_exit:
004B F0                         178             ret
                                179     ;
004C                            180     char_in:
```

270061-93

```
                                181   ; Get a character from the software serial port
                                182   ;
                                183                                     ; wait for character ready
004C 3001FD             R       184           bbc     rcve_state,0,char_in
004F F2                         185           pushf                     ; set up a critical region
0050 71FE01             R       186           andb    rcve_state,#not(rxrdy)
0053 AC021C             R       187           ldbze   al,rcve_buf
0056 F3                         188           popf                      ; leave the critical region
0057 F0                         189           ret
                                190   $eject
                                191   ;
0058                            192   hso_isr:
                                193   ; Fields the hso interrupts and performs the serialization of the data.
                                194   ; Note: this routine would be incorporated into the hso service strategy
                                195   ;       for an actual system.
                                196
2006                            197           cseg    at 2006h
2006 5800               R       198           dcw     hso_isr           ; Set up vector
                                199
0058                            200           cseg
0058 F2                         201           pushf
0059 64080A             R       202           add     txd_time,baud_count
005C 880006             R       203           cmp     serial_out,0      ; if character is done send a mark
005F DF0D                       204           be      send_mark
0061 080106             R       205           shr     serial_out,#1     ; else send bit 0 of serial_out and shift
0064 DB08                       206           bc      send_mark         ;   serial_out left one place.
0066                            207   send_space:
0066 B11506                     208           ldb     hso_command,#space_command
0069 A00A04             R       209           ld      hso_time,txd_time
006C 2006                       210           br      hso_isr_exit
006E                            211   send_mark:
006E B13506                     212           ldb     hso_command,#mark_command
0071 A00A04             R       213           ld      hso_time,txd_time
                                214
0074                            215   hso_isr_exit:
0074 F3                         216           popf
0075 F0                         217           ret
                                218   $eject
                                219   ;
0076                            220   init_receive:
                                221   ; Called to prepare the serial input process to find the leading edge of
                                222   ; a start bit.
                                223   ;
0076 B10015                     224           ldb     ioc0,#00000000b           ; disconnect change detector
0079 B12003                     225           ldb     hsi_mode,#00100000b       ; negative edges on HSI.2
007C                            226   flush_fifo:
007C 901600             R       227           orb     ios1_save,ios1
007F 37000B             R       228           bbc     ios1_save,7,flush_fifo_done
0082 B0061C                     229           ldb     al,hsi_status
0085 A0041C                     230           ld      ax,hsi_time               ; trash the fifo entry
```

270061-94

```
0088 717F00        R     231             andb    ios1_save,#not(80h)     ; clear bit 7.
008B 27EF                232             br      flush_fifo
008D                     233     flush_fifo_done:
008D B11015              234             ldb     ioc0,#00010000b         ; connect HSI.2 to detector
0090 F0                  235             ret
                         236
                         237
                         238     ;
0091                     239     hsi_isr:
                         240     ; Fields interrupts from the HSI unit, used to detect the leading edge
                         241     ; of the START bit
                         242     ; Note: this routine would be incorporated into the HSI strategy of an actual
                         243     ; system.
                         244     ;
2004                     245             cseg at 2004h
2004 9100          R     246             dcw     hsi_isr                 ; setup the interrupt vector
                         247
0091                     248             cseg
0091 F2                  249             pushf
0092 C81C                250             push    ax
0094 B0061C              251             ldb     al,hsi_status
0097 A00404        R     252             ld      sample_time,hsi_time
009A 341C15              253             bbc     al,4,exit_hsi
009D 3F15FD              254             bbs     ios0,7,$                ; wait for room in HSO holding reg
00A0 A00B1C        R     255             ld      ax,baud_count           ; send out sample command in 1/2
00A3 08011C              256             shr     ax,#1                   ; bit time
00A6 641C04        R     257             add     sample_time,ax
00A9 B11B06              258             ldb     hso_command,#sample_command
00AC C00404        R     259             st      sample_time,hso_time
00AF B10015              260             ldb     ioc0,#00000000b         ; disconnect hsi.2 from change detector
00B2                     261     exit_hsi:
00B2 CC1C                262             pop     ax
00B4 F3                  263             popf
00B5 F0                  264             ret
                         265     $eject
                         266     ;
00B6                     267     software_timer_isr:
                         268     ; Fields the software timer interrupt, used to deserialize the incomming data.
                         269     ; Note: this routine would be incorporated into the software timer stategy
                         270     ; in an actual system.
                         271     ;
200A                     272             cseg at 200ah
200A B600          R     273             dcw     software_timer_isr      ; setup vector
                         274
00B6                     275             cseg
00B6 F2                  276             pushf
00B7 901600        R     277             orb     ios1_save,ios1
00BA 71FE00        R     278             andb    ios1_save,#not(01h)     ; clear bit 0
00BD 51FC0100      R     279             andb    0,rcve_state,#0fch      ; All bits except rxrdy and overrun=0
00C1 D70C                280             bne     process_data
```

270061-95

```
00C3                            281   process_start_bit:
00C3 350604                     282           bbc     hsi_status,5,start_ok
00C6 2FAE                       283           call    init_receive
00C8 2032                       284           br      software_timer_exit
00CA                            285   start_ok:
00CA 910401             R       286           orb     rcve_state,#rip ; set receive in progress flag
00CD 2021                       287           br      schedule_sample
                                288
00CF                            289   process_data:
00CF 3F010E             R       290           bbs     rcve_state,7,check_stopbit
00D2 180103             R       291           shrb    rcve_reg,#1
00D5 350603                     292           bbc     hsi_status,5,datazero
00D8 918003             R       293           orb     rcve_reg,#80h   ; set the new data bit
00DB                            294   datazero:
00DB 751001             R       295           addb    rcve_state,#10h ; increment bit count
00DE 2010                       296           br      schedule_sample
                                297
00E0                            298   check_stopbit:
00E0 3506FD                     299           bbc     hsi_status,5,$  ; DEBUG ONLY
00E3 B00302             R       300           ldb     rcve_buf,rcve_reg
00E6 910101             R       301           orb     rcve_state,#rxrdy
00E9 710301             R       302           andb    rcve_state,#03h ; Clear all but ready and overrun bits
00EC 2F88                       303           call    init_receive
00EE 200C                       304           br      software_timer_exit
                                305
00F0                            306   schedule_sample:
00F0 3F15FD                     307           bbs     ios0,7,$        ; wait for holding reg empty
00F3 B11806                     308           ldb     hso_command,#sample_command
00F6 640804             R       309           add     sample_time,baud_count
00F9 C00404             R       310           st      sample_time,hso_time
                                311
00FC                            312   software_timer_exit:
00FC F3                         313           popf
00FD F0                         314           ret
                                315
                                316
00FE                            317           end

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND
```

270061-96

APPENDIX D
MOTOR CONTROL PROGRAM

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE:  :F3:MOTCON.A96
OBJECT FILE:  :F3:MOTCON.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND:  NOSB

ERR LOC  OBJECT          LINE      SOURCE STATEMENT
                            1  $TITLE ('MOTCON.A96:  Motor Control Example Program')
                            2
                            3  ;       USE WITH C-STEP or later parts
                            4
                            5  ;                                        December 20, 1984
                            6
                            7  $INCLUDE(DEMO96.INC)
                  =1        8  $nolist  ;  Turn listing off for include file
                  =1       56           ;  End of include file
                           57
                           58  ;;;;;;;;;;;     Initial Values
                           59
     001E                  60  min_hsi1_t      equ     30  ; min period for PHA edges in mode1 before mode2
                           61
     003C                  62  min_hsi_t       equ     2*min_hsi1_t
                           63                          ; min period for PHA edges in mode0 before mode1
                           64
     0069                  65  max_hsi1_t      equ     3*min_hsi1_t + min_hsi1_t/2
                           66                          ; max period for PHA edges in mode1 before mode0
                           67
                           68
     006E                  69  HSO0_dly_period equ     110     ; delay for HSO timer 0 (timed count of pulses)
                           70                          ; min period for 5 T2 clocks before mode 1
                           71
     00FA                  72  swt1_dly_period equ     250     ; delay for software timer 1
     00FA                  73  swt2_dly_period equ     250     ; delay for software timer 2
     00FF                  74  max_power       equ     0ffh
     00FF                  75  max_brake       equ     0ffh
     0080                  76  maximum_hold    equ     080H
     04B0                  77  brake_pnt       equ     1200
     0064                  78  position_pnt    equ     100
     0010                  79  velocity_pnt    equ     16
                           80
                           81
   0024                    82  RSEG at 024H
                           83
   0024                    84          tmp:            dsl 1
   0028                    85          timer_2:        dsl 1
```

270061-97

```
002C                    86          tmr2_old:       dsl 1
0030                    87          position:       dsl 1
0034                    88          des_pos:        dsl 1
0038                    89          pos_err:        dsl 1
003C                    90          delta_p:        dsl 1
0040                    91          time:           dsl 1
0044                    92          des_time:       dsl 1
0048                    93          time_err:       dsl 1
                        94
                        95  $EJECT
                        96
004C                    97          last_time_err:  dsw 1
004E                    98          last_pos_err:   dsw 1
0050                    99          pos_delta:      dsw 1
0052                   100          time_delta:     dsw 1
0054                   101          last_pos:       dsw 1
0056                   102          last1_time:     dsw 1
0058                   103          last2_time:     dsw 1
005A                   104          boost:          dsw 1
005C                   105          tmp1:           dsw 1
005E                   106          out_ptr:        dsw 1
0060                   107          offset:         dsw 1
0062                   108          nxt_pos:        dsw 1
0064                   109          rpwr:           dsw 1
0066                   110          old_t2:         dsw 1
                       111
0068                   112          direct:         dsb 1   ;  1=forward, 0=reverse
0069                   113          pwm_dir:        dsb 1
006A                   114          hsi_s0:         dsb 1
006B                   115          last_stat:      dsb 1
006C                   116          pwm_pwr:        dsb 1
006D                   117          ios1_bak:       dsb 1
006E                   118          TR_COL:         DSB 1   ; COLLECT TRACE IF TR_COL=00
006F                   119          main_dly:       dsb 1
                       120
0070                   121          max_pwr:        dsw 1
0072                   122          max_brk:        dsw 1
0074                   123          max_hold:       dsw 1
0076                   124          vel_pnt:        dsw 1
0078                   125          brk_pnt:        dsw 1
007A                   126          pos_pnt:        dsw 1
007C                   127          HS00_dly:       dsw 1
007E                   128          swt1_dly:       dsw 1
0080                   129          swt2_dly:       dsw 1
0082                   130          min_hsi:        dsw 1
0084                   131          min_hsi1:       dsw 1
0086                   132          max_hsi1:       dsw 1
                       133
                       134
0100                   135  dseg at 100H
```

270061-98

```
                        136
0100                    137 mode_view:      dsb     1
0102                    138 count_out:      dsw     1
0104                    139 err_view:       dsw     1
                        140
                        141
                        142 $eject
                        143
                        144 ;       PIN#    PORT    FLAG USAGE
                        145
                        146 ;       22      P1.0    mode0 0   mode1 1   mode2 1  or 0
                        147 ;       23      P1.1          0         0         1     1
                        148 ;       24      P1.2    software timer 2 routine enter/leave
                        149 ;       25      P1.3    Main program toggle
                        150 ;       26      P1.4    HSI overflow toggle
                        151 ;       37      P1.5    software timer 0 routine enter/leave
                        152 ;       38      P1.6    hsi_int enter/leave
                        153 ;       39      P1.7    software timer 1 routine enter/leave
                        154 ;       40      P2.6    Input direction (0=reverse, 1=forward)
                        155 ;       45      P2.7    direction 0=rev, 1=fwd
                        156
2000                    157 cseg    at      2000H
2000 0022               158         dcw     timer_ovf_int
2002 1020               159         dcw     atod_done_int
2004 0424               160         dcw     hsi_data_int
2006 8022               161         dcw     hso_exec_int
2008 1020               162         dcw     hsi_0_int
200A 2022               163         dcw     soft_tmr_int
200C 1020               164         dcw     ser_port_int
200E 1020               165         dcw     external_int
                        166
2010                    167 atod_done_int:
2010                    168 hsi_0_int:
2010                    169 ser_port_int:
2010                    170 external_int:
                        171
2080                    172 cseg    at      2080H
                        173
2080 A1F00018           174 init:   ld      sp,#0F0H
2084 B1FF17             175         ldb     pwm_control,#0FFH
                        176
2087 1168               177         clrb    direct
2089 A170175C           178         ld      tmp1,#6000          ; wait about 3 seconds for motor
208D 055C               179 delay:  dec     tmp1            ;   to come to a stop
208F E068FD             180         djnz    direct,$            ; wait 0.512 milliseconds
2092 88005C             181         cmp     tmp1,zero
2095 D2F6               182         jgt     delay
                        183
2097 B1FF0F             184         ldb     port1,#0FFH
209A B1FF10             185         ldb     port2,#0ffH
```

270061-99

```
209D B12516          186             ldb     IOC1,#00100101B ; Disable HSO.4,HSO.5, HSI_INT=first,
                     187                                     ; Enable PWM,TXD,TIMER1_OVRFLOW_INT
                     188
20A0 71FC0F          189             andb    Port1,#11111100B        ; clear P1.0,1 (set mode 0)
20A3 B19903          190             ldb     HSI_mode,#10011001B     ; set hsi.1,3 -; hsi.0,2 +
20A6 B15715          191             ldb     IOC0,#01010111B         ; Enable all hsi
                     192                                             ; T2 CLOCK=T2CLK,  T2RST=T2RST
                     193                                             ; Clear timer2
                     194     $eject
                     195
20A9 A00400          196             ld      zero,hsi_time
20AC 0140            197             clr     time
20AE 0142            198             clr     time+2
20B0 0128            199             clr     timer_2
20B2 012A            200             clr     timer_2+2
20B4 0130            201             clr     position
20B6 0132            202             clr     position+2
20B8 0154            203             clr     last_pos
20BA 0134            204             clr     des_pos
20BC 0136            205             clr     des_pos+2
20BE 0144            206             clr     des_time
20C0 0146            207             clr     des_time+2
20C2 A00A56          208             ld      last1_time,Timer1
20C5 4900085658      209             sub     last2_time,last1_time,#800H
20CA 116D            210             clrb    ios1_bak
20CC 1109            211             clrb    int_pending
20CE A1F0015E        212             ld      out_ptr,#1F0H
20D2 A13C0082        213             ld      min_hsi,#min_hsi_t
20D6 A11E0084        214             ld      min_hsi1,#min_hsi1_t
20DA A1690086        215             ld      max_hsi1,#max_hsi1_t
20DE A16E007C        216             ld      HSO0_dly,#HSO0_dly_period
20E2 A1FA007E        217             ld      swt1_dly,#swt1_dly_period
20E6 A1FA0080        218             ld      swt2_dly,#(swt2_dly_period)
20EA A1FF0070        219             ld      max_pwr,#max_power
20EE A1FF0072        220             ld      max_brk,#max_brake
20F2 A1B00074        221             ld      max_hold,#maximum_hold
20F6 A1B00478        222             ld      brk_pnt,#brake_pnt
20FA A164007A        223             ld      pos_pnt,#position_pnt
20FE A1100076        224             ld      vel_pnt,#velocity_pnt
2102 A1002962        225             ld      nxt_pos,#pos_table
2106 B0006C          226             ldb     pwm_pwr,zero
2109 B10169          227             ldb     pwm_dir,#01h            ; FORWARD
                     228
210C B12D08          229             ldb     int_mask,#00101101B     ; Enable tmr_ovf, hsi, swt, HSO,interrupts
210F B13006          230             ldb     hso_command,#30H        ; set HSO_0
2112 447C0A04        231             add     hso_time,timer1,HSO0_dly
2116 FD              232             nop
2117 FD              233             NOP
2118 B13906          234             ldb     hso_command,#39H        ; set swt_1
211B 447E0A04        235             add     hso_time,timer1,swt1_dly
```

270061-A0

```
211F FD                       nop
2120 FD                       nop
2121 B13A06                   ldb     hso_command,#3AH        ; set swt_2
2124 44800A04                 add     hso_time,timer1,swt2_dly

2128 A00A40                   ld      time,TIMER1
212B A00C2C                   ld      tmr2_old,timer2
212E FB                       ei

212F E7CE06                   br      main_prog

                      $eject


                      ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                      ;;;;;;                      TIMER  INTERRUPT  SERVICE                  ;;;;;;;;;;;
                      ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

2200                          CSEG AT 2200H

2200                  timer_ovf_int:
2200 F2                       pushf

2201 90166D                   orb     ios1_bak,IOS1
2204 356D05           chk_t1: jbc     ios1_bak,5,tmr_int_done
2207 0742                     inc     time+2
2209 71DF6D                   andb    ios1_bak,#11011111B     ; clear bit 5
220C                  tmr_int_done:
220C F3                       popf
220D F0                       ret             ; End of timer interrupt routine



                      ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                      ;;;;;           SOFTWARE TIMER INTERRUPT SERVICE ROUTINE         ;;;;;;;;;
                      ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

2220                          CSEG AT 2220H


2220                  soft_tmr_int:
2220 F2                       pushf
2221 90166D                   orb     ios1_bak,IOS1
2224                  chk_swt0:
2224 306D03                   jbc     ios1_bak,0,chk_swt1
2227 71FE6D                   andb    ios1_bak,#11111110B     ; Clear bit 0 - end swt0
                      ;       call    swt0_expired
222A                  chk_swt1:
222A 316D06                   jbc     ios1_bak,1,chk_swt2
222D 71FD6D                   andb    ios1_bak,#11111101B     ; Clear bit 1
```

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6

```
2230 EFCD03                        call    swt1_expired
2233                       chk_swt2:
2233 326D06                        jbc     ios1_bak,2,chk_swt3
2236 71FB6D                        andb    ios1_bak,#11111011B      ; Clear bit 2
2239 EF4401                        call    swt2_expired
223C                       chk_swt3:
223C 346D03                        jbc     ios1_bak,4,swt_int_done
223F 71F76D                        andb    ios1_bak,#11110111B      ; Clear bit 3
                           ;       call    swt3_expired

2242                       swt_int_done:
2242 F3                            popf
2243 F0                            ret     ; END OF SOFTWARE TIMER INTERRUPT ROUTINE

                           $eject

                           ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                           ;;;;;;                  SOFTWARE TIMER ROUTINE 0                    ;;;;;;;;;;;
                           ;;;;;;                  NOW  USING HSO.0 TO TRIGGER                 ;;;;;;;;;;;
                           ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

2280                               CSEG AT 2280H

2280                       hso_exec_int:                      ; Check mode -- Update position in mode 2

2280 F2                            PUSHF
2281 B13006                        ldb     HSO_COMMAND,#30H
2284 447C0A04                      add     HSO_TIME,TIMER1,HSO0_dly

2288 91200F                        orb     port1,#00100000B         ; set P1.5
228B A00C28                        ld      Timer_2,TIMER2
228E 390F18                        jbs     Port1,1,in_mode2

2291                       in_mode1:
2291 4866285C                      sub     tmp1,Timer_2,old_t2      ; Check count difference in tmp1
2295 8902005C                      cmp     tmp1,#2
2299 D94C                          jh      end_swt0
229B                       set_mode0:
229B 300F49                        jbc     Port1,0,end_swt0         ; if already in mode 0
229E 71FC0F                        andb    Port1,#11111100B         ; Clear P1.0, P1.1 (set mode 0)
22A1 B15515                        ldb     IOC0,#01010101B          ; enable all HSI
22A4 B0006B                        ldb     last_stat,zero
22A7 203E                          br      end_swt0

22A9                       in_mode2:
22A9 482C283C                      sub     delta_p,timer_2,tmr2_old        ; get timer2 count difference
22AD A0282C                        ld      tmr2_old,timer_2

22B0 306808                        jbc     direct,0,in_rev

```

270061-A2

```
22B3 643C30           in_fwd: add    position,delta_p
22B6 A40032                   addc   position+2,zero
22B9 2006                     br     chk_mode

22BB 683C30           in_rev: sub    position,delta_p
22BE A80032                   subc   position+2,zero

22C1                  chk_mode:
22C1 4B66285C                 sub    tmp1,Timer_2,old_t2      ; Check count difference in tmp1
22C5 8905005C                 cmp    tmp1,#5                  ; set mode1 if count is too low
22C9 D21C                     jgt    end_swt0                 ; count <= 5

22CB                  set_mode1:
22CB 71FD0F                   andb   Port1,#11111101B         ; Clear P1.1, set P1.0 (set mode 1)
22CE 91010F                   orb    Port1,#00000001B
22D1 B10515                   ldb    IOC0,#00000101B          ; enable HSI 0 and 1
22D4 A00400                   ld     zero, HSI_TIME
22D7 48840A56                 sub    last1_time,Timer1,min_hsi1
                                                ; set up so (time-last2_time)>min_hsi1 on next HSI
                      $EJECT

22DB                  clr_hsi:
22DB A00400                   ld     ZERO, HSI_TIME
22DE 717F6D                   andb   ios1_bak,#01111111B              ; clear bit 7
22E1 90166D                   orb    ios1_bak,ios1
22E4 3F6DF4                   jbs    ios1_bak,7,clr_hsi       ; If hsi is triggered then clear hsi

22E7                  end_swt0:
22E7 A02866                   ld     old_t2,TIMER_2
22EA 71DF0F                   andb   port1,#11011111B         ; clear P1.5
22ED F3                       POPF
22EE F0                       ret




                      ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                      ;;;;;;                  SOFTWARE TIMER ROUTINE 2               ;;;;;;;;;;;
                      ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

2380                          CSEG AT 2380H

2380                  swt2_expired:
2380 F2                       pushf
2381 B13A06                   ldb    hso_command,#3AH         ; set swt_2
2384 44800A04                 add    hso_time,timer1,swt2_dly

2388 91040F                   orb    port1,#00000100B         ; set port 1.2
238B 89FF075E                 cmp    out_ptr,#7ffH
238F D104                     bnh    pulsing
2391 A1F0015E                 ld     out_ptr,#1f0H
```

270061-A3

6

```
                 pulsing:
2395
2395 306E0C              jbc     tr_col,0,swt2_done

2398 C25F32              st      position+2,[out_ptr]+    ;  position high, position low
239B C25F30              st      position,[out_ptr]+

239E C25F68              st      direct,[out_ptr]+
23A1 C25F6C              st      pwm_pwr,[out_ptr]+

                                                          ; store 8 bytes externally

23A4             swt2_done:
23A4 48560A5C            sub     tmp1,timer1,last1_time
23A8 8900185C            cmp     tmp1,#1800H
23AC D104                jnh     swt2_ret          ; keep (Timer1-last1_time)<2000H

23AE 65001056            add     last1_time,#1000H
23B2             swt2_ret:
23B2 71FB0F              andb    port1,#11111011B         ; clear port1.2
23B5 F3                  popf
23B6 F0                  ret

                 $EJECT
                 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                 ;;;;;            HSI DATA AVAILABLE INTERRUPT ROUTINE                 ;;;;;;;;;;;;
                 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                 ;  This routine keeps track of the current time and position of the motor.
                 ;  The upper word of information is provided by the timer overflow routine.

2400                     CSEG AT 2400H
2400 20CE        now_mode_1:     br      in_mode_1        ; used to save execution time for
2402 20C7        no_int1:        br      no_int           ; worst case loop

2404 F2          hsi_data_int:   pushf
2405 91400F              orb     port1,#01000000B         ; set P1.6
2408 717F6D              andb    ios1_bak,#01111111B      ; Clear ios1_bak.7
240B 90166D              orb     ios1_bak,ios1
240E 376DF1              jbc     ios1_bak,7,no_int1       ; If hsi is not triggered then
                                                          ; jump to no_int
2411             get_values:
2411 A00C28              ld      timer_2,TIMER2
2414 5155066A            andb    hsi_s0,HSI_STATUS,#01010101B
2418 A00440              ld      time, HSI_TIME

241B 380FE2              jbs     port1,0,now_mode_1       ; jump if in mode 1

241E             In_mode_0:
241E 386A0B              jbs     hsi_s0,0,a_rise
```

270061–A4

```
2421 3A6A2C                436             jbs     hsi_s0,2,a_fall
2424 3C6A4D                437             jbs     hsi_s0,4,b_rise
2427 3E6A5A                438             jbs     hsi_s0,6,b_fall
242A 2094                  439             br      no_cnt
                           440
242C A05658                441     a_rise: ld      last2_time,last1_time
242F A04056                442             ld      last1_time,time
2432 685840                443             sub     time,last2_time
2435 888240                444             cmp     time,min_hsi
2438 D906                  445             jh      tst_statr
                           446     ;set mode1-
243A 91010F                447             orb     Port1,#00000001B        ; Set P1.0 (in mode 1)
243D B10515                448             ldb     IOC0,#00000101B         ; Enable HSI 0 and 1
2440                       449     tst_statr:
2440 3E6B5B                450             jbs     last_stat,6,going_fwd
2443 3C6B67                451             jbs     last_stat,4,going_rev
2446 3A6B50                452             jbs     last_stat,2,change_dir
2449 98006B                453             cmpb    last_stat,zero
244C DF46                  454             je      first_time              ; first time in mode0
244E 27B2                  455             br      no_int1
                           456
2450 A05658                457     a_fall: ld      last2_time,last1_time
2453 A04056                458             ld      last1_time,time
2456 685840                459             sub     time,last2_time
2459 888240                460             cmp     time,min_hsi
245C D906                  461             jh      tst_statf
                           462     ;set mode1-
245E 91010F                463             orb     Port1,#00000001B        ; Set P1.0 (in mode 1)
2461 B10515                464             ldb     IOC0,#00000101B         ; Enable HSI 0 and 1
                           465     $EJECT
2464                       466     tst_statf:
2464 3C6B37                467             jbs     last_stat,4,going_fwd
2467 3E6B43                468             jbs     last_stat,6,going_rev
246A 386B2C                469             jbs     last_stat,0,change_dir
246D 98006B                470             cmpb    last_stat,zero
2470 DF22                  471             je      first_time              ; first time in mode0
2472 2057                  472             br      no_int
                           473
2474 386B27                474     b_rise: jbs     last_stat,0,going_fwd
2477 3A6B33                475             jbs     last_stat,2,going_rev
247A 3E6B1C                476             jbs     last_stat,6,change_dir
247D 98006B                477             cmpb    last_stat,zero
2480 DF12                  478             je      first_time              ; first time in mode0
2482 2047                  479             br      no_int
                           480
2484 3A6B17                481     b_fall: jbs     last_stat,2,going_fwd
2487 386B23                482             jbs     last_stat,0,going_rev
248A 3C6B0C                483             jbs     last_stat,4,change_dir
248D 98006B                484             cmpb    last_stat,zero
2490 DF02                  485             je      first_time              ; first time in mode0
```

270061-A5

```
2492 2037                    br      no_int

2494                         first_time:
2494 C46B6A                  stb     hsi_s0,last_stat
2497 2072                    br      done_chk        ; add delta position


2499                         change_dir:
2499 1268                    notb    direct
249B 30680F                  no_inc: jbc     direct,0,going_rev

249E                         going_fwd:
249E 914010                  orb     PORT2,#01000000B        ; set P2.6
24A1 B10168                  ldb     direct,#01              ; direction = forward
24A4 65010030                add     position,#01
24A8 A40032                  addc    position+2,zero
24AB 200D                    br      st_stat
24AD                         going_rev:
24AD 71BF10                  andb    PORT2,#10111111B        ; clear P2.6
24B0 B10068                  ldb     direct,#00              ; direction = reverse
24B3 69010030                sub     position,#01
24B7 A80032                  subc    position+2,zero

24BA                         st_stat:
24BA C46B6A                  stb     hsi_s0,last_stat
24BD                         load_lasts:
24BD A0282C                  ld      tmr2_old,timer_2
24C0 717F6D                  no_cnt: andb    ios1_bak,#01111111B     ; clr bit 7
24C3 90166D                  orb     ios1_bak,ios1
24C6 376D02                  jbc     ios1_bak,7,no_int
24C9 2746                    again:  br      get_values

24CB 71BF0F                  no_int: andb    port1,#10111111B        ; Clear P1.6
24CE F3                      popf
24CF F0                      ret     ; end of hsi_data interrupt routine
                                     ; Routine for mode 1 follows and then returns to "load_lasts"
                             $EJECT


24D0                         In_mode_1:              ; mode 1 HSI routine

24D0 51506A5C                andb    tmp1,hsi_s0,#01010000B
24D4 D7EA                    jne     no_cnt
24D6                         cmp_time:                               ; Procedure which sets mode 1 also
                                                                     ; sets times to pass the tests
24D6 A05658                  ld      last2_time,last1_time
24D9 A04056                  ld      last1_time,time

24DC 4858405C                cmp1:   sub     tmp1,time,last2_time
24E0 88845C                  cmp     tmp1,min_hsi1
```

270061-A6

```
24E3 D914                  jh      check_max_time

24E5                 set_mode_2:
24E5 91020F                orb     Port1,#00000010B        ; Set P1.1 (in mode 2)
24E8 B10015                ldb     IOC0,#00000000B         ; Disable all HSI
24EB A00400          mt_hsi: ld    zero,hsi_time           ; empty the hsi fifo
24EE 717F6D                andb    ios1_bak,#01111111B            ; clear bit 7
24F1 90166D                orb     ios1_bak,ios1
24F4 3F6DF4                jbs     ios1_bak,7,mt_hsi       ; If hsi is triggered thenrclear hsi
24F7 2012                  br      done_chk

24F9                 check_max_time:
24F9 4858405C              sub     tmp1,time,last2_time
24FD 88865C                cmp     tmp1,max_hsi1           ; max_hsi = addition to min_hsi for
                                                           ; total time
2500 D109                  jnh     done_chk

2502                 set_mode_0:
2502 71FC0F                andb    Port1,#11111100B        ; clear P1.0,1  set mode 00
2505 B15515                ldb     IOC0,#01010101B         ; Enable all HSI
2508 B0006B                ldb     last_stat,zero

250B                 done_chk:
250B 482C283C              sub     delta_p,timer_2,tmr2_old        ; get timer2 count!difference
250F 306808                jbc     direct,0,add_rev
2512                 add_fwd:
2512 643C30                add     position,delta_p
2515 A40032                addc    position+2,zero
2518 27A3                  br      load_lasts
251A                 add_rev:
251A 683C30                sub     position,delta_p
251D A80032                subc    position+2,zero
2520 279B                  br      load_lasts

                     $eject
                     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                     ;;;;;;               SOFTWARE TIMER ROUTINE 1              ;;;;;;;;;;;
                     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

2600                 CSEG AT 2600H

2600                 swt1_expired:

2600 F2                    pushf
2601 91800F                orb     port1,#10000000B        ; set port1.7

2604 B10D08                ldb     int_mask,#00001101B     ; enable HSI, Tovf, HSO

2607 B13906                ldb     HSO_COMMAND,#39H
260A 447E0A04              add     HSO_TIME,TIMER1,swt1_dly
```

270061–A7

6

```
                        586
260E A0464A             587             ld      time_err+2,des_time+2   ; Calculate time & position error
2611 A0363A             588             ld      pos_err+2,des_pos+2
2614 48404448           589             sub     time_err,des_time,time          ; values are set
2618 A8424A             590             subc    time_err+2,time+2
261B 48303438           591             sub     pos_err,des_pos,position
261F A8323A             592             subc    pos_err+2,position+2
                        593
2622 FB                 594             EI
                        595
2623 48484C52           596             sub     time_delta,last_time_err,time_err
2627 A0484C             597             ld      last_time_err,time_err
                        598
262A 48384E50           599             sub     pos_delta,last_pos_err,pos_err
262E A0384E             600             ld      last_pos_err,pos_err
                        601
                        602     ;;;;;           Time_err = Desired time to finish - current time
                        603     ;;;;;           Pos_err  = Desired position to finish - current position
                        604     ;;;;;           Pos_delta  = Last position error - Curent position error
                        605     ;;;;;           Time_delta = Last time error - Current time error
                        606     ;;;;;              note that errors should get smaller so deltas will be
                        607     ;;;;;              positive for forward motion (time is always forward)
                        608
                        609
2631                    610     chk_dir:
2631 88003A             611             cmp     pos_err+2,zero
2634 D60D               612             jge     go_forward
                        613
2636                    614     go_backward:
2636 0338               615             neg     pos_err                 ; Pos_err = ABS VAL (pos_err)
2638 B10069             616             ldb     pwm_dir,#00h
263B 89FFFF3A           617             cmp     pos_err+2,#0ffffH
263F D70A               618             jne     ld_max
2641 200D               619             br      chk_brk
                        620
2643                    621     go_forward:
2643 B10169             622             ldb     pwm_dir,#01H
2646 88003A             623             cmp     pos_err+2,zero
2649 DF05               624             je      chk_brk
                        625     $EJECT
                        626
264B B0706C             627     ld_max: ldb     pwm_pwr,max_pwr
264E 2051               628             br      chk_sanity
                        629
2650                    630     Chk_brk:                        ;  Position_Error now = ABS(pos_err)
2650 887A38             631             cmp     pos_err,pos_pnt
2653 D11E               632             jnh     hold_position   ; position_error<position_control_point
2655 887838             633             cmp     pos_err,brk_pnt
```

270061-A8

```
2658 D9F1                       jh      ld_max          ; position_error>brake_point
                                
265A                            
265A 880050             braking:
265D D602                       cmp     pos_delta,zero
265F 0350                       jge     chk_delta
2661                            neg     pos_delta
2661 887650             chk_delta:
2664 D10D                       cmp     pos_delta,vel_pnt       ; velocity = pos_delta/sample_time
                                jnh     hold_position           ; jmp if  ABS(velocity) < vel_pnt
2666 B0726C                     
2669 B06824             brake:  ldb     pwm_pwr,max_brk
266C 1224                       ldb     tmp,direct              ; If braking apply power in opposite
266E B02469                     notb    tmp                     ; direction of current motion
                                ldb     pwm_dir,tmp
2671 2030                       
                                br      ld_pwr
2673                            
2673 89020038           Hold_position:                  ; position hold mode
2677 D906                       cmp     pos_err,#02
2679 0126                       jh      calc_out        ; if position error < 2 then turn off power
267B 015A                       clr     tmp+2
267D 201F                       clr     boost
                                BR      output
267F                            
267F 5DFF7424           calc_out:
2683 6C3824                     mulub   tmp,max_hold,#255
2686 880050                     mulu    tmp,pos_err             ; Tmp = pos_err * max_hold
2689 D709                       cmp     pos_delta,zero
268B 6504005A                   jne     no_bst
268F 645A26                     add     boost,#04               ; Boost is integral control
2692 2002                       add     tmp+2,boost             ; TMP+2 = MSB(pos_err*max_hold)
2694 015A                       br      ck_max
2696 887426             no_bst: clr     boost
2699 D103               ck_max: cmp     tmp+2,max_hold
269B A07426                     jnh     output
269E B0266C             maxed:  ld      tmp+2,max_hold
                        output: ldb     pwm_pwr,tmp+2
                                
                                
26A1                    chk_sanity:
26A1 2000                       br      ld_pwr
                        ;;
                        ;;
                        $EJECT
                                
26A3                    ld_pwr:
26A3 B06C64                     ldb     rpwr,pwm_pwr
26A6 1264                       notb    rpwr
26A8 38690A                     jbs     pwm_dir,0,p2fwd
                                
```

270061-A9

```
26AB FA                p2bkwd: DI
26AC 717F10                    andb    port2,#01111111B        ; clear P2.7
26AF B06417                    ldb     pwm_control,rpwr
26B2 FB                        EI
26B3 2008                      br      pwrset
26B5 FA                p2fwd:  DI
26B6 918010                    orb     port2,#10000000B        ; set P2.7
26B9 B06417                    ldb     pwm_control,rpwr
26BC FB                        EI

26BD                   pwrset:
26BD 88004A                    cmp     time_err+2,zero  ; do pos_table when err is negative
26C0 D225                      jgt     end_p
                       ;;;     br      end_p

26C2 89202962                  cmp     nxt_pos,#(32+pos_table)
26C6 DE06                      jlt     get_vals                ; jump if lower
26C8 A1002962                  ld      nxt_pos,#pos_table
26CC 0142                      clr     time+2
26CE                   get_vals:

26CE A26334                    ld      des_pos,[nxt_pos]+
26D1 A26336                    ld      des_pos+2,[nxt_pos]+
26D4 A26346                    ld      des_time+2,[nxt_pos]+
26D7 A26370                    ld      max_pwr,[nxt_pos]+
26DA A07072                    ld      max_brk,max_pwr
26DD 646034                    add     des_pos,offset
26E0 A40036                    addc    des_pos+2,zero
26E3 4830344E                  sub     last_pos_err,des_pos,position

26E7 717F0F            end_p:  andb    port1,#01111111B        ; clear P1.7

26EA F3                        popf
26EB F0                        ret

                       $EJECT

                       ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                       ;;;;;;;;;;;;;;;;;;;;;;;        main  program           ;;;;;;;;;;;;;;;;;;;;;;;
                       ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;


2800                           CSEG at 2800H

2800                   MAIN_PROG:
2800 90166D                    orb     ios1_bak,ios1
2803 366D09                    jbc     ios1_bak,6,control
2806 71BF6D                    andb    ios1_bak,#10111111B     ; clear ios1_bak.6
2809 95100F                    xorb    Port1,#00010000B        ; Compl Bit P1.4
280C EFF5FB                    call    HSI_DATA_INT            ; prevent lockup
```

270061-B0

```
280F                    734   control:
280F 912D08             735           orb     int_mask,#00101101B     ; enable hsi, hso, swt, tovf interrupts
2812 FD                 736           nop
2813 FD                 737           nop
2814 FD                 738           nop
2815 E06FFD             739           djnz    main_dly,$
2818 FD                 740           nop
2819 95080F             741           xorb    port1,#00001000B        ; compliment p1.3
281C 27E2               742           BR      MAIN_PROG
                        743
                        744
2900                    745           CSEG AT 2900H
                        746
2900                    747   pos_table:
                        748
2900 00000000           749           dcl     00000000H       ; position 0
2904 20008000           750           dcw     0020H, 0080H    ; next time, power
2908 00C00000           751           dcl     0000c000H       ; position 1
290C 40004000           752           dcw     0040H, 0040H    ; next time, power
2910 00000000           753           dcl     00000000H       ; position 2
2914 6000C000           754           dcw     0060H, 00c0H    ; next time, power
2918 0080FFFF           755           dcl     0FFFF8000H      ; position 3
291C 80008000           756           dcw     0080H, 0080H    ; next time, power
                        757
2920 00080000           758           dcl     00000800H       ; position 4
2924 58008000           759           dcw     0058H, 0080H    ; next time, power
2928 00300000           760           dcl     00003000H       ; position 5
292C 7000FF00           761           dcw     0070H, 00ffH    ; next time, power
2930 00000000           762           dcl     00000000H       ; position 6
2934 9000F000           763           dcw     0090H, 00f0H    ; next time, power
2938 00000000           764           dcl     00000000H       ; position 7
293C 9100F000           765           dcw     0091H, 00f0H    ; next time, power
                        766
                        767
2940                    768           END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

270061-B1

intel®

APPLICATION NOTE

AP-275

October 1988

An FFT Algorithm For MCS®-96 Products Including Supporting Routines and Examples

IRA HORDEN
ECO APPLICATIONS ENGINEER

Order Number: 270189-002

AN FFT ALGORITHM FOR MCS®-96 PRODUCTS INCLUDING SUPPORTING ROUTINES AND EXAMPLES

CONTENTS

Figures

Listings

1.0 INTRODUCTION

Intel's 8096 is a 16-bit microcontroller with processing power sufficient to perform many tasks which were previously done by microprocessors or special building block computers. A new field of applications is opened by having this much power available on a single chip controller.

The 8096 can be used to increase the performance of existing designs based on 8051s or similar 8-bit controllers. In addition, it can be used for Digital Signal Processing (DSP) applications, as well as matrix manipulations and other processing oriented tasks. One of the tasks that can be performed is the calculation of a Fast Fourier Transform (FFT). The algorithm used is similar to that in many DSP and matrix manipulation applications, so while it is directly applicable to a specific set of applications, it is indirectly applicable to many more.

FFTs are most often used in determining what frequencies are present in an analog signal. By providing a tool to identify specific waveforms by their frequency components, FFTs can be used to compare signals to one another or to set patterns. This type of procedure is used in speech detection and engine knock sensors. FFTs also have uses in vision systems where they identify objects by comparing their outlines, and in radar units to detect the dopler shift created by moving objects.

This application note discusses how FFTs can be calculated using Intel's MCS®-96 microcontrollers. A review of fourier analysis is presented, along with the specific code required for a 64 point real FFT. Throughout this application note, it is assumed that the reader has a working knowledge of the 8096. For those without this background the following two publications will be helpful:

1986 Microcontroller Handbook

Using the 8096, AP-248

These books are listed in the bibliography, along with other good sources of information on the MCS-96 product family and on Fast Fourier Transforms.

2.0 PROGRAM OVERVIEW

This application note contains program modules which are combined to create a program which performs an FFT on an analog signal sampled by the on-board ADC (Analog to Digital Converter) of the 8097. The results of the FFT are then provided over the serial channel to a printer or terminal which displays the results. In the applications listed in the previous section, the data from this FFT program would be used directly by another program instead of being plotted. However, the plotted results are used here to provide an example of what the FFT does. There are four program modules discussed in this application note:

FFTRUN - Runs a 64 point FFT on its data buffer. It produces 32 14-bit complex output values and 32 14-bit output magnitudes. A fast square root routine and log conversion routine are included.

A2DCON - Fills one of two buffers with analog values at a set sample rate. The sample time can be as fast as 50 microseconds using 8x9xBH components.

PLOTSP - Plots the contents of a buffer to a serially connected printer. Routines are provided for console out and hexadecimal to decimal conversion and printing.

FTMAIN - The main module which controls the other modules.

Each of the modules will be described separately. In order to better understand how the programs work together, a brief tutorial on FFTs will be presented first, followed by descriptions of the programs in the order listed above.

The final program uses 64 real data points, taken from either a table or analog input 1. Each of the data points is a 16-bit signed number. The processing takes 12.5 milliseconds when internal RAM is used as the data space. If external RAM is used, 14 milliseconds are required. Larger FFTs can be performed by slightly modifying the programs. A 256-point FFT would take approximately 65 milliseconds, and a 1024-point version would require about 300 milliseconds.

In the program presented, the analog sampling time is set for 1 sample every 100 microseconds, providing the 64 samples in 6.4 milliseconds. The sampling time can be reduced to around 60 microseconds per point by changing a variable, and less than 50 microseconds by using the 8x9xBH series of parts, since they have a 22 microsecond A to D conversion time.

The programs are set up to be run in a sequence instead of concurrently. This provides the fastest operation if the sampling speed were reduced to the minimum possible. For the fastest operation above about 80 microseconds a sample, the programs could be run concurrently, but this would require some minor modifications of the program. Figure 1 shows the timing of the program as presented.

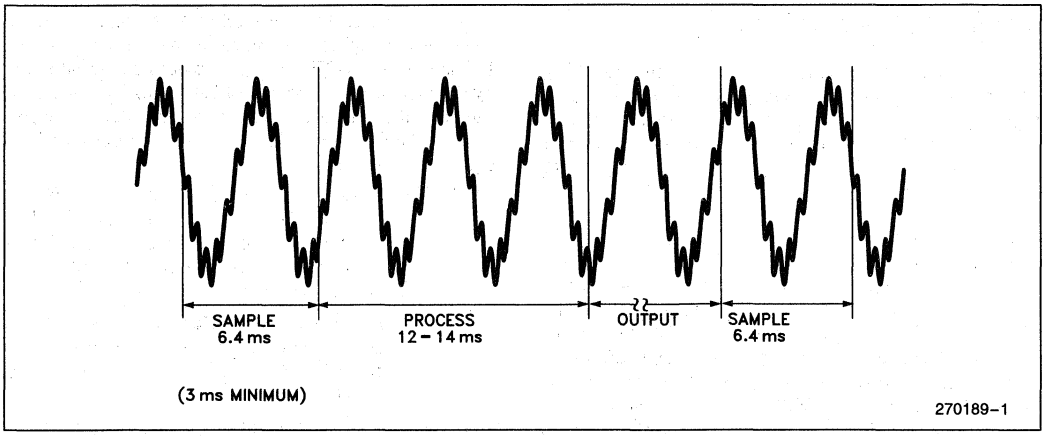


Figure 1. Timing of the FFT Program

These programs have run in the Intel Microcontroller Operation Application's Lab and produced the results presented in this application note. Since the programs have not undergone any further testing, we cannot guarantee them to be bug proof. We, therefore, recommend that they be thoroughly tested before being used for other than demonstration purposes.

3.0 FOURIER TRANSFORMS

A Fourier Transform is a useful analytical tool that is frequently ignored due to its mathematically oriented derivations. This is unfortunate, since Fourier transforms can be used without fully understanding the mathematics behind them. Of course, if one understands the theory behind these transforms, they become much more powerful.

The majority of this application note deals with how a Fast Fourier Transform (FFT) can be used for spectrum analysis. This procedure takes an input signal and separates it into its frequency components. One can almost treat the FFT as a black box, which has as its output, the frequency components and magnitudes of the input signal, much like a spectrum analyzer.

From a mathematical standpoint, Fourier Transforms change information in the time domain into the frequency domain. The theory behind the Fourier transform stems from Fourier analysis, also called frequency analysis.

There are many books on the topic of Fourier analysis, several of which are listed in the bibliography. In this application note, only the pertinent formulas and uses will be presented, not their derivations.

The main idea in Fourier analysis is that a function can be expressed as a summation of sinusoidal functions of different frequencies, phase angles, and magnitudes. This idea is represented by the Fourier Integral:

$$H(f) = \int_{-\infty}^{\infty} h(t)\, e^{-j2\pi ft}\, dt \qquad (1)$$

Where: H(f) is a function of frequency
h(t) is a function of time

Since

$$e^{-j\theta} = \cos\theta - j\sin\theta \qquad (2)$$

$$H(f) = \int_{-\infty}^{\infty} h(t)\,(\cos(2\pi ft) - j\sin(2\pi ft))\, dt \qquad (3)$$

Figure 2 shows a rectangular pulse and its Fourier transform. Note that the results in the frequency domain are continuous rather than discrete. The horizontal axis in Figure 2a is frequency, while that of Figure 2b is time.

In a simplified case, the varying phase angles can be removed, and the integral changed to a summation, known as a Fourier Series. All periodic functions can be described in this way. This series, as shown below, can help provide a more graphical understanding of Fourier analysis.

$$y(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos(2\pi nf_0t) + b_n \sin(2\pi nf_0t)] \qquad (4)$$

for $n = 1$ to ∞

Where $f_0 = \frac{1}{T_0}$, the fundamental frequency.

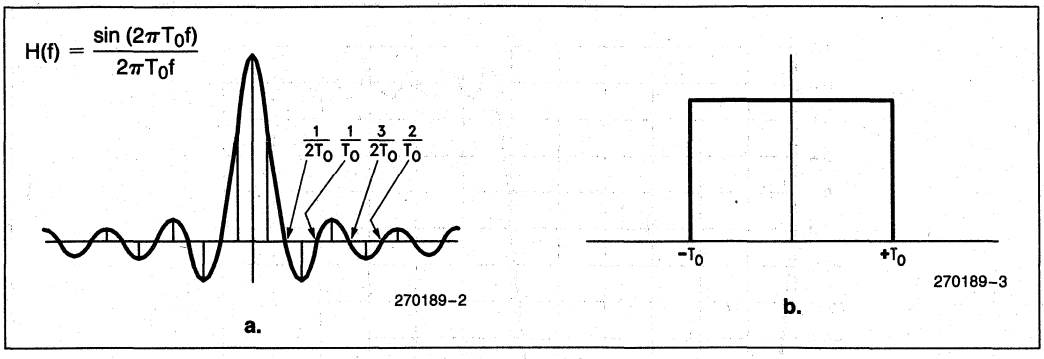


Figure 2. Rectangular Pulse and Its Fourier Transform

This formula can also be represented in complex form as:

$$\sum_{n=-\infty}^{\infty} \alpha n \, e^{j2\pi n f_0 t} \qquad (5)$$

The Fourier series for a square wave is

$$\sum_{K=0}^{\infty} \frac{\sin((2k+1)\,2\pi f_0 t)}{(2k+1)} \qquad (6)$$

If these sinusoids are summed, a square wave will be formed. Figure 3 shows the graphical summation of the first 3 terms of the series. Since the higher frequencies contribute to the squareness of the waveform at the corners, it is reasonable to compare only the flatness of the top of the waveform. The sharpness or risetime of the waveform can be determined by the highest frequency term being summed. With rise and fall times of 10% of the period, the waveform generated by the first 3 terms is within 20% of ideal. At 7 terms it is within 10%, and at 20 terms it is within 5%. With a 5% risetime, it is within 20% of ideal after 5 terms, 10% after 13 terms and 5% after 32 terms. Figure 4 shows the resultant waveforms after the summation of 7, 15 and 30 terms.

Fourier analysis can be used on equation 4 to find the coefficients a_n and b_n. To make this process easier to use with a computer, a discrete form, rather than a continuous one, must be used. The discrete Fourier transform, shown in Equation 7, is a good approximation to the continuous version. The closeness of the approximation depends on several conditions which will be discussed later. The input to this transform is a set of N equally spaced samples of a waveform taken over a period of NT. The period NT is frequently referred to as the "Sampling Window".

6

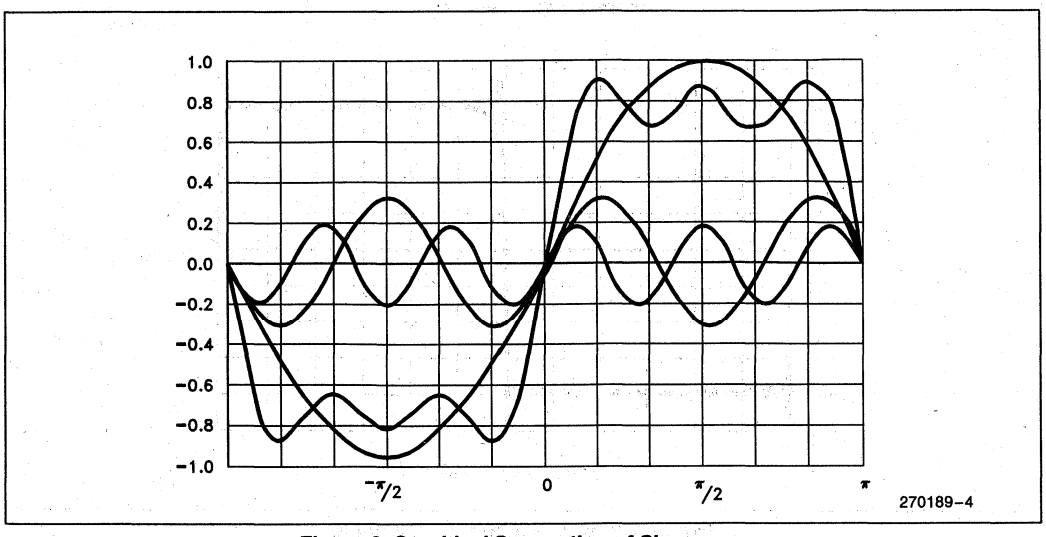
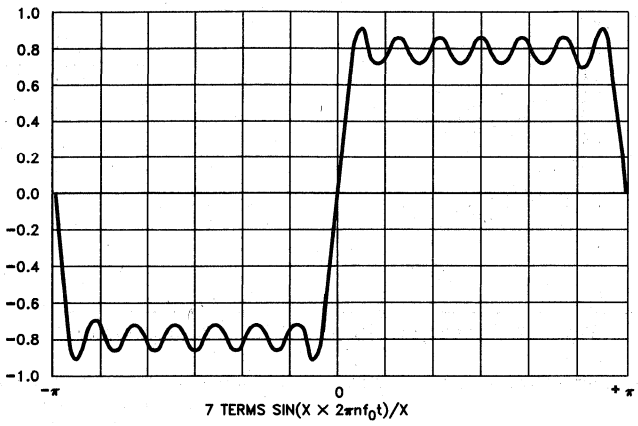
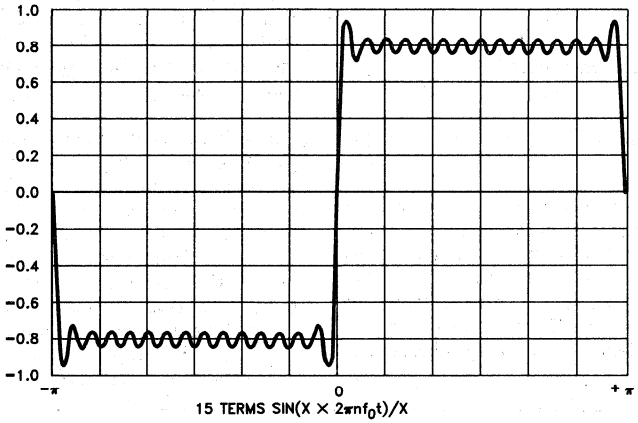


Figure 3. Graphical Summation of Sinewaves



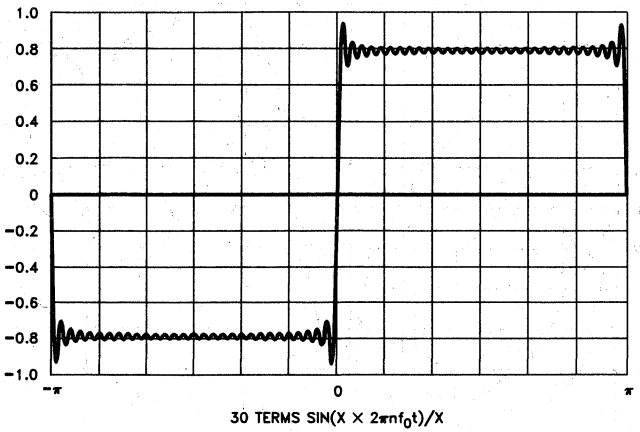
7 TERMS $\sin(X \times 2\pi nf_0t)/X$

270189-5



15 TERMS $\sin(X \times 2\pi nf_0t)/X$

270189-6



30 TERMS $\sin(X \times 2\pi nf_0t)/X$

270189-7

Figure 4. Square Wave from Sinusoids

$$H\left(\frac{n}{NT}\right) = \sum_{k=0}^{N-1} h(kT)e^{-j2\pi nk/N}$$

$$n = 0, 1, \ldots, N-1 \qquad (7)$$

Where: H(f) is a function of frequency

h(t) is a function of time

T is the time span between samples

N is the number of samples in the window

n = 0,1,2 ... N-1

This transform is used for many applications, including Fourier Harmonic Analysis. This procedure uses the transform to calculate the coefficients used in Equation 5. In order to do this, the factor T/NT must be added to the transform as follows:

$$H\left(\frac{n}{NT}\right) = \frac{T}{(NT)} \sum_{k=0}^{N-1} h(kT)\, e^{-j2\pi nk/N}$$

$$n = 0, 1, 2, 3, \ldots, N-1 \qquad (8)$$

The factor provides compensation for the number of samples taken. Note that the functions H(f) and h(t) are complex variables, so the simplicity of the equation can be misleading. Once the values of h(t) are known, (ie. the value of the input at the discrete times (t)), the Fourier Transform can be used to find the magnitude and phase shift of the signal at the frequencies (f).

A spectrum analyzer can provide similar information on an analog input signal by using analog filters to separate the frequency components. Regardless of its source, the information on component frequencies of a signal can be used to detect specific frequencies present in a signal or to compare one signal to another. Many lab experiments and product development tests can make use of this type of information. Using these methods, the purity of signals can be measured, specific harmonics can be detected in mechanical equipment, and noise bursts can be classified. All of this information can be obtained while still treating the FFT process as a black box.

Consider the discrete transform of a square wave as shown in Figure 5. Note that the component magnitudes, as shown in the series of Equation 6, are shown in a mirrored form in the transform. This will happen whenever only real data is used as the FFT input, if both real and imaginary data were used the output would not be guaranteed to be symmetrical. For this reason, there is duplicate information in the transform for many applications. Later in this section a method to make the most of this characteristic is discussed.

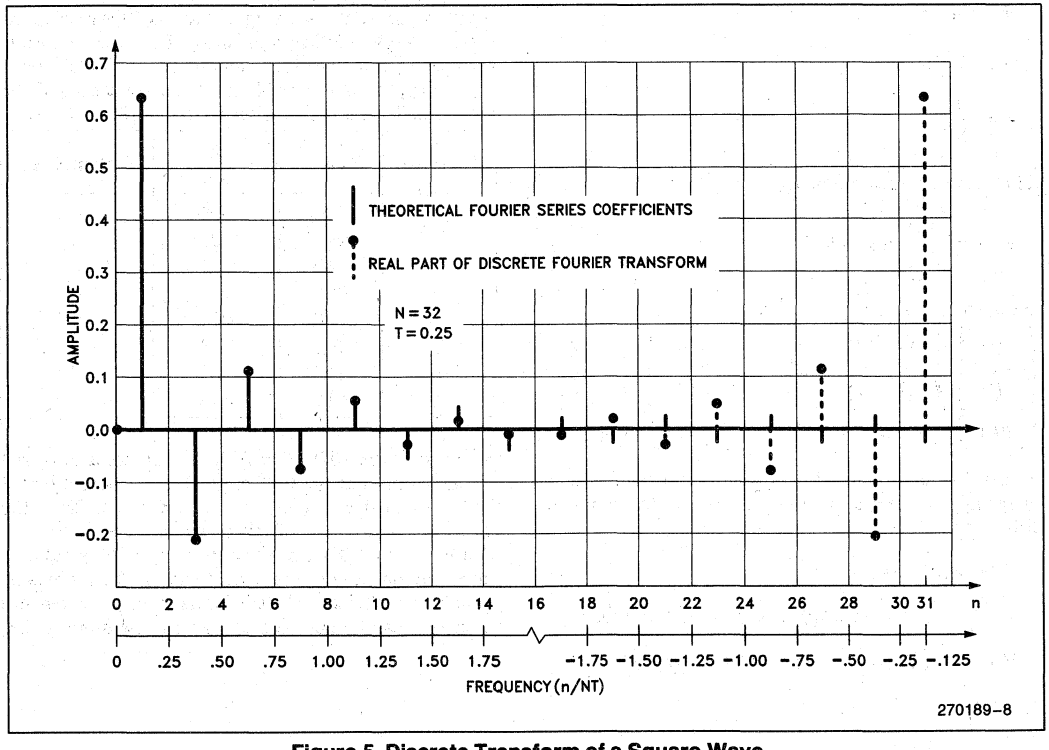


Figure 5. Discrete Transform of a Square Wave

If one looks at Equation 8, it can be seen that the calculation of a discrete Fourier transform requires N squared complex multiplications. If N is large, the calculation time can easily become unrealistic for real-time applications. For example, if a complex multiplication takes 40 microseconds, at N = 16, 10 milliseconds would be used for calculation, while at N = 128, over half a second would be needed. A Fast Fourier Transform is an algorithm which uses less multiplications, and is therefore faster. To calculate the actual time savings, it is first necessary to understand how a FFT works.

4.0 THE FFT ALGORITHM

The FFT algorithm makes use of the periodic nature of waveforms and some matrix algebra tricks to reduce the number of calculations needed for a transform. A more complete discussion of this is in Appendix A, however, the areas that need to be understood to follow the algorithm are presented here. This information need not be read if the reader's intent is to use the program and not to understand the mathematical process of the algorithm

To simplify notation the following substitutions are made in Equation 8.

$$W = e^{-j2\pi/N}$$

$$k = kT$$

$$n = \frac{n}{NT}$$

The resultant equation being

$$x(n) = \sum_{k=0}^{N-1} n(k)W^{nk} \qquad (9)$$

Expressed as a matrix operation

$$\begin{bmatrix} X(1) \\ X(2) \\ X(3) \\ \vdots \\ X(N\text{-}1) \end{bmatrix} = \begin{bmatrix} W^0 & W^0 & W^0 & \cdots & W^0 \\ W^0 & W^1 & W^2 & \cdots & W^N \\ W^0 & W^2 & W^4 & \cdots & W^{2N} \\ \vdots & \vdots & \vdots & & \vdots \\ W^0 & W^{(N-1)} & W^{2(N-1)} & \cdots & W^{(N-1)^2} \end{bmatrix} \begin{bmatrix} X_0(0) \\ X_0(1) \\ X_0(2) \\ \vdots \\ X_0(N-1) \end{bmatrix}$$

A brief review of matrix properties can be found in Appendix A. Because of the periodic nature of W the following is true:

$$W^{nk} \text{ MOD } N = W^{nk} \qquad (10)$$

$$= \text{COS}(2\pi\, nk/N) - j\,\text{SIN}(2\pi nk/N)$$

$W^0 = 1$ therefore, if $nk \text{ MOD } N = 0$, $W^{nk} = 1$

This reduces the calculations as several of the W terms go to 1 and the highest power of W is N. All of W values are complex, so most of the operations will have to be complex operations. We will continue to use only the W, X(n) and X0(k) symbols to represent these complex quantities.

The FFT algorithm we will use requires that N be an integral power of 2. Other FFT algorithms do not have this restriction, but they are more complex to understand and develop. Additionally, for the relatively small values of N we are using this restriction should not provide much of a problem. We will define EXPONENT as log base 2 of N. Therefore,

$$N = 2^{EXPONENT}$$

The magic of the FFT, (as detailed in Appendix A), involves factoring the matrix into EXPONENT matrices, each of which has all zeros except for a 1 and a W^{nk} term in each row. When these matrices are multiplied together the result is the same as that of the multiplication indicated in Equation 9, except that the rows are interchanged and there are fewer non-trivial multiplications. To reorder the rows, and thus make the information useful, it is necessary to perform a procedure called "Bit Reversal".

This process requires that N first be converted to a binary number. The least significant bit (lsb) is swapped with the most significant bit (msb). Then the next lsb is swapped with the next msb, and so on until all bits have been swapped once. For N=8, 3 bits are used, and the values for N and their bit reversals are shown below:

Number	Binary	Bit Reversal	Decimal BR
0	000	000	0
1	001	100	4
2	010	010	2
3	011	110	6
4	100	001	1
5	101	101	5
6	110	011	3
7	111	111	7

Recall that the FFT of real data provides a mirrored image output, but the FFT algorithm can accept inputs with both real and imaginary components. Since the inputs for harmonic analysis provided by a single A to D are real, the FFT algorithm is doing a lot of calculations with one input term equal to zero. This is obviously not very efficient. More information for a given size transform can be obtained by using a few more tricks.

It is possible to perform the FFT of two real functions at the same time by using the imaginary input values to the FFT for the second real function. There is then a post processing performed on the FFT results which separate the FFTs of the two functions. Using a similar procedure one can perform a transform on 2N real samples using an N complex sample transform.

The procedure involves alternating the real sample values between the real and imaginary inputs to the FFT. If, as in our example, the input to the FFT is a 2 by 32 array containing the complex values for 32 inputs, the 64 real samples would be loaded into it as follows:

N	00 01 02 03 04 05 06 07 ..... 30 31
REAL	00 02 04 06 08 10 12 14 ..... 60 62
IMAGINARY	01 03 05 07 09 11 13 15 ..... 61 63

This procedure is referred to as a pre-weave. In order to derive the desired results, the FFT is run, and then a post-weave operation is performed. The formula for the post-weave is shown below:

$$X_r(n) = \left[\frac{R(n)}{2} + \frac{R(N-n)}{2}\right] + \cos\frac{\pi n}{N}\left[\frac{I(N)}{2} + \frac{I(N-n)}{2}\right] - \sin\frac{\pi n}{N}\left[\frac{R(n)}{2} - \frac{R(N-n)}{2}\right] \quad n = 0, 1, \ldots, N-1$$

$$X_i(n) = \left[\frac{I(n)}{2} - \frac{I(N-n)}{2}\right] - \sin\frac{\pi n}{N}\left[\frac{I(n)}{2} + \frac{I(N-n)}{2}\right] - \cos\frac{\pi n}{N}\left[\frac{R(n)}{2} - \frac{R(N-n)}{2}\right] \quad n = 0, 1, \ldots, N-1 \qquad (11)$$

Where R(n) is the real FFT output value

I(n) is the imaginary FFT output value

Xr(n) is the real post-weave output

Xi(n) is the imaginary post-weave output

Note that the output is now one-sided instead of mirrored around the center frequency as it is in Figure 5. The magnitude of the signal at each frequency is calculated by taking the square root of the sum of the squares. The magnitude can now be plotted against frequency, where the frequency steps are defined as:

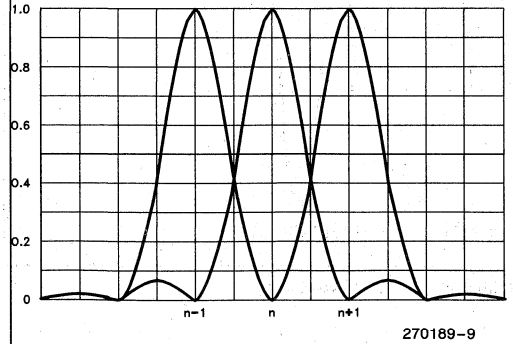
$$\frac{n}{NT} \quad n = 0, 1, 2, 3, \ldots, N-1$$

Where N is the number of complex samples (ie. 32 in this case) T is the time between samples

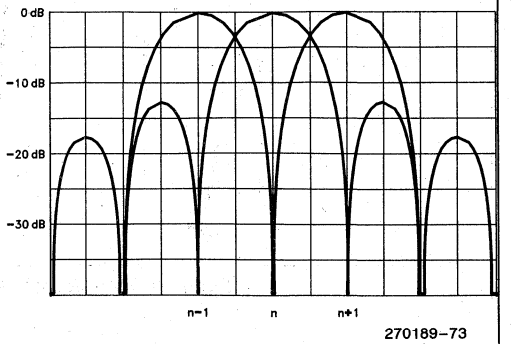
A value of zero on the frequency scale corresponds to the DC component of the waveform. Most signal analysis is done using Decibels (dB), the conversion is dB = 10 LOG (Magnitude squared). Decibels are not used as an absolute measure, instead signals are compared by the difference in decibels. If the ratio between two signals is 1:2 then there will be a 3 dB difference in their power.

5.0 USING THE FFT

There are several things to be aware of when using FFTs, but with the proper cautions, the FFT output can be used just like that of a spectrum analyzer. The



(a.) Relative Power of Windows (Side Lobes of Side Bins Removed for Clarity).



(b.) 10 Log Relative Power of Windows (Side Lobes of Side Bins Removed for Clarity).

Figure 6. Bin Windows

first precaution is that the FFT is a discrete approximation to a continuous Fourier Transform, so the output will seldom fit the theoretical values exactly, but it will be very close.

Since the programs in this application note generate a one-sided transform with N = 32, the frequency granularity is fairly course. Each of the frequency components output from the FFT is actually the sum of all energy within a narrow band centered on that frequency. This band of sensitivity is referred to as a "bin". The reported magnitude is the actual magnitude multiplied by the value of the bin window at the actual frequency. Figure 6 shows several bin windows. Note that these windows overlap, so that a frequency midway between the two center frequencies will be reported as energy split between both windows. Be careful not to confuse the *sampling window* NT with *bin windows* or with the *windowing function*.

Another area of caution is the relationship of the sampling window to the frequency of the waveform. For the best accuracy, the window should cover an exact multiple of the period of the waveform being analyzed. If it covers less than one period, the results will be invalid. Other variations from ideal will not produce invalid results, just additional noise in the output.

If the sampling window does not cover an exact multiple of all of the frequency components of a waveform, the FFT results will be noisy. The reason for this is the sharp edge that the FFT sees when the edges of the window cut off the input waveform. Figure 7 shows a waveform that is an exact multiple of the window and

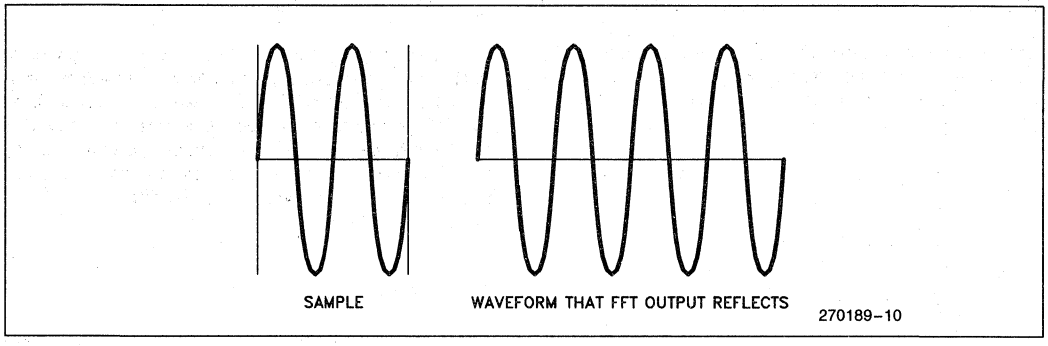


Figure 7. Waveform is a Multiple of the Window

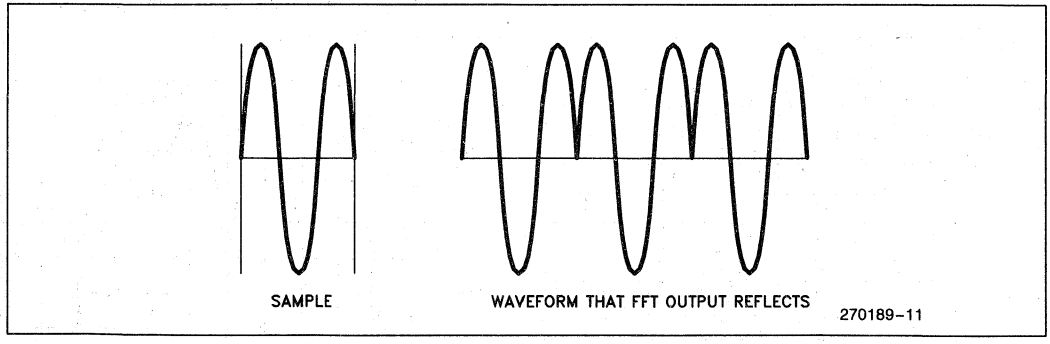
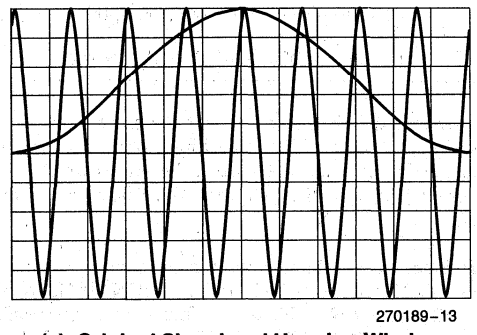


Figure 8. Waveform is Not a Multiple of the Window

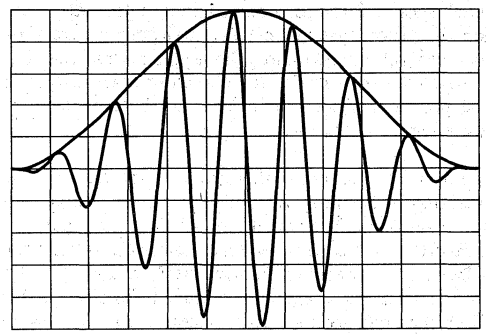
the periodic waveform that the FFT output reflects. In Figure 8, the waveform is not a multiple of the window and the waveform that the FFT output reflects has discontinuities. These discontinuities contribute to the noise in an FFT output. This noise is called "spectral leakage", or simply "leakage", since it is leakage between one frequency spectrum and another which is caused by digitization of an analog process.

To reduce this leakage, a process called windowing is used. In this procedure the input data is multiplied by specific values before being used in the FFT. The term "windowing" is used because these values act as a window through which the input data passes. If the input window goes smoothly to zero at both endpoints of the sampling window, there can be no discontinuities. Figure 9 shows a Hanning window and its effect on the input to an FFT. The Hanning window was named after its creator, Julius Von Hann, and is one of the most commonly used windows. More information on windowing and the types of windows can be found in the paper by Harris listed in the bibliography. As expected, the results of the FFT are changed because of the input windowing, but it is in a very predictable way.

Using the Hanning window results in bin windows which are wider and lower in magnitude than normal, as can be seen by comparing Figure 6 with Figure 10. For an input frequency which is equal to the center frequency of a bin window, the attenuation will be 6 dB on the center frequency. Since the bin windows are

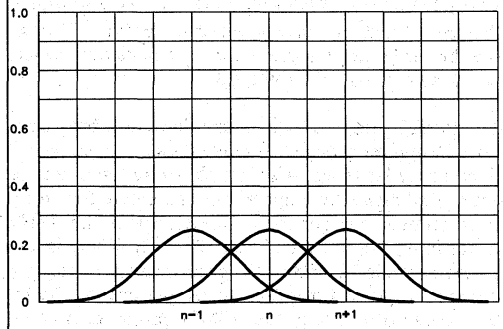


(a). Original Signal and Hanning Window

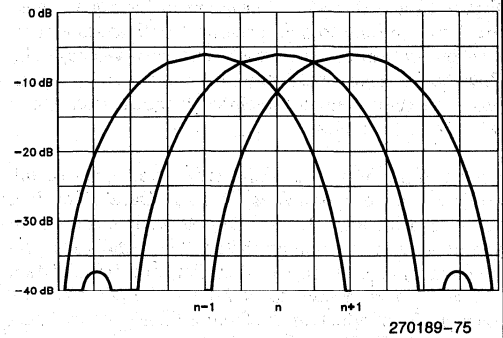


(b). Signal After Hanning Window

Figure 9. Effect of Hanning Window on FFT Input



(a.) Relative Power of Hanning Window



(b.) 10 Log Power of Hanning Window (Side Lobes of Side Bin Window Removed)

Figure 10. Bin Windows after Using Hanning Input Window

wider than normal, the input frequency will also have energy which falls into the bins on either side of center. These side bins will show a reading of 6 dB below the center window. The disadvantage of this spreading is far less than the advantage of removing leakage from the FFT output.

A set of FFT output plots are included in the Appendix. These plots show the effect of windowing on various signals. There are examples of all of the cases described above. A brief discussion of the plots is also presented.

Applications which can make use of this frequency magnitude information include a wide range of signal processing and detection tasks. Many of these tasks use digital filtering and signature analysis to match signals to a standard. This technique has been applied to anti-knock sensors for automobile engines, object identification for vision systems, cardiac arrhythmia detectors, noise separation and many other applications. The ability to do this on a single-chip computer opens a door to new products which would have not been possible or cost effective previously.

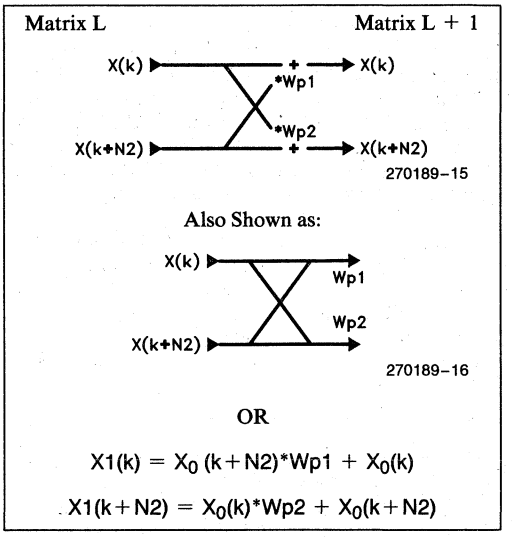
The next four sections of this application note cover the operation of the programs on a line by line basis. Section 6 shows an implementation of the FFT algorithm in BASIC. This code is used as a template to write the ASM96 code in Section 7. Sections 8, 9, and 10 cover the code sections which support the FFT module. After all of the code sections are discussed, an overview of how to use the program is presented in Section 11.

6.0 BASIC PROGRAM FOR FFTS

The algorithm for this FFT is shown in the flowchart in Figure 11 and the BASIC program in Listing 1. There are four sections to this program: initialization, pre-weaving, transform calculation, and post-weaving. The flowchart is generalized, however, the BASIC program has been optimized for assembly language conversion with 64 real samples.

On the flowchart, the initialization and pre-weaving sections are incorporated as "Read in Data". The data to be read includes the raw data as well as the size of the array and the scaling factor. The details for pre-weaving have been discussed earlier, and initialization varies from computer to computer. LOOP COUNT keeps track of which of the factored matrices are being multiplied. SHIFT is the shift count which is used to determine the power of W (as defined earlier) which will be used in the loop.

For each loop N calculations are performed in sets of two. Each calculation set is referred to as a butterfly and has the following form:



In general, the W factors are not the same. However, for the case of this FFT algorithm, Wp1 will always equal (−Wp2). This is because of the way in which "p" is calculated, and the fact that W(x) is a sinusoidal function.

The inner loop in the flowchart is performed N2 times. For LOOP = 1, N2 = N/2 and if INCNT = N2 then k = N2 and k + N2 = N, so the first loop is done and parameters LOOP, N2, and SHIFT are updated. For the first loop, all N/2 sets of calculations are performed contiguously. As LOOP increases, the number of contiguous calculations are cut in half, until LOOP = EXPONENT.

When LOOP = EXPONENT, N2 = 1, the butterfly is then performed on adjacent variables. Figure 12 shows the butterfly arrangement for a calculation where N = 8, so that EXPONENT = 3.

The BASIC program follows this flowchart, but operations have been grouped to make it easier to convert it to assembly language. Also not shown in the flowchart are several divide by 2 operations. There are five in the main section, one per loop. These provide the T/NT factor in equation 8 for N = 32 ($2^5 = 32$). There is also an extra divide by two in the post-weave section. It is required to prevent overflows when performing the 16-bit signed arithmetic in the ASM96 program. As a result of these operations, the input scale factor is $\pm 1 = \pm 32767$ and the output scaling is $\pm 1 = \pm 16384$. Note, the maximum input values are ± 0.99997.

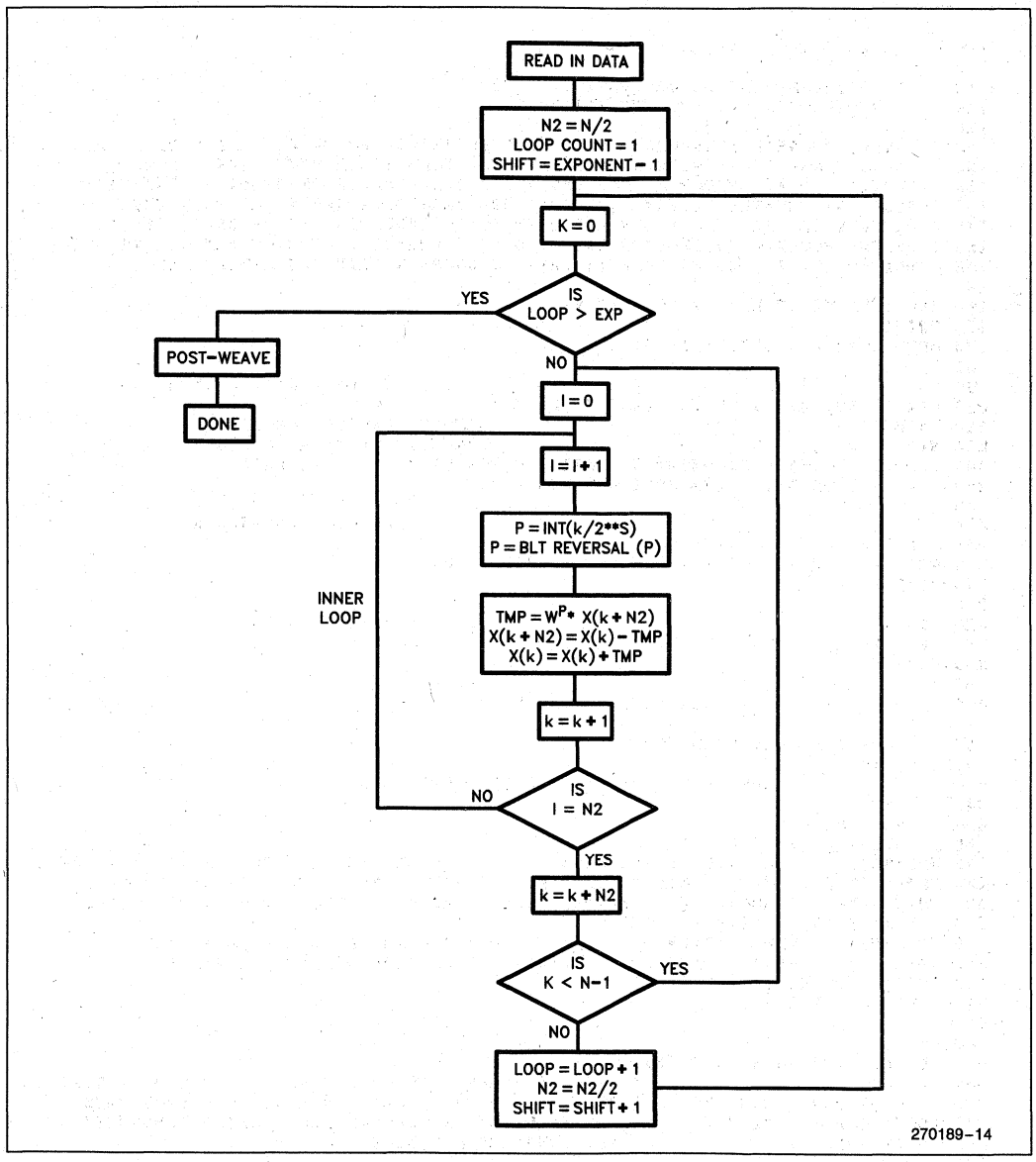


Figure 11. Flowchart of Basic Program

```
100 '  THIS IS FFT13, FEBRUARY 4, 1986
105 '
110     ' COPYRIGHT INTEL CORPORATION, 1985
115     ' BY IRA HORDEN, MCO APPLICATIONS
120 '
125 '    THIS PROGRAM PERFORMS A FAST FOURIER TRANSFORM ON 64 REAL DATA POINTS
130 ' USING A 2N-POINTS WITH AN N-POINT TRANSFORM ALGORITHM.  THE FIRST
135 ' SECTION OF THE PROGRAM PERFORMS A STANDARD TRANSFORM ON DATA THAT HAS
140 ' BEEN INTERLEAVED BETWEEN THE REAL AND IMAGINARY INPUT VALUES.  THE
145 ' RESULTS OF THAT TRANSFORM ARE THEN POST-PROCESSED IN THE SECOND SECTION
150 ' OF THE PROGRAM TO PROVIDE THE 32 OUTPUT BUCKETS.  THE OUTPUT VALUES ARE
155 ' MULTIPLIED BY "M" TO MAKE IT EASY TO COMPARE WITH THE ASM-96 PROGRAM
160 '
165 INPUT "NAME OF LIST FILE"; LST$
170 PRINT
175 OPEN LST$ FOR OUTPUT AS #1
180 '
200                                              ' SET UP VARIABLES FOR BASIC
210 DIM XR(32),XI(32),WR(32),WI(32),BR(32)
220 M=16383                                     ' M=MULT. FACTOR FOR SCALING
230 N=32 : N1=31 : N2=N/2                       ' N=NUMBER OF DATA POINTS
240 LOOP=1  : K=0 : EXPONENT=5 : SHIFT=EXPONENT-1       ' 2**E=N
250 PI=3.141592654# : TPN=2*PI/N : PIN=PI/N
260 '
270                                              ' READ IN CONSTANTS
280 FOR P=0 TO 31 : PN=P*TPN
290 WR(P)=COS(PN) : WI(P)=-SIN(PN) : READ BR(P)
300 NEXT P
310 '
320 FOR K=0 TO 31                               ' READ IN DATA
330 READ XR(K)  : READ XI(K)
350 NEXT K
360 '
400             ' INITIALIZATION OF LOOP
410 K=0
420 IF LOOP>EXPONENT THEN 700
430 INCNT=0
440             ' ACTUAL CALCULATIONS BEGIN HERE
445 '
450 INCNT=INCNT+1
460 P=BR(INT(K/(2^SHIFT)))
470 WRP=WR(P) : WIP=WI(P) : KN2=K+N2       ' WRP AND WIP ARE CONSTANTS BASED ON
480 TMPR= (WRP*XR(KN2) - WIP*XI(KN2))/2    ' SINES AND COSINES OF BIT REVERSED
490 TMPI= (WRP*XI(KN2) + WIP*XR(KN2))/2    ' VALUES OF K SHIFTED RIGHT S TIMES
500 TMPR1=XR(K)/2 : TMPI1=XI(K)/2
510 XR(K+N2) = TMPR1 - TMPR      ' TMPR, TMPI ARE THE REAL AND IMAGINARY
520 XI(K+N2) = TMPI1 - TMPI      ' RESULTS OF A COMPLEX MULTIPLICATION
530 XR(K) = TMPR1 + TMPR
540 XI(K) = TMPI1 + TMPI
550 '
560 K=K+1
570 IF INCNT<N2 THEN GOTO 450
580 K=K+N2                    ' SINCE THE ARRAY IS PROCESSED 2 POINTS AT A TIME,
590 IF K<N1 THEN GOTO 430     ' ONLY N/2 LOOPS NEED TO BE MADE.  ON EACH PASS,
600 LOOP=LOOP+1 : N2=N2/2     ' THE VALUE OF N2 CHANGES AND SMALLER CONSECUTIVE
605 SHIFT=SHIFT-1             ' SECTIONS ARE PROCESSED.
610 GOTO 400
620 '
690 '
691 '
692 '
693 '
```

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Listing 1—BASIC FFT Program

```
694 '
695 '
696 '
697 '
700                                 ' POST-PROCESSING AND REORDERING BEGIN HERE
710 '
720 FOR K = 0 TO 31
730 KPIN=K*PIN
740 XRBRK=XR(BR(K)) : XIBRK=XI(BR(K))    ' CONDENSED FOR EASE OF ASM PROGRAMMING
750 XRBRNK=XR(BR(N-K)) : XIBRNK=XI(BR(N-K))
760 TI = (XIBRK+XIBRNK)/2
770 TR = (XRBRK-XRBRNK)/2
780 XRT= (XRBRK+XRBRNK)/4
790 XIT= (XIBRK-XIBRNK)/4
800 OUTR= XRT + TI*COS(KPIN)/2 - TR*SIN(KPIN)/2
810 OUTI= XIT - TI*SIN(KPIN)/2 - TR*COS(KPIN)/2
820 '
830 MAGSQ = OUTR*OUTR+OUTI*OUTI     ' THE ASM-96 PROGRAM USES A TABLE LOOK-UP
840 MAG = SQR(MAGSQ)                ' ROUTINE TO CALCULATE SQUARE ROOTS
845 IF MAGSQ*M < .5 THEN DECIBEL=0 : GOTO 900
847 DBFACT=M/2/32767*M   ' M^2 / 64K
850 DECIBEL=10*LOG(MAGSQ*DBFACT)
860 DECIBEL=DECIBEL * .434294481#
900    GOTO 930
910 PRINT #1, USING "######  "; K,
920 PRINT #1, USING "\       \"; HEX$(M*OUTR), HEX$(M*OUTI), HEX$(M*MAG)
930 ' GOTO 950
942 PRINT #1, USING "##  "; K;
943 PRINT #1, USING "##.#####  "; OUTR,OUTI,MAG;
945 PRINT #1, USING "###.###  "; DECIBEL;
947 PRINT #1, USING "######   "; M*OUTR, M*OUTI, M*MAG
950 NEXT K
960 '
970 IF LST$<>"SCRN:" THEN PRINT #1, CHR$(12)
999 END
1000 END
1010              ' DATA FOR BR(P)  - BIT REVERSAL
1020 DATA 0,16,8,24,4,20,12,28,2,18,10,26,6,22,14,30
1030 DATA 1,17,9,25,5,21,13,29,3,19,11,27,7,23,15,31
1040              ' DATA FOR XR,XI
1050 DATA 2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2
1060 DATA 2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2
1070 DATA -2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2
1080 DATA -2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2,-2
```

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Listing 1—BASIC FFT Program (Continued)

6

Lines 165-175 set up the file for printing the data, this can be SCRN:, LPT1:, or any other file.

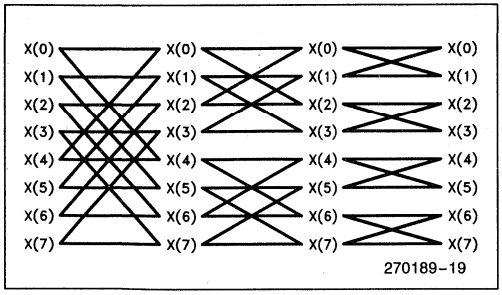

Figure 12. Butterflies with N = 8

Lines 200-310 set up the constants and calculate the WP terms which are stored in the matrices WR(p) and WI(p), for the real and imaginary component respectively.

Lines 320-350 read in the data, alternately placing it into the real and imaginary arrays. The data is scaled by 2 to make the data table simpler.

Lines 410-430 initialize the loop and test for completion.

Lines 450-620 perform the FFT algorithm. Note that all calculations are complex, with the suffixes "R" and "I" indicating real and imaginary components respectively.

The variables on line 470, TMPR1 and TMPI1 would normally not be used in a BASIC program as more than one operation can be performed on each line. However, indirect table lookups always use a separate line of assembly code, so separate lines have been used here.

Lines 700-810 perform the post-weave. This is not in the flowchart, but can be found in Equation 11. Once again, table look-ups are separated and additional variables are used for clarity. The variables BR(x) are the bit reversal values of x.

Line 830 calculates the magnitude of the harmonic components.

Lines 900-950 print the results of the calculations, with line 900 determining if the print-out should be in hex or decimal.

Lines 1000-1080 are the data for the bit reversal values and input datapoints. The input waveform is one cycle of a square-wave.

7.0 ASM96 PROGRAM FOR FFTS

The BASIC program just presented has been used as an outline for the ASM96 program shown in Listing 2. There are many advantages to using the BASIC program as a model, the main ones being debugging and testing. Since the BASIC program is so similar in program flow to the ASM96 program, it's possible to stop the ASM96 program at almost any point and verify that the results are correct.

```
MCS-96 MACRO ASSEMBLER    FFT_RUN                          02/18/86        PAGE    1

SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE: :F2:FFTRUN.A96
OBJECT FILE: :F2:FFTRUN.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: NOSB

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                 1   $pagelength(50)
                                 2
                                 3   FFT_RUN  MODULE  STACKSIZE(6)
                                 4
                                 5   ; Intel Corporation, January 24, 1986
                                 6   ; by Ira Horden, MCO Applications
                                 7
                                 8
                                 9   ;      This module performs a fast fourier transform (FFT) on 64 real data
                                10   ; points using a 2N-point algorithm.  The algorithm involves using a standard
                                11   ; FFT procedure for 32 real and 32 imaginary numbers.  The real and imaginary
                                12   ; arrays are filled alternately with real data points, and the output of the
                                13   ; FFT is run through a post-processor.  The result is a one sided array with 32
                                14   ; output buckets.  The post processing includes a table lookup algorithm for
                                15   ; taking the square root of an unsigned 32-bit number.
                                16
                                17   ;     All of the calculations in the main FFT program are done using 16-bit
                                18   ; signed integers.  The maximum value of any frequency component is therefore
                                19   ; +/- 32K.  (Note that a square wave of +/-32K has a fundamental component
                                20   ; greater than +/- 40K).  Wherever possible tables are used to increase the
                                21   ; speed of math operations.  The complete transform, including obtaining the
                                22   ; absolute magnitude of each frequency component, executes in 12
                                23   ; milliseconds with internal variables, 14 ms with external.
                                24
                                25   ;     The program requires two 32-word input arrays, with the sample values
                                26   ; alternated between the two.  These start at XREAL and XIMAG.  The resultant
                                27   ; magnitude will be placed in a 32-word array at FFT_OUT.  These are all
                                28   ; externally defined variables.  The external constant SCALE_FACTOR is used to
                                29   ; divide the output when averaging will be used.  Since the program averages
                                30   ; its output, it is necessary to clear the array based at FFT_OUT before
                                31   ; calling FFT_CALC to start the program.
                                32
                                33   ;     The program was originally written in BASIC for testing purposes.  The
                                34   ; comments include these BASIC statements to make it easier to follow the
                                35   ; algorithm.
                                36
                                37   $EJECT
```

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```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                  02/18/86          PAGE    2

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                 38
    0000                         39  RSEG
                                 40   EXTRN  port1, zero, error
                                 41
    0024                         42  OSEG at 24H
    0024                         43          TMPR:   dsl     1       ; Temporary register, Real
    0028                         44          TMPI:   dsl     1       ; Temporary register, Imaginary
    002C                         45          TMPR1:  dsl     1       ; Temporary register1, Real
    0030                         46          TMPI1:  dsl     1       ; Temporary register1, Imaginary
    0034                         47          XRTMP:  dsl     1       ; Temporary data register, Real
    0038                         48          XITMP:  dsl     1       ; Temporary data register, Imaginary
    003C                         49          XRRK:   dsl     1
    0040                         50          XRRNK:  dsl     1
    0044                         51          XIRK:   dsl     1
    0048                         52          XIRNK:  dsl     1
      003C                       53          diff    equ     xrrk    :long   ; Table difference for square root
      0040                       54          sqrt    equ     xrrnk   :long   ; Square root
      0040                       55          log     equ     xrrnk   :long   ; 10 Log magnitude^2
      0044                       56          nxtloc  equ     xirk    :long   ; Next location in table
                                 57
      003C                       58          WRP     equ     xrrk    :word   ; Multiplication factor, Real
      003E                       59          WIP     equ     xrrk+2  :word   ; Multiplication factor, Imaginary
      0040                       60          PWR     equ     xrrnk   :word
      0042                       61          IN_CNT  equ     xrrnk+2 :word
      0044                       62          NDIV2   equ     xirk    :word   ; n divided by 2  (0 < n < N) *2
                                 63
    004C                         64          KPTR:           dsw     1       ; K for counter *2 to index words
    004E                         65          KN2:            dsw     1       ; KPTR + NDIV2
    0050                         66          N_SUB_K:        dsw     1       ; N-K *2 to index words
    0052                         67          RK:             dsw     1       ; Bit reversed pointer of KPTR
    0054                         68          RNK:            dsw     1       ; Bit reversed pointer of N_SUB_K
    0056                         69          SHFT_CNT:       dsw     1
    0058                         70          LOOP_CNT:       dsb     1
      004E                       71          ptr     equ     kn2     :word   ; Pointer for square root table
    0000                         72  DSEG
                                 73
                                 74  EXTRN   FFT_MODE        ; FFT_MODE: mode for FFT input and graphing
                                 75  EXTRN   XREAL, XIMAG    ; XREAL, XIMAG: Base  addresses for 32 16-bit signed
                                 76                          ; entries for real and imaginary numbers respectively.
                                 77  EXTRN   FFT_OUT         ; FFT_OUT: Starting address for 32 word array
                                 78                          ; of magnitude information.
                                 79
    0000                         80          OUTR:   dsw     32      ; Real component of fft
    0040                         81          OUTI:   dsw     32      ; Imaginary component of waveform
                                 82   PUBLIC OUTR,OUTI
                                 83
                                 84  $EJECT
```

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```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                    02/18/86          PAGE    3

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                 85
    2280                         86  CSEG at 2280H
                                 87
                                 88   PUBLIC fft_calc        ; Starting point for FFT algorithm
                                 89
                                 90   EXTRN  scale_factor    ; Shift factor used to prevent overflow when averaging
                                 91                          ; fft outputs
                                 92
                                 93
                                 94  ;                                ;;;;    START FOURIER CALCULATIONS
    2280                         95  FFT_CALC:                        ;;;;    400  ' INITIALIZATION OF LOOP
    2280 1100              E     96          clrb    error
    2282 B10100            E     97          ldb     port1,#00000001b                    ;*** Indication Only
                                 98
    2285 FC                      99          clrvt
    2286 B10158                 100          ldb     loop_cnt,#1
    2289 B10456                 101          ldb     shft_cnt,#4
    228C A1200044               102          ld      ndiv2,#32
                                103  ;                                ;;;;    410 K=0
    2290                        104  OUT_LOOP:
    2290 950400            E    105          xorb    port1,#00000100B                    ;***  Indication Only
    2293 014C                   106          clr     kptr
                                107  ;                                ;;;;    420 IF LOOP > EXP THEN 700
    2295 990558                 108          cmpb    loop_cnt, #5    ; 32=2^5
    2298 DA0220A3               109  !       bgt     UNWEAVE
                                110
                                111
    229C                        112  MID_LOOP:                        ;;;;    430 INCNT=0
    229C 0142                   113          clr     in_cnt
                                114
                                115                                  ;;;;    440  ' CALCULATIONS BEGIN HERE
    229E                        116  IN_LOOP:
    229E 65020042               117          add     in_cnt,#2       ;;;;    450 INCNT=INCNT+1
                                118  ;                               ;;;;    460 P=BR(INT(K/(2^SHIFT)))
    22A2 A04C40                 119          ld      pwr,kptr
    22A5 085640                 120          shr     pwr,shft_cnt            ;; Calculate multiplication factors
    22A8 71FE40                 121          andb    pwr,#11111110B
    22AB A341003840             122          ld      pwr,brev[pwr]
                                123  ;                                ;;;;    470 WRP=WR(P) : WIP=WI(P) : KN2=K+N2
    22B0 A34144393C             124  gw:     ld      wrp,wr[pwr]
    22B5 A34186393E             125          ld      wip,wi[pwr]
    22BA 44444C4E               126          add     kn2,kptr,ndiv2
                                127  $eject
```

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Listing 2—ASM96 FFT Program (Continued)

```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                  02/18/86          PAGE    4

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                               128           ;; Complex multiplication follows
                               129
                               130   ;                                   ;;;;    480 TMPR= (WRP*XR(KN2) - WIP*XI(KN2))/2
    22BE FE4F4F00003C24    E   131   gm:     mul     tmpr,wrp,xreal[kn2]
    22C5 FE4F4F00003E28    E   132         mul     tmpi,wip,ximag[kn2]
    22CC 682A26                133         sub     tmpr+2,tmpi+2
                               134   ;                                   ;;;;    490 TMPI= (WRP*XI(KN2) + WIP*XR(KN2))/2
    22CF FE4F4F00003C2C    E   135         mul     tmprl,wrp,ximag[kn2]
    22D6 FE4F4F00003E28    E   136         mul     tmpi,wip,xreal[kn2]
    22DD 642E2A                137         add     tmpi+2,tmprl+2
                               138
                               139                 ;;  using the high byte only of a signed multiply
                               140                 ;;  provides an effective divide by two
                               141
    22E0 DC55                  142         BVT     ERR1    ; Branch on error in complex multiplications
                               143
    22E2 A34D00002C        E   144         ld      tmprl,xreal[kptr]       ;;;;    500 TMPR1=XR(K)/2 :
    22E7 0A012C                145         shra    tmprl,#1                ;;;;        TMPI1=XI(K)/2
    22EA A34D0000030       E   146         ld      tmpil,ximag[kptr]
    22EF 0A0130                147         shra    tmpil,#1
                               148
                               149   ;                                   ;;;;    510 XR(KN2) = TMPR1 - TMPR
    22F2 48262C34              150   gr2:    sub     xrtmp,tmprl,tmpr+2
    22F6 C34F000034        E   151         st      xrtmp,xreal[kn2]
                               152   ;                                   ;;;;    520 XI(KN2) = TMPI1 - TMPI
    22FB 482A3038              153   gx2:    sub     xitmp,tmpil,tmpi+2
    22FF C34F000038        E   154         st      xitmp,ximag[kn2]
                               155   ;                                   ;;;;    530 XR(K) = TMPR1 + TMPR
    2304 44262C34              156         add     xrtmp,tmprl,tmpr+2
    2308 C34D000034        E   157         st      xrtmp,xreal[kptr]
                               158   ;                                   ;;;;    540 XI(K) = TMPI1 + TMPI
    230D 442A3038              159   gx:     add     xitmp,tmpil,tmpi+2
    2311 C34D000038        E   160         st      xitmp,ximag[kptr]
                               161
    2316 DC23                  162         BVT     ERR2    ; Branch on error in complex additions
                               163
                               164   $eject
```

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```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                    02/18/86          PAGE    5

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               165   ;                                ;;;;    560 K=K+1
    2318 6502004C              166   ik:     add     kptr,#2
                               167
                               168   ;                                ;;;;    570 IF INCNT<N2 THEN  GOTO 450
    231C 884442                169           cmp     in_cnt,ndiv2
    231F D602277B              170   !       blt     IN_LOOP
                               171
                               172   ;                                ;;;;    580 K=K+N2
    2323 64444C                173           add     kptr,ndiv2
                               174   ;                                ;;;;    590 IF K<N1 THEN GOTO 430
    2326 893E004C              175           cmp     kptr,#62
    232A D602276E              176   !       blt     MID_LOOP
                               177
                               178                                    ;;;;    600 LOOP=LOOP+1 : N2=N2/2
    232E 1758                  179           incb    loop_cnt         ;;;;    605 SHIFT=SHIFT+1
    2330 0A0144                180           shra    ndiv2,#1
    2333 1556                  181           decb    shft_cnt
                               182   ;                                ;;;;    610 GOTO 400
    2335 2759                  183           br      OUT_LOOP
                               184
                               185
    2337 B10100          E     186   ERR1:   ldb     error,#01        ; overflow error, 1st set of calculations
    233A F0                    187           ret
    233B B10200          E     188   ERR2:   ldb     error,#02        ; overflow error, 2nd set of calculations
    233E F0                    189           ret
                               190
                               191   $EJECT
```

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Listing 2—ASM96 FFT Program (Continued)

```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                    02/18/86          PAGE    6

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                192
                                193  ;                        ;;;;    700 ' POST-PROCESING AND REORDERING STARTS HERE
    233F                        194  UNWEAVE:
    233F B10200           E     195          ldb     portl,#00000010b                    ;****
                                196
                                197  ;                                ;;;;    720 FOR K=0 TO 31
    2342 014C                   198          clr     kptr
    2344 A1400050               199          ld      n_sub_k,#64
    2348                        200  UN_LOOP:
                                201  ;                                ;;;;    740 XIBRK=XI(BR(K)) : XRBRK=XR(BR(K)
    2348 A34D003852             202          ld      rk,brev[kptr]
    234D A35300003C       E     203          ld      xrrk,xreal[rk]
    2352 063C                   204          ext     xrrk
    2354 A353000044       E     205          ld      xirk,ximag[rk]
    2359 0644                   206          ext     xirk
                                207  ;                                ;;;;    750 XIBRNK=XI(BR(N-K):XRBRNK=XR(BR(N-K)
    235B A351003854             208          ld      rnk,brev[n_sub_k]
    2360 A355000040       E     209          ld      xrrnk,xreal[rnk]
    2365 0640                   210          ext     xrrnk
    2367 A355000048       E     211          ld      xirnk,ximag[rnk]
    236C 0648                   212          ext     xirnk
                                213  ;                                ;;;;    760 TI=(XIBRK + XIBRNK)/2
    236E 44484428               214  ar:     add     tmpi,xirk,xirnk
    2372 A04A2A                 215          ld      tmpi+2,xirnk+2
    2375 A4462A                 216          addc    tmpi+2,xirk+2
    2378 0E0128                 217          shral   tmpi,#1          ; 16 bit result in tmpi
                                218
                                219                                   ;;;;    770 TR=(XRBRK - XRBRNK)/2
    237B 48403C24               220          sub     tmpr,xrrk,xrrnk
    237F A03E26                 221          ld      tmpr+2,xrrk+2
    2382 A84226                 222          subc    tmpr+2,xrrnk+2
    2385 0E0124                 223          shral   tmpr,#1          ; 16 bit result in tmpr
                                224
                                225                                   ;;;;    780 XRT= (XRBRK + XRBRNK)/4
    2388 44403C34               226          add     xrtmp,xrrk,xrrnk
    238C A03E36                 227          ld      xrtmp+2,xrrk+2
    238F A44236                 228          addc    xrtmp+2,xrrnk+2
    2392 0D0E34                 229          shll    xrtmp,#14        ; 32 bit result in xrtmp
                                230
                                231                                   ;;;;    790 XIT= (XIBRK-XIBRNK)/4
    2395 48484438               232          sub     xitmp,xirk,xirnk
    2399 A0463A                 233          ld      xitmp+2,xirk+2
    239C A84A3A                 234          subc    xitmp+2,xirnk+2
    239F 0D0E38                 235          shll    xitmp,#14        ; 32 bit result in xitmp
                                236
                                237  $eject
```

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Listing 2—ASM96 FFT Program (Continued)

```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                    02/18/86          PAGE    7

ERR LOC  OBJECT                LINE      SOURCE STATEMENT
                                238  ;       ;;;;;                  Multiply will provide effective divide by 2
                                239
                                240  ;                       ;;;;    800 OUTR= (XRT + TI*COSFN(K)/2 - TR*SINFN(K)/2)
                                241
    23A2 FE4F4D4038242C         242  mr:     mul     tmprl,tmpr,sinfn[kptr]
    23A9 FE4F4DC2382830         243          mul     tmpil,tmpi,cosfn[kptr]
    23B0 643034                 244          add     xrtmp,tmpil
    23B3 A43236                 245          addc    xrtmp+2,tmpil+2
    23B6 682C34                 246          sub     xrtmp,tmprl
    23B9 A82E36                 247          subc    xrtmp+2,tmprl+2
    23BC C34D000036       R     248          st      xrtmp+2,outr[kptr]      ;; OUTR = Real Output Values
                                249
                                250
                                251  ;                       ;;;;    810 OUTI= (XIT - TI*SINFN(K)/2 - TR*COSFN(K)/2)
                                252
    23C1 FE4F4DC238242C         253  mi:     mul     tmprl,tmpr,cosfn[kptr]
    23C8 FE4F4D40382830         254          mul     tmpil,tmpi,sinfn[kptr]
    23CF 683038                 255          sub     xitmp,tmpil
    23D2 A8323A                 256          subc    xitmp+2,tmpil+2
    23D5 682C38                 257          sub     xitmp,tmprl
    23D8 682E3A                 258          sub     xitmp+2,tmprl+2
    23DB C34D40003A       R     259          st      xitmp+2,outi[kptr]      ;; OUTI = Imaginary Output values
                                260
                                261
                                262                                  ;;;;    830 MAG =SQR(OUTR*OUTR + OUTI*OUTI)
                                263
    23E0                        264  GET_MAG:                                ;; Get Magnitude of Vector
    23E0 A03624                 265          ld      tmpr,xrtmp+2
    23E3 A03A28                 266          ld      tmpi,xitmp+2
                                267
    23E6 FE6C2424               268          mul     tmpr,tmpr               ; tmpr = tmpi**2 + tmpr**2
    23EA FE6C2828               269          mul     tmpi,tmpi
    23EE 642824                 270          add     tmpr,tmpi
    23F1 A42A26                 271          addc    tmpr+2,tmpi+2
                                272
    23F4 32004C           E     273          bbc     FFT_MODE,2,CALC_SQRT
                                274
                                275  $eject
```

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Listing 2—ASM96 FFT Program (Continued)

```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                  02/18/86          PAGE    8

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                276
                                277                ;;;;  ***  CALCULATE 10 log magnitude^2  ***
                                278  ; Output = 512*10*LOG(x)  x=1,2,3 ... 64K
                                279
    23F7                        280  CALC_LOG:
    23F7 0156                   281          clr     shft_cnt
    23F9 0F5624                 282          normal  tmpr,shft_cnt   ; Normalize and get normalization factor
    23FC 990F56                 283          cmpb    shft_cnt,#15
    23FF DA04                   284          jle     LOG_IN_RANGE    ;  Jump if SHIFT_CNT <= 15
                                285
    2401 0140                   286          clr     log
    2403 202C                   287          br      LOG_STORE
                                288
    2405                        289  LOG_IN_RANGE:
    2405 44566656               290          add     shft_cnt,shft_cnt,shft_cnt      ; Make shift_cnt a pointer
                                291
    2409 AC274E                 292          ldbze   ptr,tmpr+3      ; Most significant byte is table pointer
    240C 444E4E4E               293          add     ptr,ptr,ptr     ;
    2410 65083A4E               294          add     ptr,# LOG_TABLE-256     ; ptr= Table + offset  (offset=tmpr+3)
                                295                                  ; Use -256 since tmpr+3 is always >= 128
    2414 A24F40                 296          ld      log, [ptr]+
    2417 A24E44                 297          ld      nxtloc, [ptr]           ;; Linear Interpolation
                                298
    241A 684044                 299          sub     nxtloc,log      ; nxtloc = next log - log
                                300
    241D AC263C                 301          ldbze   diff,tmpr+2     ; diff+1 = nxtloc * tmpr+2 / 256
    2420 6C443C                 302          mulu    diff,nxtloc
                                303
    2423 0C083C                 304          shrl    diff,#8         ; log = log + diff/256
    2426 643C40                 305          add     log,diff
    2429 080540                 306          shr     log,#5          ; 8192/32 * 20LOG(x) = 256 * 20LOG(x)
                                307
    242C A7570A3C40             308          addc    log,log_offset[shft_cnt]        ; add log of normalization factor
                                309
                                310                  ;; Log (M*N) = Log M + Log N
                                311
    2431                        312  LOG_STORE:
    2431 080040           E    313          shr     log,#SCALE_FACTOR
    2434 A40040           E    314          addc    log,zero                ; Divide to prevent overflow during
    2437 674D000040       E    315          add     log,FFT_OUT[kptr]       ; averaging of outputs
    243C C34D000040       E    316          st      log,FFT_OUT[kptr]
                                317
    2441 2045                   318          BR      ENDL
                                319  $eject
```

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```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                   02/18/86          PAGE    9

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               320                          ;;;;  ***  CALCULATE SQUARE  ROOT  ***
    2443                       321   CALC_SQRT:
                               322
    2443 0156                  323   clr     shft_cnt
    2445 0F5624                324         norml   tmpr,shft_cnt   ; Normalize and get normalization factor
                               325
    2448 D705                  326         jne     SQRT_IN_RANGE   ;  Jump if tmpr > 0
    244A C04200          E     327         st      zero,sqrt+2
    244D 2029                  328         br      SQRT_STORE
                               329
    244F                       330   SQRT_IN_RANGE:
    244F AC274E                331         ldbze   ptr,tmpr+3      ; Most significant byte is table pointer
    2452 444E4E4E              332         add     ptr,ptr,ptr
    2456 650B394E              333         add     ptr,# SQ_TABLE-256      ; ptr= Table + offset  (offset=tmpr+3)
                               334                                 ; Use -256 since tmpr+3 is always >= 128
    245A A24F40                335         ld      sqrt, [ptr]+
    245D A24E44                336         ld      nxtloc, [ptr]           ;; Linear Interpolation
                               337
    2460 684044                338         sub     nxtloc,sqrt     ; nxtloc =  sqrt - next sqrt
                               339
    2463 AC263C                340         ldbze   diff,tmpr+2     ; diff+1 = nxtloc * tmpr+2 / 256
    2466 6C443C                341         mulu    diff,nxtloc
                               342
    2469 AC3D3C                343         ldbze   diff,diff+1     ; sqrt = sqrt + delta   (diff < 0FFH)
    246C 643C40                344         add     sqrt,diff
                               345
    246F 44565656              346         add     shft_cnt,shft_cnt,shft_cnt
                               347
    2473 6F57C83940            348         mulu    sqrt,tab_sqr[shft_cnt]  ; divide by normalization factor
                               349
                               350                                 ;; mulu acts as divide since if tab2=0FFFFH
                               351                                 ;; sqrt would remain essentialy unchanged
    2478                       352   SQRT_STORE:
    2478 080042          E     353         shr     sqrt+2,#SCALE_FACTOR
    247B A40042          E     354         addc    sqrt+2,zero             ; Divide to prevent overflow during
    247E 674D000042      E     355         add     sqrt+2,FFT_OUT[kptr]    ; averaging of outputs
    2483 C34D000042      E     356         st      sqrt+2,FFT_OUT[kptr]
                               357
                               358   ;             ;;;;    ***  END  OF  LOOP  ***
                               359
                               360                                 ;;;;    950 NEXT K
    2488 6502004C              361   ENDL:   add     kptr,#2
    248C 69020050              362         sub     n_sub_k,#2
    2490 DF0226B4              363   !       bne     UN_LOOP
                               364
    2494 F0                    365         RET
                               366   $eject
```

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```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                    02/18/86          PAGE   10

ERR LOC  OBJECT                  LINE       SOURCE STATEMENT
                                  367   ;$nolist
    3800                          368           CSEG  AT  3800H          ;;;;    Use 2k for tables
                                  369
    3800                          370   BREV:   ; 2*bit reversal value
                                  371
    3800 0000200010003000         372   DCW     2*0, 2*16, 2*8,  2*24, 2*4, 2*20, 2*12, 2*28
    3810 0400240014003400         373   DCW     2*2, 2*18, 2*10, 2*26, 2*6, 2*22, 2*14, 2*30
    3820 0200220012003200         374   DCW     2*1, 2*17, 2*9,  2*25, 2*5, 2*21, 2*13, 2*29
    3830 0600260016003600         375   DCW     2*3, 2*19, 2*11, 2*27, 2*7, 2*23, 2*15, 2*31
                                  376
    3840                          377   SINFN:
    3840 00008C0CF9182825         378   DCW         0,  3212,  6393,  9512, 12539, 15446, 18204, 20787
    3850 825AF1626D6AE270         379   DCW     23170, 25329, 27245, 28898, 30273, 31356, 32137, 32609
    3860 FF7F617F897D7C7A         380   DCW     32767, 32609, 32137, 31356, 30273, 28898, 27245, 25329
    3870 825A33511C47563C         381   DCW     23170, 20787, 18204, 15446, 12539,  9512,  6393,  3212
    3880 000074F307E7D8DA         382   DCW         0, -3212, -6393, -9512,-12539,-15446,-18204,-20787
    3890 7EA50F9D93951E8F         383   DCW    -23170,-25329,-27245,-28898,-30273,-31356,-32137,-32609
    38A0 01809F8077828485         384   DCW    -32767,-32609,-32137,-31356,-30273,-28898,-27245,-25329
    38B0 7EA5CDAEE4B8AAC3         385   DCW    -23170,-20787,-18204,-15446,-12539, -9512, -6393, -3212
    38C0 0000                     386   DCW         0
                                  387
    38C2                          388   COSFN:
    38C2 FF7F617F897D7C7A         389   DCW     32767, 32609, 32137, 31356, 30273, 28898, 27245, 25329
    38D2 825A33511C47563C         390   DCW     23170, 20787, 18204, 15446, 12539,  9512,  6393,  3212
    38E2 000074F307E7D8DA         391   DCW         0, -3212, -6393, -9512,-12539,-15446,-18204,-20787
    38F2 7EA50F9D93951E8F         392   DCW    -23170,-25329,-27245,-28898,-30273,-31356,-32137,-32609
    3902 01809F8077828485         393   DCW    -32767,-32609,-32137,-31356,-30273,-28898,-27245,-25329
    3912 7EA5CDAEE4B8AAC3         394   DCW    -23170,-20787,-18204,-15446,-12539, -9512, -6393, -3212
    3922 00008C0CF9182825         395   DCW         0,  3212,  6393,  9512, 12539, 15446, 18204, 20787
    3932 825AF1626D6AE270         396   DCW     23170, 25329, 27245, 28898, 30273, 31356, 32137, 32609
    3942 FF7F                     397   DCW     32767
                                  398
    3944                          399   WR:             ;;;;    WR = COS(K*2PI/N)
    3944 FF7F897D41766D6A         400   DCW     32767, 32137, 30273, 27245, 23170, 18204, 12539,  6393
    3954 000007E705CFE4B8         401   DCW         0, -6393,-12539,-18204,-23170,-27245,-30273,-32137
    3964 01807782BF899395         402   DCW    -32767,-32137,-30273,-27245,-23170,-18204,-12539, -6393
    3974 0000F918FB301C47         403   DCW         0,  6393, 12539, 18204, 23170, 27245, 30273, 32137
    3984 FF7F                     404   DCW     32767
                                  405
    3986                          406   WI:             ;;;;    WI = -SIN(K*2PI/N)
    3986 000007E705CFE4B8         407   DCW        -0, -6393,-12539,-18204,-23170,-27245,-30273,-32137
    3996 01807782BF899395         408   DCW    -32767,-32137,-30273,-27245,-23170,-18204,-12539, -6393
    39A6 0000F918FB301C47         409   DCW         0,  6393, 12539, 18204, 23170, 27245, 30273, 32137
    39B6 FF7F897D41766D6A         410   DCW     32767, 32137, 30273, 27245, 23170, 18204, 12539,  6393
    39C6 0000                     411   DCW         0
                                  412   $eject
```

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```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                    02/18/86          PAGE   11

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               413
                               414
    39C8                       415  TAB_SQR:        ; 65535/(square root of 2**SHFT_CNT) ;  0<=SHFT_CNT<32
                               416
                               417    ;;    1       2       4       8       16      32      64      128
    39C8 FFFF04B50080825A      418  DCW     65535,  46340,  32768,  23170,  16384,  11585,  8192,  5793
                               419
                               420    ;;    256     512     1024    2048    4096    8192    16384   32768
    39D8 0010500B0008A805      421  DCW     4096,   2896,   2048,   1448,   1024,   724,    512,   362
                               422
                               423    ;;    65536,  131072, 262144, 524288, ...
    39E8 0001B50080005B00      424  DCW     256,    181,    128,    91,     64,     45,     32,    23
    39F8 10000B0008000600      425  DCW     16,     11,     8,      6,      4,      3,      2,     1
                               426
                               427
    3A08                       428  SQ_TABLE:       ; square root of n * 2**24  N=128, 129, 130 ... 255
                               429
    3A08 05B5BAB56EB621B7      430  DCW      46341, 46522, 46702, 46881, 47059, 47237, 47415, 47591
    3A18 97BA46BBF5BBA3BC      431  DCW      47767, 47942, 48117, 48291, 48465, 48637, 48809, 48981
    3A28 00C0AAC054C1FDC1      432  DCW      49152, 49322, 49492, 49661, 49830, 49998, 50166, 50332
    3A38 43C5E9C58EC633C7      433  DCW      50499, 50665, 50830, 50995, 51159, 51323, 51486, 51649
    3A48 63CA04CBA6CB46CC      434  DCW      51811, 51972, 52134, 52294, 52454, 52614, 52773, 52932
    3A58 62CF00D09DD03AD1      435  DCW      53090, 53248, 53406, 53562, 53719, 53874, 54030, 54185
    3A68 44D4DED477D511D6      436  DCW      54340, 54494, 54647, 54801, 54954, 55106, 55258, 55410
    3A78 09D9A0D936DACCDA      437  DCW      55561, 55712, 55862, 56012, 56162, 56311, 56459, 56608
    3A88 B4DD47DEDBDE6EDF      438  DCW      56756, 56903, 57051, 57198, 57344, 57490, 57636, 57781
    3A98 46E2D7E267E3F7E3      439  DCW      57926, 58071, 58215, 58359, 58503, 58646, 58789, 58931
    3AA8 C1E64FE7DDE76AE8      440  DCW      59073, 59215, 59357, 59498, 59639, 59779, 59919, 60059
    3AB8 27EBB2EB3DECC7EC      441  DCW      60199, 60338, 60477, 60615, 60754, 60891, 61029, 61166
    3AC8 77EF00F088F010F1      442  DCW      61303, 61440, 61576, 61712, 61848, 61984, 62119, 62254
    3AD8 B4F33BF4C1F446F5      443  DCW      62388, 62523, 62657, 62790, 62924, 63057, 63190, 63323
    3AE8 DFF763F8E7F86AF9      444  DCW      63455, 63587, 63719, 63850, 63982, 64113, 64243, 64374
    3AF8 F8FB7AFCFBFC7DFD      445  DCW      64504, 64634, 64763, 64893, 65022, 65151, 65280, 65408
                               446
                               447  $eject
```

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Listing 2—ASM96 FFT Program (Continued)

```
MCS-96 MACRO ASSEMBLER    FFT_RUN                                    02/18/86        PAGE   12

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               448
    3B08                       449   LOG_TABLE:  ;   16384*10*LOG(n/128)     n=128,129,130 ... 256
                               450
    3B08 00002A024F047006      451   DCW          0,   554,  1103,  1648,  2190,  2727,  3260,  3789
    3B18 DA10E312E914EA16      452   DCW       4314,  4835,  5353,  5866,  6376,  6883,  7386,  7885
    3B28 BD20A92292247826      453   DCW       8381,  8873,  9362,  9848, 10330, 10810, 11286, 11758
    3B38 C42F973166333335      454   DCW      12228, 12695, 13158, 13619, 14076, 14531, 14983, 15432
    3B48 063EC13F7A413043      455   DCW      15878, 16321, 16762, 17200, 17635, 18067, 18497, 18925
    3B58 954B3C4DDF4E8150      456   DCW      19349, 19772, 20191, 20609, 21024, 21436, 21846, 22254
    3B68 8458175AA85B365D      457   DCW      22660, 23063, 23464, 23862, 24259, 24653, 25045, 25435
    3B78 DE646066E0675D69      458   DCW      25822, 26208, 26592, 26973, 27353, 27730, 28106, 28479
    3B88 B370247294730275      459   DCW      28851, 29220, 29588, 29954, 30318, 30680, 31040, 31399
    3B98 0B7C687DCF7E2F80      460   DCW      31755, 32110, 32463, 32815, 33165, 33512, 33859, 34203
    3BA8 F28647889B89ED8A      461   DCW      34546, 34887, 35227, 35565, 35902, 36236, 36570, 36901
    3BB8 7091B892FF934595      462   DCW      37232, 37560, 37887, 38213, 38537, 38860, 39181, 39501
    3BC8 8B9BC89C049E3E9F      463   DCW      39819, 40136, 40452, 40766, 41079, 41390, 41700, 42009
    3BD8 4CA57EA6AFA7DEA8      464   DCW      42316, 42622, 42927, 43230, 43533, 43833, 44133, 44431
    3BE8 B9AEE0AF07B12CB2      465   DCW      44729, 45024, 45319, 45612, 45905, 46196, 46486, 46774
    3BF8 D6B7F4B811BA2DBB      466   DCW      47062, 47348, 47633, 47917, 48200, 48482, 48763, 49042
    3C08 A9C0                  467   DCW      49321
                               468
    3C0A                       469   LOG_OFFSET:     ; 512*10*LOG(2**(15-n))    n= 0,1,2,3 ... 15
                               470                   ; 512*10*LOG(0.5)          n= 16,17,18 ... 31
                               471
    3C0A 4F5A4A54454E3F48      472   DCW      23119, 21578, 20037, 18495, 16954, 15413, 13871, 12330
    3C1A 252A20241A1E1518      473   DCW      10789,  9248,  7706,  6165,  4624,  3083,  1541,     0
                               474
    3C2A                       475   END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

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Listing 2—ASM96 FFT Program (Continued)

The BASIC program is used as comments in the ASM96 program. Some of the variables in the ASM96 program have slightly different names than their counter-parts in the BASIC program. This was to make the comments fit into the ASM96 code. Highlights in this section of code are a table driven square root routine and log conversion routine which can easily be adapted for use by any program.

Both the square root routine and the log conversion routine use the 32-bit value in the variable TMPR. The square root routine calculates the square root of that value in the variable SQRT+2, a 16-bit variable. In this program, the square root value is averaged and stored in a table.

The log conversion routine divides the value in TMPR by 65536 (2^{16}) and uses table lookup to provide the common log. The result is a 16-bit number with the value 512 * 10 Log (TMPR/65536) stored in the variable LOG. This calculation is used to present the results of the FFT in decibels instead of magnitude. With an input of 63095, the output is 512*48 dB. The graph program, (Section 10), prints the output value of the plot as INPUT/512 dB.

The following descriptions of the ASM code point out some of the highlights and not-so-obvious coding:

Lines 1-104 initialize the code and declare variables. The input and output arrays of the program are declared external. Note that many of the registers are overlayable, use caution when implementing this routine with others with overlayable registers.

Lines 116–124 calculate the power of W to be used. Note that KPTR is always incremented by 2. The multiple right shift followed by the AND mask creates an even address and the indirect look to the BR (Bit Reversal) table quickly calculates the power PWR.

Lines 130-138 perform the complex multiplications. Since WIP and WRP range from −32767 to +32767, the multiplication is easy to handle. The automatic divide by two which occurs when using the upper word only of the 32-bit result is a feature in this case.

Lines 144-163 use right shifts for a fast divide, then add or subtract the desired variables and store them in the array. Note that the upper word of TMPR and TMPI is used, and the same array is used for both the input and output of the operations.

Lines 165-189 update the loop variables and then check for errors on the complex multiplications and additions. If there are no overflows at this time the data will run smoothly through the rest of the program.

Lines 200-212 load variables with values based on the bit reversed values of pointers.

Lines 214-236 perform additions and subtractions to prepare for the next set of formulas. Note that XITMP and XRTMP are 32-bit values.

Lines 240-260 perform multiplies and summations resulting in 32-bit variables. This saves a bit or two of accuracy. The upper words are then stored as the results.

Lines 263-272 generate the squared magnitude of the harmonic component as a 32-bit value.

Lines 278-310 calculate 10 Log (TMPR/65536). The 32-bit register TMPR is divided by 65536 so that the output range would be reasonable.

First, the number is normalized. (It is shifted left until a 1 is in the most significant bit, the number of shifts required is placed in SHFT_CNT.) If it had to be shifted more than 15 times the output is set to zero.

Next, the most significant BYTE is used as a reference for the look-up table, providing a 16-bit result. The next most significant BYTE is then used to perform linear interpolation between the referenced table value and the one above it. The interpolated value is added to the directly referenced one.

The 16-bit result of this table look-up and interpolation is then added to the Log of the normalization factor, which is also stored in a table. This table look-up approach works fast and only uses 290 bytes of table space.

Lines 321-357 calculate the square root of the 32-bit register TMPR using a table look-up approach.

First, the number is normalized. Next, the most significant BYTE is used as a reference for the look-up table, providing a 16-bit result. The next most significant BYTE is then used to perform linear interpolation between the referenced table value and the one above it. The interpolated value is added to the directly referenced one.

The 16-bit result of this table look-up and interpolation is then divided by the square root of the normalization factor, which is also stored in a table. This table look-up approach works fast and only uses 320 bytes of table space. The results are valid to near 14-bits, more than enough for the FFT algorithm.

Lines 352-360 average the magnitude value, if multiple passes are being performed, and then store the value in the array. The loop-counters are incremented and the process repeats itself.

This concludes the FFT routine. In order to use it, it must be called from a main program. The details for calling this routine are covered in the next section.

8.0 BACKGROUND CONTROL PROGRAM

The main routine is shown in Listing 3. It begins with declarations that can be used in almost any program. Note that these are similar, but not identical, to other 8096 include files that have been published. Comments on controlling the Analog to Digital converter routine follow the declarations.

```
MCS-96 MACRO ASSEMBLER    FFT_MAIN_APNOTE                                  02/18/86          PAGE    1

SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE: :F2:FTMAIN.A96
OBJECT FILE: :F2:FTMAIN.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: NOSB

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                  1   $pagelength(50)
                                  2
                                  3   FFT_MAIN_APNOTE MODULE MAIN, STACKSIZE(6)
                                  4
                                  5   ; Intel Corporation, January 24, 1986
                                  6   ; by Ira Horden, MCO Applications
                                  7
                                  8
                                  9   ;    This program performs an FFT on real data and plots it on a printer.
                                 10   ; It uses the program modules A2DCON, PLOTSP, and FFTRUN.  The adjustable
                                 11   ; parameters of each of the programs are set by this main module.
                                 12
                                 13
                                 14   $INCLUDE (:F0:DEMO96.INC)       ; Include SFR definitions
                               =1 15   ;$nolist  ;  Turn listing off for include file
                               =1 16
                               =1 17   ;*******************************************************************************
                               =1 18   ;
                               =1 19   ;               Copyright 1985, Intel Corporation
                               =1 20   ;               October 28,1985
                               =1 21   ;               by Ira Horden, MCO Applications
                               =1 22   ;
                               =1 23   ; DEMO96.INC - DEFINITION OF SYMBOLIC NAMES FOR THE I/O REGISTERS OF THE 8096
                               =1 24   ;
                               =1 25   ;*******************************************************************************
                               =1 26   ;
0000                           =1 27   ZERO            EQU   00h:WORD      ; R/W   Zero Register
0002                           =1 28   AD_COMMAND      EQU   02H:BYTE      ;   W   A to D command register
0002                           =1 29   AD_RESULT_LO    EQU   02H:BYTE      ; R     Low byte of result and channel
0003                           =1 30   AD_RESULT_HI    EQU   03H:BYTE      ; R     High byte of result
0003                           =1 31   HSI_MODE        EQU   03H:BYTE      ;   W   Controls HSI transition detector
0004                           =1 32   HSO_TIME        EQU   04H:WORD      ;   W   HSI time tag
0004                           =1 33   HSI_TIME        EQU   04H:WORD      ; R     HSO time tag
0006                           =1 34   HSO_COMMAND     EQU   06H:BYTE      ;   W   HSO command tag
0006                           =1 35   HSI_STATUS      EQU   06H:BYTE      ; R     HSI status register (reads fifo)
0007                           =1 36   SBUF            EQU   07H:BYTE      ; R/W   Serial port buffer
0008                           =1 37   INT_MASK        EQU   08H:BYTE      ; R/W   Interrupt mask register
0009                           =1 38   INT_PENDING     EQU   09H:BYTE      ; R/W   Interrupt pending register
0011                           =1 39   SPCON           EQU   11H:BYTE      ;   W   Serial port control register
0011                           =1 40   SPSTAT          EQU   11H:BYTE      ; R     Serial port status register
000A                           =1 41   WATCHDOG        EQU   0AH:BYTE      ;   W   Watchdog timer
```

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```
MCS-96 MACRO ASSEMBLER    FFT_MAIN_APNOTE                                  02/18/86          PAGE    2

ERR LOC  OBJECT              LINE       SOURCE STATEMENT
      000A                   =1    42   TIMER1          EQU   0AH:WORD      ; R     Timer1 register
      000C                   =1    43   TIMER2          EQU   0CH:WORD      ; R     Timer2 register
      000E                   =1    44   PORT0           EQU   0EH:BYTE      ; R     I/O port 0
      000E                   =1    45   BAUD_REG        EQU   0EH:BYTE      ;   W   Baud rate register
      000F                   =1    46   PORT1           EQU   0FH:BYTE      ; R/W   I/O port 1
      0010                   =1    47   PORT2           EQU   10H:BYTE      ; R/W   I/O port 2
      0015                   =1    48   IOC0            EQU   15H:BYTE      ;   W   I/O control register 0
      0015                   =1    49   IOS0            EQU   15H:BYTE      ; R     I/O status register 0
      0016                   =1    50   IOC1            EQU   16H:BYTE      ;   W   I/O control register 1
      0016                   =1    51   IOS1            EQU   16H:BYTE      ; R     I/O status register 1
      0017                   =1    52   PWM_CONTROL     EQU   17H:BYTE      ;   W   PWM control register
      0018                   =1    53   SP              EQU   18H:WORD      ; R/W   System stack pointer
                             =1    54
      000D                   =1    55   CR              EQU   0DH
      000A                   =1    56   LF              EQU   0AH
                             =1    57
                             =1    58   PUBLIC ZERO,AD_COMMAND,AD_RESULT_LO,AD_RESULT_HI,HSI_MODE,HSO_TIME,HSI_TIME
                             =1    59   PUBLIC HSO_COMMAND
                             =1    60   PUBLIC HSI_STATUS,SBUF,INT_MASK,INT_PENDING,WATCHDOG,TIMER1,TIMER2
                             =1    61   PUBLIC BAUD_REG, PORT0, PORT1, PORT2,SPSTAT,SPCON,IOC0,IOC1,IOS0,IOS1
                             =1    62   PUBLIC PWM_CONTROL,SP,CR,LF
                             =1    63
      001C                   =1    64   RSEG at 1CH
                             =1    65
      001C                   =1    66           AX:     DSW     1          ; Temp registers used in conformance
      001E                   =1    67           DX:     DSW     1          ; with PLM-96(tm) conventions.
      0020                   =1    68           BX:     DSW     1
      0022                   =1    69           CX:     DSW     1
                             =1    70
        001C                 =1    71           AL      EQU     AX      :BYTE
        001D                 =1    72           AH      EQU     (AX+1)  :BYTE
        0020                 =1    73           BL      EQU     BX      :BYTE
                             =1    74
                             =1    75    public ax, bx, cx, dx, al, ah, bl
                             =1    76
                             =1    77   $list    ;  Turn listing back on
                             =1    78            ;  End of include file
                                   79
                                   80   ; A2D UTILITY COMMANDS/RESPONSES FOR "CONTROL_A2D" ____________________________
                                   81
        0007                       82   busy            equ     7
        0010                       83   con_b0          equ     00010000b;convert to BUFF0
        0028                       84   dump_b0_p_s     equ     00101000b; download  BUFF0  as PAIRED SIGNED data
                                   85   ;_____________________________________________________________________________
                                   86
        0001                       87   AVR_NUM         equ     1       ; Number of times to average the waveform
                                   88                                   ;    AVR_NUM < 256
```

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```
MCS-96 MACRO ASSEMBLER    FFT_MAIN_APNOTE                          02/18/86          PAGE    3

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                                 89
      0000                       90   SCALE_FACTOR     equ     0       ; Number of rights shifts performed on
                                 91                                    ; output of FFT.  Used to prevent overflow
                                 92                                    ; on summation
                                 93
      0100                       94   PLOT_RES         equ     256             ; Number of input units per plot unit
      0080                       95   PLOT_RES_2       equ     plot_res/2
      9100                       96   PLOT_MAX         equ     plot_res*145    ; 145 chrs/row
                                 97
                                 98    PUBLIC scale_factor, plot_res, plot_res_2, plot_max
                                 99
                                100
      0024                       101  OSEG at 24H     ; common oseg area
                                102
      0024                       103          tmpreal:        dsl     1
      0028                       104          tmpimag:        dsl     1
      002C                       105          wndptr:         dsw     1
      002E                       106          varptr:         dsw     1
                                107
      0000                       108  RSEG
      0000                       109          fft_mode:       dsb     1
      0001                       110          error:          dsb     1
      0002                       111          avr_cnt:        dsb     1
                                112    PUBLIC error, fft_mode
                                113
                                114          EXTRN   sample_period, control_a2d
                                115
                                116
      0080                       117  DSEG at 80h
      0080                       118          XREAL:                          ; For FFT routine
      0080                       119          DEST_BUFF_BASE: DSW     64      ; For A2D routine
        00C0                     120          XIMAG equ       XREAL+64        ; For FFT routine
                                121
                                122    PUBLIC DEST_BUFF_BASE, XREAL, XIMAG
                                123
                                124
      0200                       125  DSEG AT 200H
                                126
      0200                       127          PLOT_IN:
      0200                       128          FFT_OUT:        DSW     32      ; For FFT routine
      0240                       129          BUFF0_BASE:     DSW     64      ; For A2D routine
      02C0                       130          BUFF1_BASE:     DSW     64      ; For A2D routine
                                131
                                132          PUBLIC  BUFF0_BASE, BUFF1_BASE, FFT_OUT, PLOT_IN
                                133  $eject
```

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Listing 3—Main Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    FFT_MAIN_APNOTE                          02/18/86          PAGE    4

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               134
    2080                       135   CSEG AT 2080H
                               136
                               137           EXTRN   INIT_OUTPUT, DRAW_GRAPH, CON_OUT        ; For Plot Routine
                               138           EXTRN   FFT_CALC                                 ; For FFT routine
                               139           EXTRN   A2D_BUFF_UTIL                            ; For A2D routine
                               140
    2080 A1000018          R   141           LD      SP,#STACK
    2084 A30100301C            142           LD      AX,3000H
    2089                       143   SBE_WAIT:
    2089 E01CFD                144           djnz    al,sbe_wait     ; WAIT FOR SBE TO CLEAR SERIAL PORT INTERRUPTS
    208C E01DFA                145           djnz    ah,sbe_wait
                               146
    208F EF0000            E   147   BEGIN:  CALL    INIT_OUTPUT     ; Initialize serial port
                               148
    2092                       149   NEW_TRANSFORM_SET:
    2092 B10000            R   150           ldb     fft_mode,#0000B         ;  Bit 0 - Real data / Tabled data#
                               151                                           ;  Bit 1 - Windowed / Unwindowed#
                               152                                           ;  Bit 2 - 10log Mag^2 / Magnitude#
                               153                                           ;  Bit 3 - 256*db plot / Normal Plot#
    2095 B10102            R   154           ldb     avr_cnt,#avr_num
    2098 0120                  155           clr     bx
    209A C321000200            156   CLRRAM: st      zero,fft_out[bx]        ; clear fft magnitude array
    209F 65020020              157           add     bx,#2
    20A3 89400020              158           cmp     bx,#64
    20A7 DEF1                  159           blt     CLRRAM
                               160
    20A9 300004            R   161   C_load: bbc     fft_mode,0,do_tab       ; Branch if real data is not used
    20AC 2819                  162           CALL    LOAD_DATA
    20AE 2002                  163           br      C_win
                               164
    20B0 282F                  165   do_tab: CALL    TABLE_LOAD
                               166
    20B2 310002            R   167   C_win:  bbc     fft_mode,1,calc         ; Branch if windowing is not used
    20B5 28CB                  168           CALL    DO_WINDOW
                               169
    20B7 EF0000            E   170   CALC:   CALL    FFT_CALC
    20BA 980001            R   171   errtrp: cmpb    error,zero
    20BD D7FB                  172           jne     errtrp
                               173
    20BF E00205            R   174           DJNZ    avr_cnt, LOAD_DATA      ; repeat for AVR_NUM counts
                               175
    20C2 EF0000            E   176           CALL    DRAW_GRAPH
                               177
    20C5 27CB                  178           BR      NEW_TRANSFORM_SET
                               179   $eject
```

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```
MCS-96 MACRO ASSEMBLER    FFT_MAIN_APNOTE                                  02/18/86          PAGE    5

ERR LOC  OBJECT                  LINE      SOURCE STATEMENT
                                  180  ;-------------------------------------------------------------------
    20C7                          181  LOAD_DATA:                    ;;;;    LOAD DATA INTO RAM
                                  182
    20C7 B1000F                   183          ldb     port1,#00                    ;**** FOR INDICATION ONLY
                                  184
    20CA                          185  SET_A2D:
    20CA B11000             E     186          ldb     control_a2d,#con_b0    ; Set converter for buffer0
    20CD 910100             E     187          orb     control_a2d,#01        ; Convert channel 1
    20D0 A1320000           E     188          ld      sample_period,#50      ; 100 us sample period
                                  189
    20D4 EF0000             E     190          CALL    a2d_buff_util          ; Start the conversion process
    20D7 3F00FD             E     191          jbs     control_a2d,busy,$     ; wait for all conversions to be done
                                  192
    20DA                          193  Down_load:
    20DA B12800             E     194          ldb     control_a2d,#dump_b0_p_s       ; download b0 paired/signed
    20DD EF0000             E     195          CALL    a2d_buff_util
    20E0 F0                       196          RET
                                  197
                                  198  ;-------------------------------------------------------------------
    20E1                          199  TABLE_LOAD:
    20E1 0120                     200          clr     bx
    20E3 A102211C                 201          ld      ax,#DATA0      ; Load tabled data for testing
    20E7 A21D22                   202  load:   ld      cx,[ax]+
    20EA A21D1E                   203          ld      dx,[ax]+
    20ED C321800022               204          st      cx,xreal[bx]
    20F2 C321C0001E               205          st      dx,ximag[bx]
    20F7 65020020                 206          add     bx,#2
    20FB 89400020                 207          cmp     bx,#64
    20FF DBE6                     208          blt     LOAD
    2101 F0                       209          RET
                                  210
    2102                          211  DATA0:          ; SQUARE WAVE
                                  212
    2102 FF7FFF7FFF7FFF7F         213  DCW      32767,  32767,  32767,  32767,  32767,  32767,  32767,  32767
    2112 FF7FFF7FFF7FFF7F         214  DCW      32767,  32767,  32767,  32767,  32767,  32767,  32767,  32767
    2122 FF7FFF7FFF7FFF7F         215  DCW      32767,  32767,  32767,  32767,  32767,  32767,  32767,  32767
    2132 FF7FFF7FFF7FFF7F         216  DCW      32767,  32767,  32767,  32767,  32767,  32767,  32767,  32767
    2142 0180018001800180         217  DCW     -32767, -32767, -32767, -32767, -32767, -32767, -32767, -32767
    2152 0180018001800180         218  DCW     -32767, -32767, -32767, -32767, -32767, -32767, -32767, -32767
    2162 0180018001800180         219  DCW     -32767, -32767, -32767, -32767, -32767, -32767, -32767, -32767
    2172 0180018001800180         220  DCW     -32767, -32767, -32767, -32767, -32767, -32767, -32767, -32767
                                  221
                                  222  $eject
```

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Listing 3—Main Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    FFT_MAIN_APNOTE                                  02/18/86          PAGE    6

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               223   ;-------------------------------------------------------------------
    2182                       224   DO_WINDOW:                              ;;;; PERFORM HANNING WINDOW
    2182 012C                  225           clr     wndptr
    2184 012E                  226           clr     varptr                    ; Windowing provides an effective
    2186                       227   WINDOW:                                 ; divide by 2 because of the multiply
    2186 A32DBE211C            228           ld      ax,hanning[wndptr]
    218B A32DC02120            229           ld      bx,hanning+2[wndptr]
    2190 FE4F2FB00001C24       230           mul     tmpreal,ax,xreal[varptr]
    2197 FE4F2FC0002028        231           mul     tmpimag,bx,ximag[varptr]
    219E 0D0124                232           shll    tmpreal,#1
    21A1 0D0128                233           shll    tmpimag,#1                      ; Compensate for the divide by 2
    21A4 C32FB00026            234           st      tmpreal+2,xreal[varptr]
    21A9 C32FC0002A            235           st      tmpimag+2,ximag[varptr]
    21AE 6504002C              236           add     wndptr,#4
    21B2 6502002E              237           add     varptr,#2
    21B6 8940002E              238           cmp     varptr,#64
    21BA D7CA                  239           jne     window
    21BC F0                    240           RET
                               241
    21BE                       242   HANNING:        ; Windowing function
                               243
    21BE 00004F003B01C102      244   DCW         0,   79,  315,  705, 1247, 1935, 2761, 3719
    21CE BF126617711CD421      245   DCW      4799, 5990, 7281, 8660,10114,11628,13187,14778
    21DE 004045467C4C9352      246   DCW     16384,17989,19580,21139,22653,24107,25486,26777
    21EE 406D787136757078      247   DCW     27968,29048,30006,30832,31520,32062,32452,32688
    21FE FF7FB07FC47E3E7D      248   DCW     32767,32688,32452,32062,31520,30832,30006,29048
    220E 406D99688E632B5E      249   DCW     27968,26777,25486,24107,22653,21139,19580,17989
    221E 0040BA3983336C2D      250   DCW     16384,14778,13187,11628,10114, 8660, 7281, 5990
    222E BF12870EC90ABF07      251   DCW      4799, 3719, 2761, 1935, 1247,  705,  315,   79
    223E 0000                  252   DCW         0
                               253
                               254   $eject
```

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Listing 3—Main Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    FFT_MAIN_APNOTE                          02/18/86        PAGE    7

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                               255
    3D00                       256   CSEG AT 3D00H          ; ADDITIONAL  TABLES  FOR  TESTING
                               257                  ; SINE 7.0 X
    3D00                       258   DATA1:
    3D00 00003351897DE270      259   DCW          0, 20787, 32137, 28898, 12539, -9512,-27245,-32609
    3D10 7EA574F31C477C7A      260   DCW     -23170, -3212, 18204, 31356, 30273, 15446, -6393,-25329
    3D20 01800F9D08E7563C      261   DCW     -32767,-25329, -6392, 15446, 30273, 31356, 18204, -3212
    3D30 7EA59F809395D8DA      262   DCW     -23170,-32609,-27245, -9512, 12539, 28898, 32137, 20787
    3D40 0000CDAE77821E8F      263   DCW         -0,-20787,-32137,-28898,-12539,  9512, 27245, 32609
    3D50 825A8C0CE4B88485      264   DCW      23170,  3212,-18204,-31356,-30273,-15446,  6393, 25329
    3D60 FF7FF162F818AAC3      265   DCW      32767, 25329,  6392,-15446,-30273,-31356,-18204,  3212
    3D70 825A617F6D6A2825      266   DCW      23170, 32609, 27245,  9512,-12539,-28898,-32137,-20787
                               267
    3D80                       268   DATA2:          ; SINE 7.5 X
                               269
    3D80 0000F555617FCF66      270   DCW          0, 22005, 32609, 26319,  6393,-16846,-31356,-29621
    3D90 05CF1F2BE270297C      271   DCW     -12539, 11039, 28898, 31785, 18204, -4808,-25329,-32728
    3DA0 7EA5B8F933519C7E      272   DCW     -23170, -1608, 20787, 32412, 27245,  7962,-15446,-30852
    3DB0 BF8946C92825C96D      273   DCW     -30273,-14010,  9512, 28105, 32137, 19519, -3212,-24279
    3DC0 018029A174F33F4C      274   DCW     -32767,-24279, -3212, 19519, 32137, 28105,  9512,-14010
    3DD0 BF897C87AAC31A1F      275   DCW     -30273,-30852,-15446,  7962, 27245, 32412, 20787, -1608
    3DE0 7EA528800F9D38ED      276   DCW     -23170,-32728,-25329, -4808, 18205, 31785, 28898, 11039
    3DF0 05CF4B8C848533BE      277   DCW     -12539,-29621,-31356,-16845,  6393, 26319, 32609, 22005
                               278
    3E00                       279   DATA3:          ; .707*SINE 7.5X
                               280
    3E00 0000C63C0F5AAF48      281   DCW          0, 15558, 23055, 18607,  4520,-11910,-22169,-20942
    3E10 5FDD7C1ECF4FCB57      282   DCW      -8865,  7804, 20431, 22472, 12870, -3399,-17908,-23138
    3E20 03C08FFB69398459      283   DCW     -16381, -1137, 14697, 22916, 19262,  5629,-10921,-21812
    3E30 65AC4FD9451A9E4D      284   DCW     -21403, -9905,  6725, 19870, 22721, 13800, -2271,-17165
    3E40 82A5F3BC21F7E835      285   DCW     -23166,-17165, -2271, 13800, 22721, 19870,  6725, -9905
    3E50 65ACCCAA58D5FD15      286   DCW     -21403,-21812,-10920,  5629, 19262, 22916, 14696, -1137
    3E60 03C09EA50CBAB9F2      287   DCW     -16381,-23138,-17908, -3399, 12871, 22472, 20431,  7804
    3E70 5FDD32AE67A97AD1      288   DCW      -8865,-20942,-22169,-11910,  4520, 18607, 23055, 15557
                               289
    3E80                       290   DATA4:          ; .707*SINE(11x) /16
                               291
    3E80 0000FD04B40472FF      292   DCW          0,  1277,  1204,  -142, -1338, -1119,   282,  1386
    3E90 00045CFE74FA69FC      293   DCW       1024,  -420, -1420,  -919,   554,  1441,   804,  -683
    3EA0 58FA55FD2403A105      294   DCW      -1448,  -683,   804,  1441,   554,  -919, -1420,  -420
    3EB0 00046A051A01A1FB      295   DCW       1024,  1386,   282, -1119, -1338,  -142,  1204,  1277
    3EC0 000003FB4CFBBE00      296   DCW         -0, -1277, -1204,   142,  1338,  1119,  -282, -1386
    3ED0 00FCA4018C059703      297   DCW      -1024,   420,  1420,   919,  -554, -1441,  -804,   683
    3EE0 A805AB02DCFC5FFA      298   DCW       1448,   683,  -804, -1441,  -554,   919,  1420,   420
    3EF0 00FC96FAE6FE5F04      299   DCW      -1024, -1386,  -282,  1119,  1338,   142, -1204, -1277
                               300
    3F00                       301   DATA5:          ; .707*(SINE 7.5X + 1/16 SINE 11X)
```

```
MCS-96 MACRO ASSEMBLER    FFT_MAIN_APNOTE                                  02/18/86        PAGE    8

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                               302
    3F00 0000C241C35E2148      303    DCW          0, 16834, 24259, 18465,  3182,-13029,-21886,-19557
    3F10 5EE1D81C434A3154      304    DCW      -7842,  7384, 19011, 21553, 13425, -1958,-17103,-23821
    3F20 5BBAE5F88D3C245F      305    DCW     -17829, -1819, 15501, 24356, 19816,  4710,-12341,-22232
    3F30 65B0B9DE5F1B3F49      306    DCW     -20379, -8519,  7007, 18751, 21383, 13658, -1067,-15888
    3F40 82A5F6B76DF27636      307    DCW     -23166,-18442, -3475, 13942, 24059, 20990,  6442,-11290
    3F50 65A870ACE4DA9419      308    DCW     -22427,-21392, -9500,  6548, 18708, 21475, 13892,  -454
    3F60 ABC54BABE8B618ED      309    DCW     -14933,-22456,-18712, -4840, 12317, 23391, 21851,  8225
    3F70 5FD9CBA84DA8D9D5      310    DCW      -9889,-22328,-22451,-10791,  5857, 18749, 21851, 14281
                               311
                               312
    3F80                       313    END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

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Listing 3—Main Routine (Continued)

```
SERIES-III MCS-96 RELOCATOR AND LINKER, V2.0
Copyright 1983 Intel Corporation

INPUT FILES: :F2:FTMAIN.OBJ, :F2:FFTRUN.OBJ, :F2:PLOTSP.OBJ, :F2:A2DCON.OBJ
OUTPUT FILE: :F2:FFTOUT
CONTROLS SPECIFIED IN INVOCATION COMMAND:
   IX


INPUT MODULES INCLUDED:
   :F2:FTMAIN.OBJ(FFT_MAIN_APNOTE)  02/18/86
   :F2:FFTRUN.OBJ(FFT_RUN)  02/18/86
   :F2:PLOTSP.OBJ(PLOT_SERIAL)  02/18/86
   :F2:A2DCON.OBJ(A2D_BUFFERING_UTILITY)  02/18/86


SEGMENT MAP FOR :F2:FFTOUT(FFT_MAIN_APNOTE):

            TYPE    BASE      LENGTH    ALIGNMENT    MODULE NAME
            ----    ----      ------    ---------    -----------

**RESERVED*         0000H     001AH
            REG     001AH     0001H     BYTE         PLOT_SERIAL
*** GAP ***         001BH     0001H
            REG     001CH     0008H     ABSOLUTE     FFT_MAIN_APNOTE
            OVRLY   0024H     0035H     ABSOLUTE     FFT_RUN
**OVERLAP** OVRLY   0024H     0010H     ABSOLUTE     PLOT_SERIAL
**OVERLAP** OVRLY   0024H     000CH     ABSOLUTE     FFT_MAIN_APNOTE
*** GAP ***         0059H     0001H
            OVRLY   005AH     0006H     WORD         A2D_BUFFERING_UTILITY
            REG     0060H     000CH     WORD         A2D_BUFFERING_UTILITY
            REG     006CH     0003H     BYTE         FFT_MAIN_APNOTE
*** GAP ***         006FH     0011H
            DATA    0080H     0080H     ABSOLUTE     FFT_MAIN_APNOTE
            STACK   0100H     001EH     WORD
            DATA    011EH     0080H     WORD         FFT_RUN
*** GAP ***         019EH     0062H
            DATA    0200H     0140H     ABSOLUTE     FFT_MAIN_APNOTE
*** GAP ***         0340H     1CC2H
            CODE    2002H     0002H     ABSOLUTE     A2D_BUFFERING_UTILITY
*** GAP ***         2004H     007CH
            CODE    2080H     01C0H     ABSOLUTE     FFT_MAIN_APNOTE
*** GAP ***         2240H     0040H
            CODE    2280H     0215H     ABSOLUTE     FFT_RUN
*** GAP ***         2495H     006BH
            CODE    2500H     0168H     ABSOLUTE     PLOT_SERIAL
            CODE    2668H     00ECH     BYTE         A2D_BUFFERING_UTILITY
*** GAP ***         2754H     10ACH
            CODE    3800H     042AH     ABSOLUTE     FFT_RUN
*** GAP ***         3C2AH     00D6H
            CODE    3D00H     0280H     ABSOLUTE     FFT_MAIN_APNOTE
*** GAP ***         3F80H     C080H
```

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Listing 3—Main Routine (Continued)

6

Several constants are then setup for other routines. The purpose of centrally locating these constants was the ease of modifying the operation of the routines. Note that AVR__NUM and SCALE__FACTOR must be changed at the same time. SCALE__FACTOR is the shift count used to divide each FFT output value before it is added to the output array. AVR__NUM must be less than 2**SCALE__FACTOR or an overflow could occur. Next, the public variables are declared for the arrays and a few other parameters.

The program then begins by setting the stack pointer and waiting for the SBE-96 to finish talking to the terminal. If this is not done, there may be serial port interrupts occurring for the first twenty five milliseconds of program operation.

Initialization of the plotter is next, followed by setting the FFT__MODE byte. This byte controls the graphing, loading and magnitude calculation of the FFT data. Since FFT__MODE is declared PUBLIC in this module, and EXTERNAL in the PLOT module and FFTRUN module, the extra bits available in this byte can be used for future enhancements.

The next step is to clear the FFT output array. Since the FFT program can be set to average its results by dividing the output before adding it to the magnitude array, the array must be cleared before beginning the program.

Data is then loaded into into the FFT input array by the code at LOAD__DATA, or the code at TABLE__LOAD, depending on the value of FFT__MODE bit 0. The tabled data located at DATA0 is a square wave of magnitude 1. This waveform provides a reasonable test of the FFT algorithm, as many harmonics are generated. The results are also easy to check as the pattern contains half zeros, imaginary values which are always the same, and real values which decrease. Figure 13 shows the output in fractions, hexadecimal and decimal. The hexadecimal and decimal values are based on an output of 16384 being equal to 1.00.

Note that the magnitude is

$$\text{SQR}\ (\text{REAL}^2 + \text{IMAG}^2)$$

and the dB value is

$$10\ \text{LOG}\ (\ (\text{REAL}^2 + \text{IMAG}^2)/65536\ )$$

The divide by 65536 is used for the dB scale to provide a reasonable range for calculations. If this was not done, a 32-bit LOG function would have been needed.

After the data is loaded, the data is optionally windowed, based on FFT__MODE bit 1, and the FFT program is called. Once the loop has been performed AVR__CNT times, the graph is drawn by the plot routine.

Appended to the main routine is the FFTOUT.M96 Listing. This is provided by the relocator and linker, RL96. With this listing and the main program, it is possible to determine which sections of code are at which addresses.

Using the modular programming methods employed here, it is reasonably easy to debug code. By emulating the program in a relatively high level language, each routine can be checked for functionality against a known standard. The closer the high level implementation matches the ASM96 version, the more possible checkpoints there are between the two routines.

Once all of the program routines (modules) can be shown to work individually, the main program should work unless there is unwanted interaction between the modules. These interactions can be checked by verifying the inputs and outputs of each module. The assembly language locations to perform the program breaks can be retrieved by absolutely locating the main module. The other modules can be dynamically located by RL96.

The more interactive program modules are, the more difficult the program becomes to debug. This is especially true when multiple interrupts are occurring, and several of the interrupt routines are themselves interruptable. In these cases, it may be necessary to use debugging equipment with trace capability, like the VLSiCE-96. If this type of equipment is not available, then using I/O ports to indicate the entering and leaving of each routine may be useful. In this way it will be possible to watch the action of the program on an oscilloscope or logic analyzer. There are several places within this code that I/O port toggling has been used as an aid to debugging the program. These lines of code are marked "FOR INDICATION ONLY."

K	Fractional			dB	Decimal			Hexadecimal		
	REAL	IMAG	MAG²		REAL	IMAG	MAG²	REAL	IMAG	MAG²
0	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
1	0.0625	−1.2722	1.2738	38.225	1024	−20843	20868	400	AE95	5184
2	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
3	0.0625	−0.4213	0.4260	28.710	1024	−6903	6978	400	E509	1B42
4	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
5	0.0625	−0.2495	0.2572	24.329	1024	−4088	4214	400	F008	1076
6	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
7	0.0625	−0.1747	0.1855	21.491	1024	−2862	3039	400	F4D2	BDF
8	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
9	0.0625	−0.1321	0.1462	19.421	1024	−2165	2395	400	F78B	95B
10	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
11	0.0625	−0.1043	0.1216	17.820	1024	−1708	1992	400	F954	7C8
12	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
13	0.0625	−0.0843	0.1049	16.540	1024	−1381	1719	400	FA9B	6B7
14	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
15	0.0625	−0.0690	0.0931	15.499	1024	−1130	1525	400	FB96	5F5
16	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
17	0.0625	−0.0566	0.0844	14.645	1024	−928	1382	400	FC60	566
18	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
19	0.0625	−0.0464	0.0778	13.944	1024	−759	1275	400	FD09	4FB
20	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
21	0.0625	−0.0375	0.0729	13.374	1024	−614	1194	400	FD9A	4AA
22	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
23	0.0625	−0.0296	0.0691	12.918	1024	−484	1133	400	FE1C	46D
24	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
25	0.0625	−0.0224	0.0664	12.564	1024	−366	1088	400	FE92	440
26	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
27	0.0625	−0.0157	0.0644	12.305	1024	−256	1056	400	FF00	420
28	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
29	0.0625	−0.0093	0.0632	12.135	1024	−152	1035	400	FF68	40B
30	0.0000	0.0000	0.0000	0.000	0	0	0	0	0	0
31	0.0625	−0.0031	0.0626	12.051	1024	−50	1025	400	FFCE	401

Figure 13. FFT Output for a Square Wave Input

9.0 ANALOG TO DIGITAL CONVERTER MODULE

The module presented in Listing 4 is a general purpose one which converts analog values under interrupt control and stores them in one of two buffers. These buffers can then be downloaded to another buffer, such as the input buffer to the FFT program. During downloading, this module can convert the data into signed or unsigned formats, and fill a linear or a paired array. A paired array is like the one used in the FFT transform program. It requires N data points placed alternately in two arrays, one starting at zero and the other at N/2.

```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                    02/18/86        PAGE    1

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SOURCE FILE: :F2:A2DCON.A96
OBJECT FILE: :F2:A2DCON.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: NOSB

ERR LOC  OBJECT                 LINE        SOURCE STATEMENT
                                  1   $pagelength(50)
                                  2
                                  3   A2D_Buffering_Utility   module  stacksize(12)
                                  4   ;
                                  5   ; Intel Corporation,  July 16, 1985
                                  6   ; by Dave Ryan, Intel Applications Engineer
                                  7   ;
                                  8   ; This utility fills a memory buffer with A/D conversion results.  The
                                  9   ; conversions are done under interrupt control, and are initiated when
                                 10   ; A2D_BUFF_Util is called.  The results of the conversions are placed
                                 11   ; in one of two buffers, called BUFF0 and BUFF1.
                                 12   ;
                                 13   ; This utility provides options for the selection of the buffer lengths, data
                                 14   ; format, sample period, conversion channel and time base.  The utility also
                                 15   ; has a donwload routine that will load either buffer into a register file
                                 16   ; buffer.  Output formats can also be chosen for the downloaded buffer.  The
                                 17   ; data can be formatted as signed or unsigned linear or paried arrays.
                                 18   ;
                                 19   ; RUN-TIME OPTIONS
                                 20   ;
                                 21   ; Rather than use the STACK to pass controls, this utility gets its directions
                                 22   ; from 2 control words in memory.  The utility expects that its control words
                                 23   ; are valid at the time A2D_BUFF_Util is called and remain valid throughout
                                 24   ; A/D interrupt executions and downloads.  The control words are:
                                 25   ;
                                 26   ;       Sample_Period   ; WORD ; The time between samples in timer counts
                                 27   ;                               ; where the timer used has been specified
                                 28   ;
                                 29   ;
                                 30   ;       Control_A2D     ; BYTE ; Control information for the utility:
                                 31   ;                                  BIT#
                                 32   ;
                                 33   ;                                ;  0-2  ; Channel Number
                                 34   ;;                               ;   3   ; Signed Result/Unsigned Result#
                                 35   ;                                ;   4   ; Convert/Download#
                                 36   ;                                ;   5   ; BUFF1/BUFF0# for conversions
                                 37   ;                                        ; BUFF0/BUFF1# for downloads
                                 38   ;                                ;   6   ; Linear/Paired#
                                 39   ;                                ;   7   ; Converter BUSY/IDLE#
                                 40
                                 41   $EJECT
```

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Listing 4—A to D Converter Routine

```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                    02/18/86          PAGE    2

ERR LOC  OBJECT              LINE      SOURCE STATEMENT
                               42  ;
                               43  ; The following is a table of equates that can be used to simplify the
                               44  ; bit diddling requirements.  If you are not running conversions concurrently
                               45  ; with downloads, always LDB Control_A2D with the following command then
                               46  ; ORB Control_A2D with the channel number you wish to convert if you are
                               47  ; starting a conversion.
                               48  ;
                               49  ; Once the utility is called, care must be taken when Control_A2d is
                               50  ; modified.  You can cause downloads to occur while conversions are running,
                               51  ; but you cannot start conversions during a download.  To do this, ORB to the
                               52  ; control byte with the appropriate bits set.  Do NOT change the BUFF bit or
                               53  ; the BUSY bit.  Just set the download bit and set the data format bits to the
                               54  ; correct values.
                               55  ;
                               56  ; The BUFF bit has opposite definitions for conversions and downloads.  This
                               57  ; allows conversions to be done into BUFF0 while downloads come from BUFF1, and
                               58  ; vice versa.
                               59  ;
                               60  ; A2D UTILITY COMMANDS_____________________________________________________
                               61  ;
                               62  ;con_b0          equ     00010000b;convert to BUFF0
                               63  ;con_b1          equ     00110000b;   "       BUFF1
                               64  ;
                               65  ;dump_b0_l_u     equ     01100000b; download  BUFF0  as LINEAR USIGNED data
                               66  ;dump_b1_l_u     equ     01000000b;   "       BUFF1  "    "      "      "
                               67  ;dump_b0_p_u     equ     00100000b;   "       BUFF0  "  PAIRED   "      "
                               68  ;dump_b1_p_u     equ     00000000b;   "       BUFF1  "    "      "      "
                               69  ;dump_b0_l_s     equ     01101000b; download  BUFF0  as LINEAR SIGNED  data
                               70  ;dump_b1_l_s     equ     01001000b;   "       BUFF1  "    "      "      "
                               71  ;dump_b0_p_s     equ     00101000b;   "       BUFF0  "  PAIRED   "      "
                               72  ;dump_b1_p_s     equ     00001000b;   "       BUFF1  "    "      "      "
                               73  ;_____________________________________________________________________________
                               74  $eject
```

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Listing 4—A to D Converter Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                    02/18/86        PAGE    3

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                                 75   ;
                                 76   ; ASSEMBLY-TIME OPTIONS
                                 77   ;
                                 78   ; The base addresses and length of each conversion buffer and the destination
                                 79   ; buffer are DECLARED EXTRNal in this utility. Other options such as selection
                                 80   ; of the timer used as a timebase, the length of the buffer, and the effective
                                 81   ; number of bits in the reported result are set at assembly time through use
                                 82   ; of EQUates in this module.
                                 83   ;
                                 84   ; The following parameters need to be provided at assembly or link time.
                                 85   ; The buffer bases are declared EXTRNal by this utility, while the buffer
                                 86   ; length shift count and HSO commands are EQUated.
                                 87   ;
                                 88   ;       BUFF0_BASE      ; The starting address of BUFF0
                                 89   ;       BUFF1_BASE      ; The starting address of BUFF1
                                 90   ;       DEST_BUFF_BASE  ; The starting address of the download
                                 91   ;                               ; target buffer.
                                 92   ;
                                 93   ;       BUFF_LENGTH     ; The number of SAMPLES that each
                                 94   ;                               ; buffer must hold. must be >1 and <256
                                 95   ;
                                 96   ;       Shift_count     ; The number of times that the conversion result is
                                 97   ;                       ; to be shifted right from its natural left justified
                                 98   ;                       ; position. Setting a shift count greater than 6 will
                                 99   ;                       ; result in lost bits to the right.  Rounding is NOT
                                100   ;                       ; done.
                                101   ;
                                102   ;       CLOCK           ; Specify as either TIMER1 or T2CLK.  This is the
                                103   ;                       ; timebase used for conversions.
                                104   ;
                                105   ;       Samples are stored as words in the buffers.  The program stores
                                106   ; conversions linearly in BUFF0 and BUFF1, and linearly or paired in the
                                107   ; destination buffer as selected.  If the download is to be paired, the first
                                108   ; sample is placed in location DEST_BUFF_BASE, the second sample is placed in
                                109   ; location (DEST_BUFF_BASE + BUFF_LENGTH), the third in (DEST_BUFF_BASE + 2),
                                110   ; the fourth in (DEST_BUFF_BASE + 2 + BUFF_LENGTH), etc.
                                111   ;
                                112   $eject
```

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Listing 4—A to D Converter Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                    02/18/86          PAGE    4

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                113   ;
                                114   ;NOTES ON EXECUTION
                                115   ;
                                116   ; When a utility call directs the initiation of a set of A2D conversions, the
                                117   ; first conversion is begun at approximately one sample time plus 50 state
                                118   ; times from when the utility was called.  This assumes that no interrupts are
                                119   ; present.
                                120   ;
                                121   ; The conversion busy bit is set approximately 50 state times after a call
                                122   ; to the utility, if the convert bit was set in the A2D_Control byte.  The
                                123   ; busy bit is cleared after all conversion results have been stored in the
                                124   ; result buffer designated (BUFF0 or BUFF1).
                                125   ;
                                126   ; Take great care in modifying the A2D_Control byte to do a download while
                                127   ; conversions are taking place.  You can never download a buffer that is
                                128   ; being converted into.  The results would be invalid.
                                129   $eject
```

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Listing 4—A to D Converter Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                    02/18/86        PAGE    5

ERR LOC  OBJECT              LINE       SOURCE STATEMENT
                              130
    0000                      131           RSEG
                              132
                              133   EXTRN BUFF0_BASE, BUFF1_BASE, DEST_BUFF_BASE
                              134   EXTRN ad_command, ad_result_lo, ad_result_hi
                              135   EXTRN hso_command, hso_time,sp
                              136
      0040                    137   BUFF_LENGTH     EQU     64
      0001                    138   Shift_Count     EQU     1
      000A                    139   CLOCK           EQU     TIMER1
                              140
                              141   ; set up hso commands for correct timer *********************************
                              142
      000A                    143   TIMER1          equ     0AH
      000C                    144   T2CLK           equ     0CH
                              145
      0000                    146   MASK            equ     (10h*CLOCK)AND(40h)
                              147
      000F                    148   Start_A2D       equ     (00001111b)OR(MASK)
                              149                           ;start a2d based on timer 1, no interrupt
                              150
      0000                    151   HSO_0_Low       equ     (00000000b)OR(MASK)
                              152                           ; make hso.0 low based on timer1 no interrupt
                              153
      0020                    154   HSO_0_High      equ     (00100000b)OR(MASK)
                              155                           ; make hso.0 hi  based on timer1 no interrupt
                              156
                              157
                              158   ; set up storage ********************************************************
                              159
    0000                      160   adudtemp0:      DSW     1; temp register for download calls
                              161
    0002                      162   aductemp0:      DSW     1; temp registers for conversion calls
    0004                      163   aductemp1:      DSW     1
    0006                      164   top_of_buffer:  DSW     1
    0008                      165   sample_count:   DSB     1
                              166
    0009                      167   Control_A2D:    DSB     1; the byte that controls the utility execution
      0003                    168                   DForm   equ     3       ; Signed/Unsigned#
      0004                    169                   Con_Dwn equ     4       ; Convert/Download#
      0005                    170                   B0_B1   equ     5       ; Buff1/Buff0# for conversions
                              171                                           ; Buff0/Buff1# for downloads
      0006                    172                   Lin_Par equ     6       ; Linear/Paired#
      0080                    173                   Busy    equ     10000000B       ; Bit 8
                              174   $eject
```

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```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                    02/18/86          PAGE    6

ERR LOC  OBJECT              LINE        SOURCE STATEMENT
                             175
    000A                     176   Sample_Period:  DSW     1; the word that specifies the number of clock ticks
                             177                            ; that elapse between each sample
                             178
                             179   PUBLIC  Control_A2D, Sample_Period
                             180
                             181
    0000                     182           OSEG
                             183
    0000                     184   src_ptr:        DSW     1; some overlayable temp registers
      0000                   185           temp set src_ptr:WORD
    0002                     186   dest_ptr:       DSW     1
    0004                     187   loop_count:     DSW     1
                             188
                             189
    2002                     190           CSEG    at      2002h
                             191
                             192   PUBLIC  A2D_DONE_Vector
                             193
    2002 AC00            R   194   DCW     A2D_DONE_Vector
                             195
                             196
    0000                     197           CSEG
                             198
                             199   PUBLIC  A2D_BUFF_Util
                             200
                             201   Load_HSO_Command MACRO  var     ; Macro to load HSO
                             202
                             203           LDB     hso_command,#var
                             204           LD      hso_time,aductemp0
                             205   ENDM
                             206   $eject
```

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Listing 4—A to D Converter Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                    02/18/86        PAGE    7

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               207
    0000                       208   A2D_BUFF_Util:
                               209
    0000 3C0962          R     210           JBS     Control_A2D, Con_Dwn, Convert   ; Select convert or download
    0003                       211   Download:
    0003 A1000000        E     212           LD      src_ptr,#BUFF1_BASE
    0007 350904          R     213           JBC     Control_A2D, B0_B1,   Set_Data_Format
                               214
    000A                       215   Download_BUFF0:
    000A A1000000        E     216           LD      src_ptr,#BUFF0_BASE
                               217
                               218
    000E                       219   Set_Data_Format:                        ; Choose linear or paired
    000E A1000002        E     220           LD      dest_ptr, #DEST_BUFF_BASE
    0012 B14004          R     221           LDB     loop_count,#BUFF_LENGTH
    0015 3E091D          R     222           JBS     Control_A2D, Lin_Par,    Linear_data_loop
                               223
                               224
    0018 180104          R     225   PAIRED: SHRB    loop_count,#1           ; The paired data routine uses 1/2
                               226                                           ; as many loops as the unpaired
    001B                       227   Paired_Data_loop:
    001B A20000          R     228           LD      adudtemp0,[src_ptr]+            ; Move even word
    001E C20200          R     229           ST      adudtemp0,[dest_ptr]
    0021 65400002        R     230           ADD     dest_ptr,#BUFF_LENGTH   ; Length = # of words = 1/2 # of bytes
                               231
    0025 A20000          R     232           LD      adudtemp0,[src_ptr]+            ; Move odd word
    0028 C20200          R     233           ST      adudtemp0,[dest_ptr]+
    002B 69400002        R     234           SUB     dest_ptr,#BUFF_LENGTH
                               235
    002F E004E9          R     236           DJNZ    loop_count, Paired_Data_loop    ; Loop until done
                               237
    0032 280D                  238           CALL    Convert_Data
    0034 F0                    239           RET
                               240
                               241
    0035                       242   Linear_Data_loop:                       ; Move data linearly
    0035 A20000          R     243           LD      adudtemp0,[src_ptr]+
    0038 C20200          R     244           ST      adudtemp0,[dest_ptr]+
                               245
    003B E004F7          R     246           DJNZ    loop_count, Linear_Data_loop    ; Loop until done
                               247
    003E 2801                  248           CALL    Convert_Data
    0040 F0                    249           RET
                               250   $eject
```

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Listing 4—A to D Converter Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                    02/18/86        PAGE    8

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               251
    0041                       252   Convert_Data:                ; Convert the data in the destination buffer
                               253
    0041 A1400004          R   254           LD      loop_count,#BUFF_LENGTH
    0045 A1000000          E   255           LD      src_ptr,#DEST_BUFF_BASE
                               256
    0049 A20000            R   257   Again:  LD      adudtemp0,[src_ptr]
    004C 71C000            R   258           ANDB    adudtemp0,#11000000b
    004F 330909            R   259           JBC     Control_A2D, DForm, Unsigned_Result
                               260
    0052                       261   Signed_Result:
    0052 69E07F00          R   262           SUB     adudtemp0,#7fe0H
    0056 0A0100            R   263           SHRA    adudtemp0,#Shift_Count
    0059 2003                  264           BR      Replace_Sample
                               265
    005B                       266   Unsigned_Result:
    005B 080100            R   267           SHR     adudtemp0, #Shift_Count
                               268
    005E                       269   Replace_Sample:
    005E C20000            R   270           ST      adudtemp0,[src_ptr]+
    0061 E004E5            R   271           DJNZ    loop_count,Again        ; Loop until done
                               272
    0064 F0                    273           RET
                               274
                               275
    0065                       276   Convert:        ;; Prepare to Start Conversions
                               277
    0065 F2                    278           PUSHF
                               279
    0066 918009            R   280           ORB     Control_A2D, #Busy              ; set converter busy bit
                               281
    0069 B13F08            R   282           LDB     sample_count,#BUFF_LENGTH - 1
    006C A1000006          E   283           LD      top_of_buffer,#BUFF0_BASE
    0070 A1800004          E   284           LD      aductempl,#(BUFF0_BASE + 2*BUFF_LENGTH)
                               285
    0074 350908            R   286           JBC     Control_A2D, B0_B1, Start_Conversions
    0077 A1000006          E   287           LD      top_of_buffer,#BUFF1_BASE
    007B A1800004          E   288           LD      aductempl,#(BUFF1_BASE + 2*BUFF_LENGTH)
                               289   $eject
```

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Listing 4—A to D Converter Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                          02/18/86          PAGE    9

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               290
    007F                       291   Start_Conversions:
                               292
    007F 51070900         E    293           ANDB    ad_command,Control_A2D,#00000111b       ;load channel number
                               294
    0083 440A0A02         R    295           ADD     aductemp0,CLOCK,Sample_Period           ;start first conversion
                               296                                                           ;one sample time from
                               297                                                           ;now
                               298
                               299           Load_HSO_Command Start_A2D             ; Start A2D at Time=aductemp0
                               303
    008D CC00             R    304           POP     temp                           ; get a copy of the psw
                               305
                               306           Load_HSO_Command HSO_0_high            ; set hso.0 high at conversion
                               310                                                  ; start time for external S/H
                               311
    0095 81020200         R    312           OR      temp,#202h                     ; enable a2d interrupts
                               313
    0099 640A02           R    314           ADD     aductemp0,Sample_Period
                               315
                               316           Load_HSO_Command Start_A2D             ; start second convertion one
                               320                                                  ; sample time from the first
                               321
    00A2 C800             R    322           PUSH    temp                           ; put psw back on stack
                               323
                               324           Load_HSO_Command HSO_0_low             ;lower hso.0 for external S/H
                               328
    00AA F3                    329           POPF
    00AB F0                    330           RET
                               331   $eject
```

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Listing 4—A to D Converter Routine (Continued)

```
MCS-96 MACRO ASSEMBLER    A2D_BUFFERING_UTILITY                                  02/18/86          PAGE   10

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    00AC                        332           CSEG
                                333
    00AC                        334   A2D_DONE_Vector:                ; A/D INTERRUPT ROUTINE
    00AC F2                     335           PUSHF
                                336
    00AD C60600          E      337           STB     ad_result_lo,[top_of_buffer]+
    00B0 C60600          E      338           STB     ad_result_hi,[top_of_buffer]+
    00B3 51070900        E      339           ANDB    ad_command,Control_A2D,#00000111b       ;load channel number
                                340
    00B7 E00809          R      341           DJNZ    sample_count, Sample_Again
    00BA 1708            R      342           INCB    sample_count
                                343
    00BC 880406          R      344           CMP     top_of_buffer,aductempl         ; Check top of buffer
    00BF DF26                   345           BE      Top_of_buffers
    00C1 F3                     346           POPF
    00C2 F0                     347           RET
                                348
    00C3                        349   Sample_Again:
    00C3 640A02          R      350           ADD     aductemp0,Sample_Period         ; Set next sample time
    00C6 880406          R      351           CMP     top_of_buffer,aductempl         ; Check top of buffer
                                352                                                   ; for later jump
                                353           Load_HSO_Command Start_A2D
                                357
    00CF 30080B          R      358           JBC     sample_count,0,Make_HSO_High
                                359
    00D2                        360   Make_HSO_low:
    00D2 FD                     361           nop                             ; wait 8 states after HSO load
                                362           Load_HSO_Command HSO_0_Low
                                366                                           ; Load for change of HSO to trigger S/H
    00D9 DF0C                   367           BE      Top_of_buffers
    00DB F3                     368           POPF
    00DC F0                     369           RET
                                370
    00DD                        371   Make_HSO_high:
                                372           Load_HSO_Command HSO_0_High     ; Load for change of HSO to trigger S/H
                                376
    00E3 DF02                   377           BE      Top_of_buffers
    00E5 F3                     378           POPF
    00E6 F0                     379           RET
                                380
    00E7                        381   Top_of_buffers:
    00E7 717F09          R      382           ANDB    Control_A2D,#NOT(Busy)  ; Clear converter BUSY bit
    00EA F3                     383           POPF
    00EB F0                     384           RET
    00EC                        385   END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

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Listing 4—A to D Converter Routine (Continued)

The listing contains a fairly complete description of what the program does. The block by block operations are shown below:

Lines 1-198 describe the program, declare the variables and set up equates. Several of these variables are declared as overlayable, so the user needs to be careful if using this module for other than the FFT program.

Lines 205-210 declare a macro which is used to load the HSO unit. This will be used repeatedly through the code.

Lines 212-253 determine whether a conversion or download has been requested. If a download has been requested, the data is downloaded to the destination array as either paired or linear data. Paired data has been described earlier.

Lines 255-278 contain a subroutine which converts the destination array to either signed or unsigned numbers. The numbers are also shifted right to provide the desired full-scale value as requested by SHIFT_COUNT.

Lines 279-334 initialize the conversion routine. HSO.0 is toggled with the start of each routine so that an external sample and hold can be used. The instructions in lines 308, 316, and 326 have been interweaved with the Load_HSO_Commands to provide the required 8 state delays between HSO loadings. If this was not done, NOPs would have been needed. It is easier to understand the code if these lines are thought of as being gathered at line 326.

Lines 337-353 are the actual A/D interrupt routine. The A/D results are placed BYTE by BYTE on the buffer, the A/D is reloaded, and then the number of samples taken is compared to the number needed. Note that the A/D command register needs to be reloaded even if the channel does not change. INCB on line 348 is used to insure that the DJNZ falls through on the next pass (if sample_count is not reset).

Lines 355-396 complete the routine. The HSO is set up to trigger the next conversion and provide the HSO.0 toggle for an external sample and hold. Once again, the time between consecutive loads of the HSO is 8 states minimum. Note that this section of code has been optimized for speed by reducing branches to an absolute minimum and duplicating code where needed.

This concludes the description of the A to D buffer module. In the FFT program, this module is run, then the FFT transform module, then the plot module. This allows variables to be overlaid, saving RAM space. The time cost for this is not bad, considering the printer is the limiting factor in these conversions. If more RAM was provided, and the FFT was run with its data in external RAM, this module could be run simultaneously with the other modules.

10.0 DATA PLOTTING MODULE

The plot module is relatively straight-forward, and is shown in Listing 5. After the declarations, which include overlayable registers, an initialization routine is listed. This separately called routine sets up the serial port on the 8096 to talk to the printer. In this case, the port has to be set for 300 baud.

A console out routine follows. This routine can also be called by any program, but it is used only by the plot routine in this example. The write to port 1 is used to trace the program flow. The character to be output is passed to this routine on the stack. This conforms to PLM-96 requirements.

Since all stack operations on the 8096 are 16-bits wide, a multiple character feature has been added to the console out routine. If the high byte it receives is non-zero, the ASCII character in that byte is printed after the character in the low byte. If the high byte has a value between 128 and 255, the character in the low byte is repeated the number of times indicated by the least significant 7 bits of the high byte.

The print decimal number routine is next. It is called with two words on the stack. The first word is the unsigned value to be printed. The second byte contains information on the number of places to be printed and zero and blank suppression. This routine is not overflow-proof. The user must declare a sufficient number of places to be printed for all possible numbers.

The DRAW_GRAPH routine provides the plot. It first sends a series of carriage return, line feeds (CRLFs) to clear the printer and provides a margin on the paper. Each row is started with the row number, 2 spaces, and a "+". Asterisks are then plotted until

Number of asterisks > FFT Value / PLOT_RES

Recall that PLOT_RES is a variable set by the main program. When the number of asterisks hits the desired value, the value of the line is printed. If the Decibel mode is selected, the line value is divided by 512 and printed in integer + decimal part form, followed by "dB". If the number of asterisks reaches PLOT_MAX, no value is printed. The next line is then started. A line with only a "!" is printed before the next plot line to provide a more aesthetic display on the printer. If a CRT was used, this extra line would probably not be wanted.

```
MCS-96 MACRO ASSEMBLER    PLOT_SERIAL                                   02/18/86          PAGE    1

SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE: :F2:PLOTSP.A96
OBJECT FILE: :F2:PLOTSP.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: NOSB

ERR LOC  OBJECT                 LINE        SOURCE STATEMENT
                                   1    $pagelength(50)
                                   2
                                   3    PLOT_SERIAL  MODULE STACKSIZE (6)
                                   4
                                   5    ; Intel Corporation,  December 12, 1985
                                   6    ; by Ira Horden, MCO Applications
                                   7
                                   8    ;     This program produces a plot on serially connected printer.  The
                                   9    ; maginitude of each of the 32 input values is plotted horizontally, with one
                                  10    ; "!" followed by a linefeed between each plot line.  Each plot line starts
                                  11    ; with a "+" and the entire plot begins with 3 line feeds and ends with a form
                                  12    ; feed.  The values to be plotted are 32 unsigned words based at the externally
                                  13    ; defined pointer PLOT_IN.
                                  14
                                  15    ;     The routine INIT_OUTPUT must be run to set up the serial port when the
                                  16    ; system is turned on.  CON_OUT can be used by a program to output to the
                                  17    ; serial port.  DRAW_GRAPH is the routine that automatically plots the data.
                                  18
                                  19    ;     Sizing of the graph can be done using PLOT_RES, which determines how many
                                  20    ; units are needed for each dot, and PLOT_MAX, which is the maximum value the
                                  21    ; program will be passed.  Note that (PLOT_MAX/PLOT_RES) defines the maximum
                                  22    ; number of columns the routine will print.
                                  23    ;
                                  24
0000                              25    RSEG
                                  26            EXTRN   iocl, baud_reg, spcon, spstat, sbuf, portl
                                  27            EXTRN   zero, ax, bx, cx, dx, FFT_MODE
0000                              28            sptmp:  dsb     1
                                  29
0024                              30    OSEG at 24H
0024                              31            value:          dsl     1
0028                              32            divisor:        dsl     1
002C                              33            xptr:           dsw     1
002E                              34            yptr:           dsw     1
0030                              35            xval:           dsw     1
0032                              36            log_val:        dsw     1
                                  37
0000                              38    DSEG
                                  39            EXTRN   PLOT_IN
                                  40
                                  41    $eject
```

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```
MCS-96 MACRO ASSEMBLER    PLOT_SERIAL                                  02/18/86        PAGE    2

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                 42
    2500                         43  CSEG at 2500H           ;;;;            PROGRAM  MODULE BEGINS
                                 44
                                 45   PUBLIC INIT_OUTPUT, CON_OUT, DRAW_GRAPH
                                 46   EXTRN  PLOT_RES, PLOT_RES_2, PLOT_MAX
                                 47
    2500                         48  INIT_OUTPUT:                            ; INITIALIZE SERIAL PORT
                                 49
    2500 B12000          E       50          ldb     iocl,#00100000B ; set p2.0 to txd
                                 51
      0270                       52  baud_val        equ     624             ; 624=300 baud (at 12 MHz)
                                 53
      0082                       54  Baud_high       equ     ((baud_val-1)/256) OR 80H       ; set for XTAL1 clock
      006F                       55  baud_low        equ     (baud_val-1) MOD 256
                                 56
    2503 B16F00          E       57          ldb     baud_reg,#baud_low
    2506 B18200          E       58          ldb     baud_reg,#baud_high
                                 59
    2509 B14900          E       60          ldb     spcon,#01001001b        ; enable reciver mode 1
    250C B12000          R       61          ldb     sptmp,#00100000B        ; set TI-tmp
                                 62
    250F F0                      63          RET
                                 64
                                 65  $eject
```

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```
MCS-96 MACRO ASSEMBLER    PLOT_SERIAL                          02/18/86        PAGE    3

ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                 66
                                 67  ;-------------------------------------------------------------------------
                                 68  ;                          CONSOLE OUT ROUTINE
                                 69  ;
                                 70  ;       Call with a word parameter on stack.  The low byte has the character
                                 71  ;       to be sent.  If the high byte has a value between 81H and 8FEH, the
                                 72  ;       character is repeated 1 to 126 times respectively.  One repeat means
                                 73  ;       that the character will be printed 2 times.  If the high byte contains
                                 74  ;       a value between 1 and 7FH, the charater represented by that value will
                                 75  ;       be printed after the character in the low byte.  If the high byte
                                 76  ;       contains a value of zero only the low byte will be printed.
                                 77
    2510                         78  CON_OUT:
    2510 CC00                E   79          pop     ax                      ; cx contains the calling adress
    2512 CC00                E   80          pop     dx
    2514 3F011C              E   81          jbs     dx+1,7,onechr           ; If bit 7 is set print one character
    2517 980001              E   82          cmpb    dx+1,zero
    251A DF17                    83          je      onechr                  ; if highbyte=0 print one character
                                 84
    251C 900000              E   85  twochr: orb     sptmp,spstat            ; wait for TI
    251F 3500FA              R   86          jbc     sptmp,5,twochr
    2522 71DF00              R   87          andb    sptmp,#11011111b        ; clear TI-tmp
    2525 900000              E   88          orb     zero,spstat             ; remove possible false TI
                                 89
    2528 B00000              E   90          ldb     sbuf,dx
    252B B00100              E   91          ldb     dx,dx+1         ; Load second character
    252E 1101                E   92          clrb    dx+1            ; clear count byte
    2530 717F00              E   93          andb    dx,#07FH        ; mask MSB
                                 94
    2533 1701                E   95  onechr: incb    dx+1
    2535 717F01              E   96          andb    dx+1,#7FH
    2538 900000              E   97  wait1:  orb     sptmp,spstat            ; wait for TI
    253B 3500FA              R   98          jbc     sptmp,5,wait1
    253E 71DF00              R   99          andb    sptmp,#11011111b        ; clear TI-tmp
    2541 900000              E  100          orb     zero,spstat             ; remove possible false TI
                                101
    2544 B00000              E  102          ldb     sbuf,dx
    2547 E001EE              E  103          DJNZ    dx+1,wait1
    254A E300                E  104          BR      [ax]                    ; Effectively a RET
                                105
                                106  $eject
```

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```
MCS-96 MACRO ASSEMBLER    PLOT_SERIAL                          02/18/86        PAGE    4

ERR LOC  OBJECT                LINE      SOURCE STATEMENT
                               107   ;-------------------------------------------------------------------------
                               108   ;                          PRINT  DECIMAL  NUMBER  ROUTINE
                               109
                               110   ;       Call with two words on stack.  The first is the value to be printed.
                               111   ;       The second has mode information in the low byte.
                               112   ;               MODE:   000 = supress all zeros
                               113   ;                       001 = print all numbers
                               114   ;                       010 = supress all zeros except rightmost
                               115   ;                       1xx = do not print leading blanks
                               116   ;
                               117   ;       The high byte of the 2nd word = 2x the number of places to be printed
                               118
                               119
  254C                         120   PRINT_NUM:                      ; Send Decimal number to CON_OUT
  254C CC00              E     121           pop     cx
  254E CC00              E     122           pop     bx              ; bx is mode byte, bx+1 is divisor pointer
  2550 AC0100            E     123           ldbze   dx,bx+1
  2553 A300962528        E     124           ld      divisor,divtab[dx]
  2558 CC24                    125           pop     value
  255A                         126   div_loop:
  255A 0126                    127           clr     value+2
  255C 8C2824                  128           divu    value,divisor           ; divide ax,dx by divisor
  255F 380017            E     129           jbs     bx,0,chr_ok             ; print character regardless of value
  2562 980024            E     130           cmpb    value,zero
  2565 D70F                    131           jne     non_0                   ; jump if value is non zero
  2567                         132   Val_0:                          ; Value is zero
  2567 310003            E     133           jbc     bx,1,prntsp             ; Print space instead of 0
  256A 38280C                  134           jbs     divisor,0,chr_ok        ; If in rightmost position print 0
  256D 3A0015            E     135   prntsp: jbs     bx,2,cont       ; Do not print space if bit is set
  2570 A1F00024                136           ld      value,#0F0H     ;  0F0h+30h = 20H = space
  2574 2003                    137           br      chr_ok
                               138
  2576 910100            E     139   non_0:  orb     bx,#0001B               ; Set flag so 0's will be printed
  2579 65300024                140   chr_ok: add     value,#30h              ; 30h + n = 0 to 9 ascii
  257D 617F0024                141           and     value,#7Fh      ; send least sig seven bits, clear upper word
  2581 C824                    142           push    value
  2583 2F8B                    143           call    con_out         ; output ascii result (result<9)
  2585 A02624                  144   cont:   ld      value,value+2   ; load value with remainder
  2588 012A                    145           clr     divisor+2
  258A 8D0A0028                146           divu    divisor,#10     ; next lower power of ten
  258E 880028            E     147           cmp     divisor,zero
  2591 D7C7                    148           jne     div_loop
  2593                         149   div_done:
  2593 E300              E     150           br      [cx]
                               151
  2596                         152   DIVTAB:         ;       Number of places for result
  2596 000001000A006400        153           dcw     0, 1, 10, 100, 1000, 10000      ; divisor table - 10**n
```

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```
MCS-96 MACRO ASSEMBLER    PLOT_SERIAL                                  02/18/86          PAGE    5

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                               154
                               155
                               156
                               157
    25A2                       158   DRAW_GRAPH:                    ; Graph drawing routine
    25A2 C90D00                159         push    #0dh
    25A5 2F69                  160         call    con_out
    25A7 C90A82                161         push    #820AH           ;;;     Clear 3 lines
    25AA 2F64                  162         call    CON_OUT
    25AC C90000                163         push    #00
    25AF 2F5F                  164         call    CON_out
                               165
    25B1 012C                  166         clr     xptr
    25B3 0130                  167         clr     xval
    25B5                       168   NXT_ROW:
    25B5 C90D0A                169         push    #0A0DH           ; CRLF
    25B8 2F56                  170         call    CON_OUT
    25BA C90000                171         push    #00H             ; nul
    25BD 2F51                  172         call    CON_OUT
                               173
    25BF C830                  174         push    xval
    25C1 C9020A                175         push    #(0A00H or 0010b)       ; supress all zeros except rightmost
    25C4 2F86                  176         call    PRINT_NUM
                               177
    25C6 C92020                178         push    #2020H           ; Print 2 spaces
    25C9 2F45                  179         call    CON_OUT
    25CB C92B00                180         push    #2BH             ; +
    25CE 2F40                  181         call    con_out
                               182
    25D0 A100002E        E     183         ld      yptr,#PLOT_RES_2        ; PLOT_RES_2 = PLOT_RES/2
                               184                                         ; PLOT_RES is defined 7 lines down
                               185
    25D4                       186   NXT_COL:                               ; Next Column
    25D4 8B2D00002E      E     187         cmp     yptr,PLOT_IN[xptr]
    25D9 D911                  188         jh      PRT_NUM
    25DB                       189   PRT_MK:                                ; Print Mark
    25DB C92A00                190         push    #2AH
    25DE 2F30                  191         call    CON_OUT
    25E0                       192   INC_CNT:
    25E0 6500002E        E     193         add     yptr,#PLOT_RES  ; PLOT_RES = number of inputs per output point
    25E4 8900002E        E     194         cmp     yptr,#PLOT_MAX  ; PLOT_max = maximum line length
    25E8 D1EA                  195         jnh     nxt_col
    25EA 204F                  196         br      NXTLN
                               197   $eject
```

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```
MCS-96 MACRO ASSEMBLER    PLOT_SERIAL                              02/18/86        PAGE    6

ERR LOC  OBJECT                LINE      SOURCE STATEMENT
                               198
    25EC                       199   PRT_NUM:
    25EC 8900002E          E   200           cmp     yptr,#PLOT_RES_2        ; If value is less then minimum needed
    25F0 DF49                  201           be      NXTLN                   ; for a plot, do not print value
                               202
    25F2 C92020                203           push    #2020H                  ; print 2 spaces then value
    25F5 2F19                  204           call    con_out
    25F7 3B000B            E   205           JBS     FFT_MODE,3,db_mode
                               206
    25FA                       207   norm_mode:
    25FA CB2D0000          E   208           push    PLOT_IN[xptr]
    25FE C9000A                209           push    #(0A00H or 0000B)       ; supress all zeros
    2601 2F49                  210           call    PRINT_NUM
    2603 2036                  211           BR      NXTLN
                               212
    2605                       213   db_mode:
    2605 A32D00002E        E   214           ld      yptr,plot_in[xptr]      ; PLOT_IN = 512*10*LOG(x)
    260A 08012E                215           shr     yptr,#1                 ; yptr=265 * 10LOG(x)
    260D AC2F00            E   216           ldbze   ax,yptr+1               ; ax= 10LOG(x) = yptr/256
                               217
    2610 C800              E   218           push    ax                      ; Print AX
    2612 C9020A                219           push    #(0A00H or 0010B)       ; supress all but rightmost zero
    2615 2F35                  220           call    PRINT_NUM
    2617 C92E00                221           push    #2EH                    ; Decimal point
    261A 2EF4                  222           call    con_out
                               223
    261C B02E01            E   224           ldb     ax+1,yptr       ; high byte of ax = fractional portion of
    261F 1100              E   225           clrb    ax              ;                   10LOG(x)
                               226
    2621 6DE60300          E   227           mulu    ax,#3E6H        ; if ax=FF00H then ax+2 now = 998 decimal
    2625 370102            E   228           jbc     ax+1,7,no_rnd
    2628 0700              E   229           inc     dx              ; round value up
                               230
    262A C800              E   231   no_rnd: push    dx      ; dx=ax+2
    262C C90106                232           push    #(600H or 0001B)        ; print all numbers to three places
    262F 2F1B                  233           call    Print_num
    2631 C92000                234           push    #20H            ; space
    2634 2EDA                  235           call    con_out
    2636 C96442                236           push    #4264H          ; "dB"
    2639 2ED5                  237           call    con_out
                               238
                               239   $eject
```

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```
MCS-96 MACRO ASSEMBLER    PLOT_SERIAL                                   02/18/86        PAGE    7

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                               240
                               241                                     ; Setup for next line
    263B C90D0A                242   NXTLN:  push    #0A0DH            ; CRLF
    263E 2ED0                  243           call    CON_OUT
    2640 C90000                244           push    #00H              ; nul
    2643 2ECB                  245           call    CON_OUT
    2645 C92086                246           push    #8620H            ; 7 spaces
    2648 2EC6                  247           call    CON_OUT
    264A C92100                248           push    #21H              ; !
    264D 2EC1                  249           call    con_out
                               250
    264F 0730                  251           inc     xval
    2651 6502002C              252           add     xptr,#2
    2655 893E002C              253           cmp     xptr,#62
    2659 D2022758              254   !       ble     nxt_row           ; Start printing next row
                               255
    265D C90D0A                256   Done:   push    #0A0DH            ; CRLF  ; Form feed for next graph
    2660 2EAE                  257           call    CON_OUT
    2662 C9000C                258           push    #0C00H            ; null,FF
    2665 2EA9                  259           call    con_out
                               260
    2667 F0                    261           RET
    2668                       262   END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

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Listing 5—The Plot Module (Continued)

At the end of the plot, a form feed is given to set the printer up for the next graph. Our printer would frequently miss the character after a CRLF. To solve this problem, a null (ASCII 0) is sent after every CRLF to make sure the printer is ready for the next line. This has been found to be a problem with many devices running at close to their maximum capacity, and the nulls work well to solve it.

With the plot completed, the program begins to run again by taking another set of A to D samples.

11.0 USING THE FFT PROGRAM

The program can be used with either real or tabled data. If real data is used, the signal is applied to analog channel 1. The program as written performs A/D samples at 100 microsecond intervals, collecting the 64 samples in 6.4 milliseconds. This sets the sampling window frequency at 156 Hz. If tabled data is used, 64 words of data should be placed in the location pointed to by DATA0 in the TABLE_LOAD routine of the Main Module.

Program control is specified by FFT_MODE which is loaded in the main module. Also within the main module are settings which control the A to D buffer routine and the Plot routine. The intention was to have only one module to change and recompile to vary parameters in the entire program.

The program modules are set up to run one-at-a-time so that the code would be easy to understand. Additionally, the Plot routine takes so long relative to the other sections, that it doesn't pay to try to overlap code sections. If this code were to be converted to run a process instead of print a graph, it might be worthwhile to run the FFT and the A/D routines at the same time.

If the goal of a modified program is to have the highest frequency sampling possible, it might be desirable to streamline the A/D section and run it without interruption. When the A to D routine was complete the FFT routine could be started. The reasoning behind this is that at the fastest A/D speeds the processor will be almost completely tied up processing the A/D information and storing it away. Using an interrupt based A/D routine would slow things down.

A set of programs which will perform a FFT has been presented in this application note. These programs are available from the INSITE users library as program CA-26. More importantly, dozens of programing examples have been made available, making it easier to get started with the 8096. Examples of how to use the hardware on the 8096 have already appeared in AP-248, "Using The 8096". These two applications notes form a good base for the understanding of MCS-96 microcontroller based design.

12.0 APPENDIX A - MATRICES

Matrices are a convenient way to express groups of equations. Consider the complex discrete Fourier Transform in equation 9, with N = 4.

$$Y_n = \sum_{k=0}^{3} X(k)\, W^{nk} \qquad n = 0, 1, 2, 3$$

This can be expanded to

$$\begin{aligned}
Y(0) &= X(0)\,W^0 + X(1)\,W^0 + X(2)\,W^0 + X(3)\,W^0 \\
Y(1) &= X(0)\,W^0 + X(1)\,W^1 + X(2)\,W^2 + X(3)\,W^3 \\
Y(2) &= X(0)\,W^0 + X(1)\,W^2 + X(2)\,W^4 + X(3)\,W^6 \\
Y(3) &= X(0)\,W^0 + X(1)\,W^3 + X(2)\,W^6 + X(3)\,W^9
\end{aligned}$$

In matrix notation, this is shown as

$$\begin{bmatrix} Y(0) \\ Y(1) \\ Y(2) \\ Y(3) \end{bmatrix} = \begin{bmatrix} W^0 & W^0 & W^0 & W^0 \\ W^0 & W^1 & W^2 & W^3 \\ W^0 & W^2 & W^4 & W^6 \\ W^0 & W^3 & W^6 & W^9 \end{bmatrix} \begin{bmatrix} X(0) \\ X(1) \\ X(2) \\ X(3) \end{bmatrix}$$

The first step to simplifying this is to reduce the center matrix. Recalling that

$$W^N = W^{N \bmod N} \quad \text{and} \quad W^0 = 1$$

The matrix can be reduced to have less non-trivial multiplications.

$$\begin{bmatrix} Y(0) \\ Y(1) \\ Y(2) \\ Y(3) \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & W^1 & W^2 & W^3 \\ 1 & W^2 & W^0 & W^2 \\ 1 & W^3 & W^2 & W^1 \end{bmatrix} \begin{bmatrix} X(0) \\ X(1) \\ X(2) \\ X(3) \end{bmatrix}$$

The square matrix can be factored into

$$\begin{bmatrix} Y(0) \\ Y(2) \\ Y(1) \\ Y(3) \end{bmatrix} = \begin{bmatrix} 1 & W^0 & 0 & 0 \\ 1 & W^2 & 0 & 0 \\ 0 & 0 & 1 & W^1 \\ 0 & 0 & 1 & W^3 \end{bmatrix} \begin{bmatrix} 1 & 0 & W^0 & 0 \\ 0 & 1 & 0 & W^0 \\ 1 & 0 & W^2 & 0 \\ 0 & 1 & 0 & W^2 \end{bmatrix} \begin{bmatrix} X(0) \\ X(1) \\ X(2) \\ X(3) \end{bmatrix}$$

For this equation to work, the Y(1) and Y(2) terms need to be swapped, as shown above. This procedure is a Bit Reversal, as described in the text.

Multiplying the two rightmost matrices results in

$$\begin{aligned}
&X(0) + X(2)\,W^0 \\
&X(1) + X(3)\,W^0 \\
&X(0) + X(2)\,W^3 \\
&X(1) + X(3)\,W^2
\end{aligned}$$

requiring 4 complex multiplications & 4 complex additions

Noting that $W^0 = -W^2$, 2 of the complex multiplications can be eliminated, with the following results

$$\begin{aligned}
&X(0) + X(2)\,W^0 \\
&X(1) + X(3)\,W^0 \\
&X(0) - X(2)\,W^0 \\
&X(1) - X(3)\,W^0
\end{aligned}$$

requiring 2 complex multiplications and 4 complex additions

Since $W^1 = -W^3$, a similar result occurs when this vector is multiplied by the remaining square matrix. The resulting equations are:

$$\begin{aligned}
Y(0) &= (X(0) + X(2)\,W^0) + W^0\,(X(0) + X(3)\,W^0) \\
Y(2) &= (X(0) + X(2)\,W^0) - W^0\,(X(1) + X(3)\,W^0) \\
Y(1) &= (X(0) - X(2)\,W^0) + W^1\,(X(1) - X(3)\,W^0) \\
Y(3) &= (X(0) - X(2)\,W^0) - W^1\,(X(1) - X(3)\,W^0)
\end{aligned}$$

The number of complex multiplications required is 4, as compared with 16 for the unfactored matrix.

In general, the FFT requires

$$\frac{N * EXPONENT}{2} \text{ complex multiplications}$$

and

$$N * EXPONENT \text{ complex additions}$$

where

$$EXPONENT = \text{Log}_2\, N$$

A standard Fourier Transform requires

$$N^2 \text{ complex multiplications}$$

and

$$N(N-1) \text{ complex additions}$$

6

13.0 APPENDIX B - PLOTS

The following plots are examples of output from the FFT program. These plots were generated using tabled data, but very similar plots have also been made using the analog input module. Typically, a plot made using the analog input module will not show quite as much power at each frequency and will show a positive value for the DC component. This is because it is difficult to get exactly a full-scale analog input with no DC offset.

Plot 1 is a Magnitude plot of a square wave of period NT.

Plot 2 is the same data plotted in dB. Note how the dB plot enhances the difference in the small signal values at the high frequencies.

Plot 3 shows the windowed version of this data. Note that the widening of the bins due to windowing shows energy in the even harmonics that is not actually present. For data of this type a different window other than Hanning would normally be used. Many window types are available, the selection of which can be determined by the type of data to be plotted.[3]

Plot 4 shows a sine wave of period NT/7 or frequency 7/NT.

Plot 5 shows the same input with windowing. Note the signal shown in bins 6 and 8.

Plot 6 shows a sine wave of period NT/7.5. Note the noise caused by the discontinuity as discussed earlier.

Plot 7 uses windowing on the data used for plot 6. Note the cleaner appearance.

Plot 8 shows a sine wave input of magnitude 0.707 and period NT/7.5.

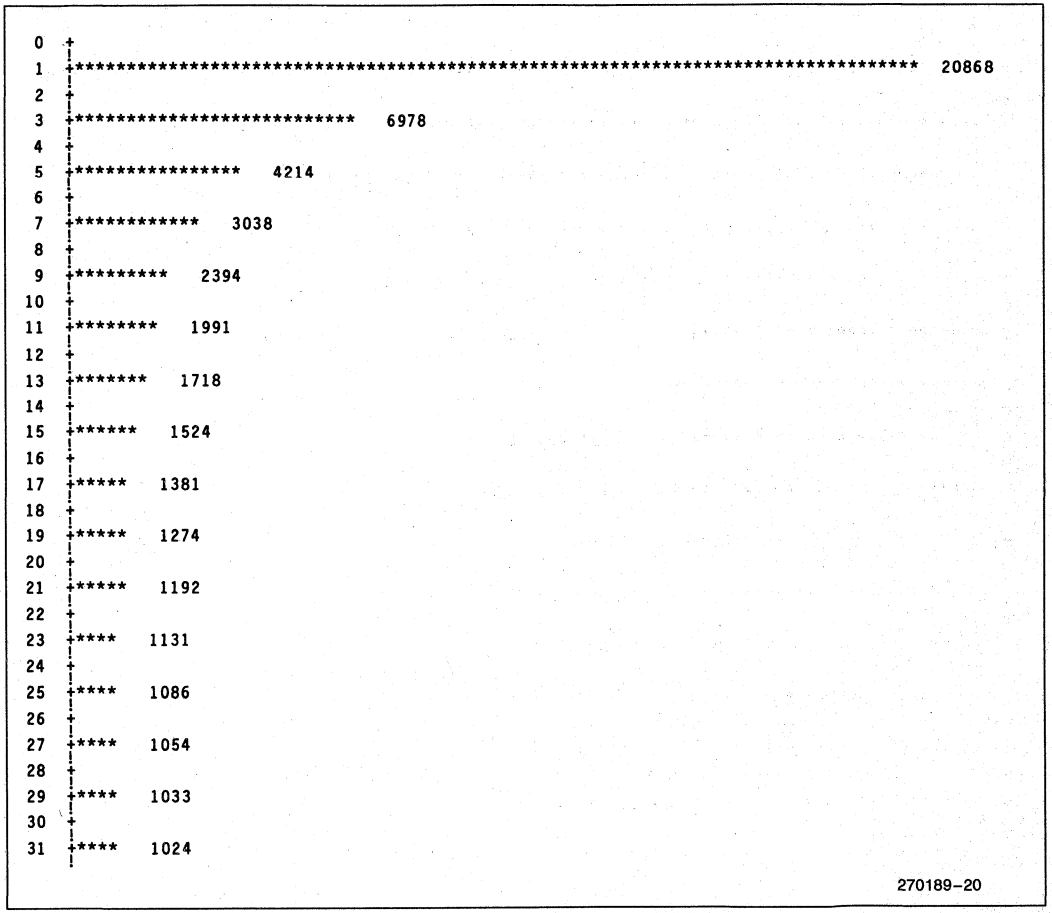
Plot 9 shows same input with windowing.

Plot 10 shows a sine wave of magnitude 0.707/16 and period NT/11.

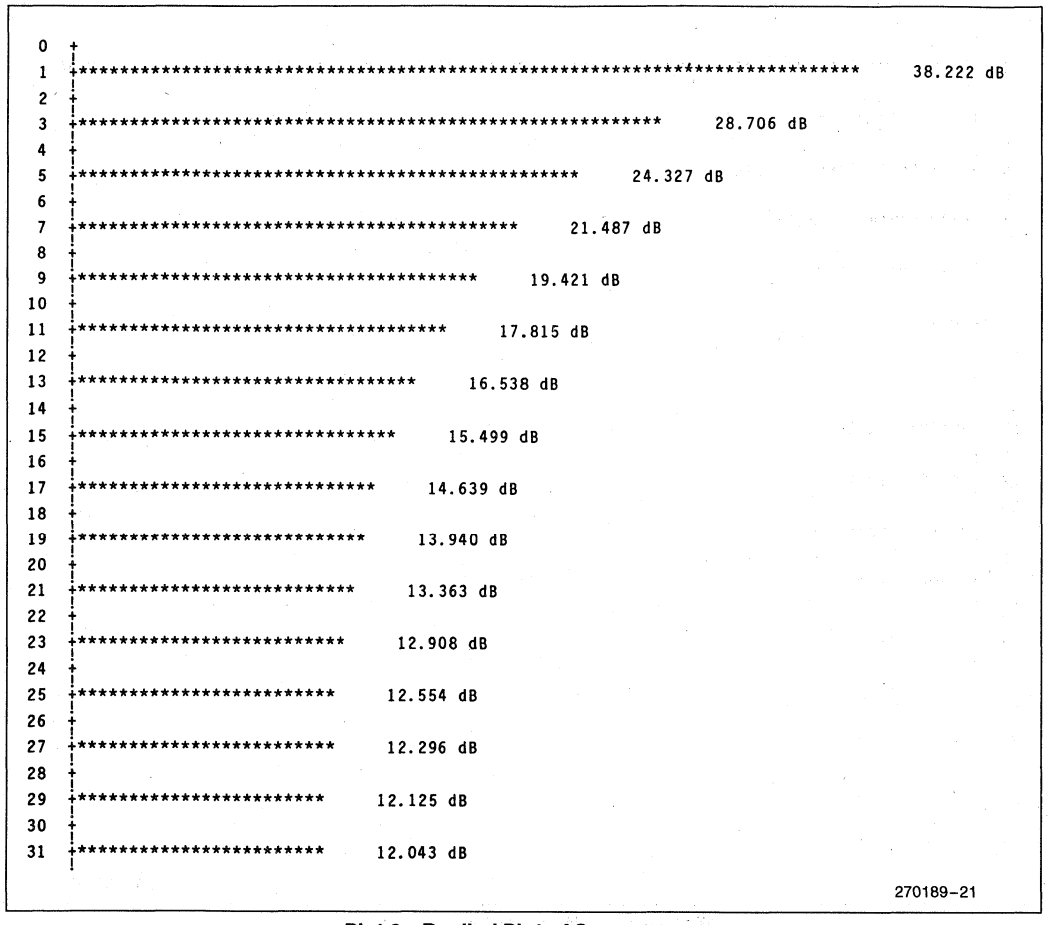
Plot 11 shows the same input with windowing. Note that there is no power shown in bins 10 and 12. This is because at 6 dB down from 3 dB they are nearly equal to zero.

Plot 12 uses the sum of the signals for plots 8 and 10 as inputs. Note that the component at period NT/11 is almost hidden.

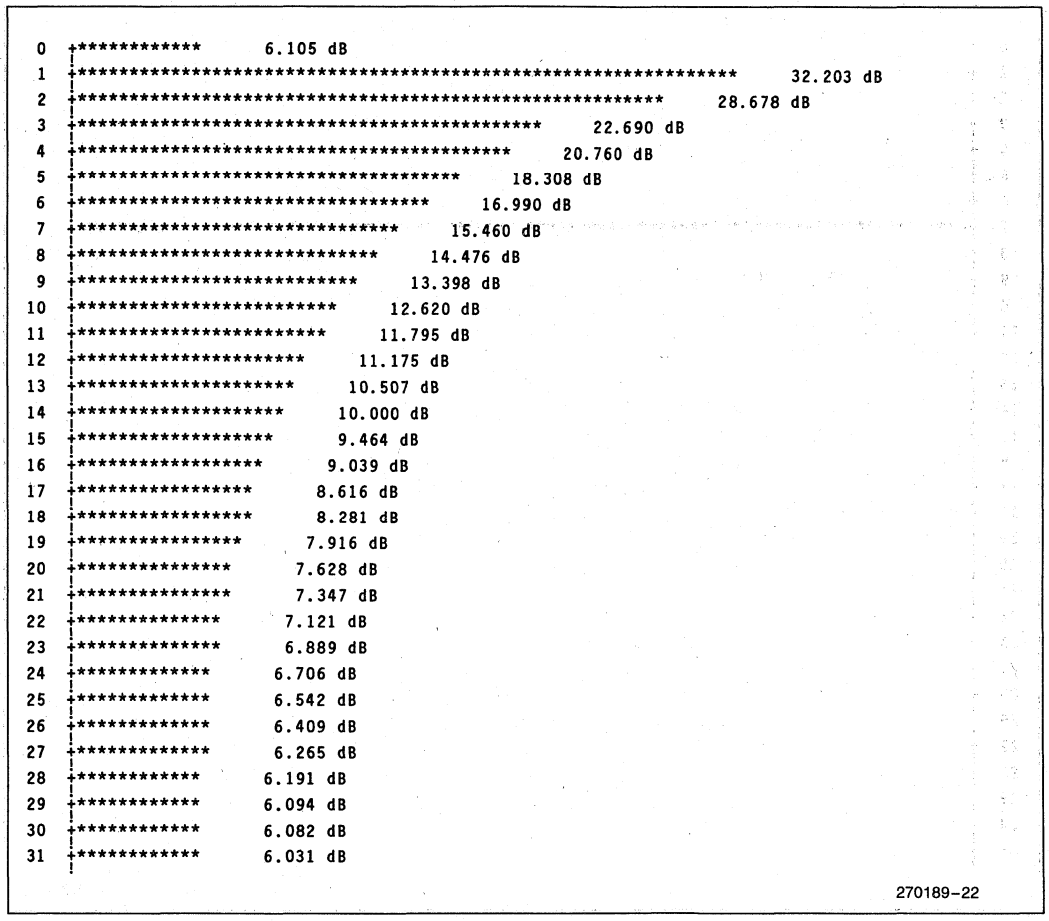
Plot 13 uses the same signal as plot 12 but applies windowing. Now the period component at NT/11 can easily be seen. The Hanning window works well in this case to separate the signal from the leakage. If the signals were closer together the Hanning window may not have worked and another window may have been needed.



Plot 1—Magnitude Plot of Squarewave

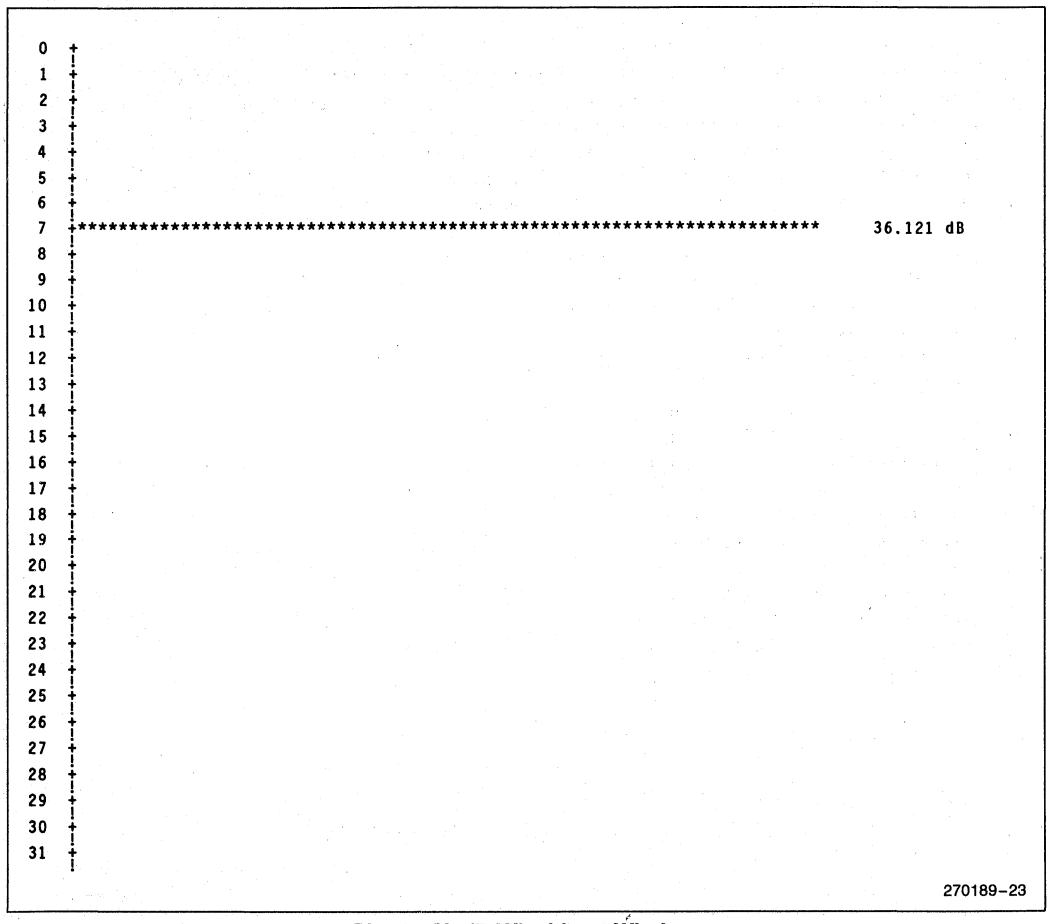


Plot 2—Decibel Plot of Squarewave

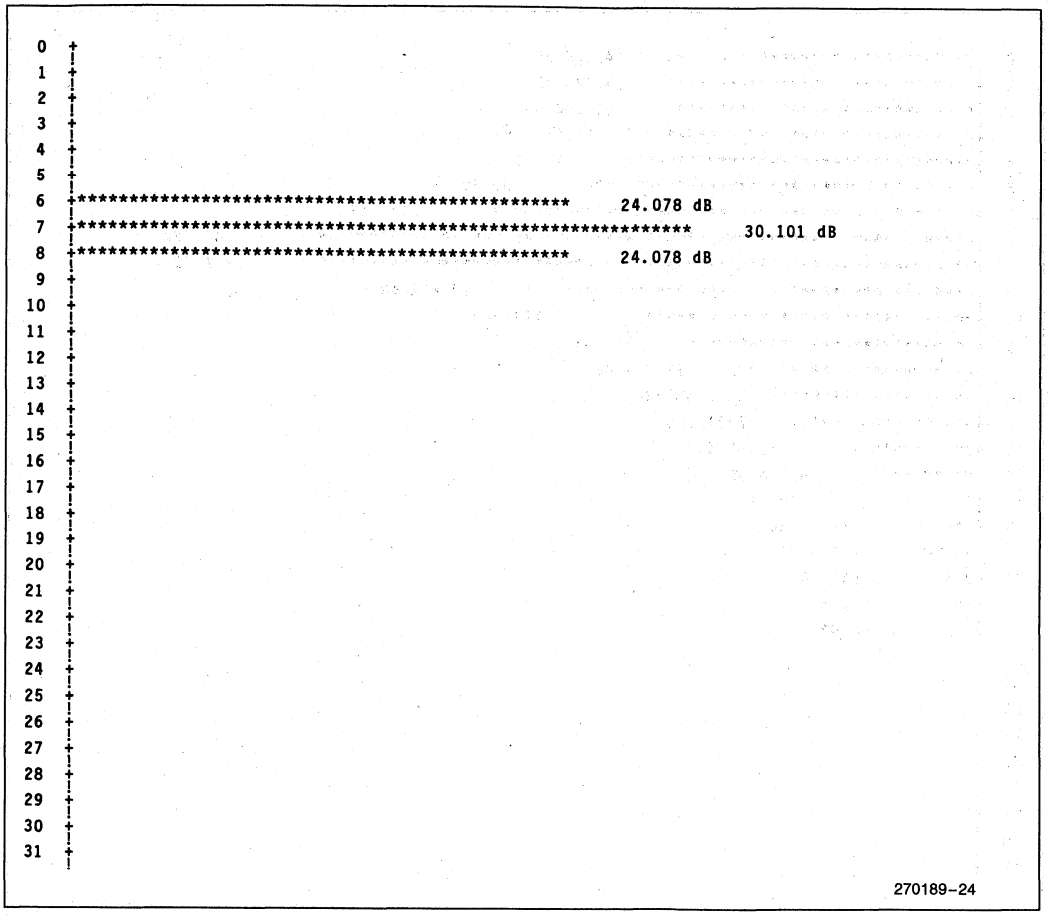


Plot 3—Plot of Squarewave with Window

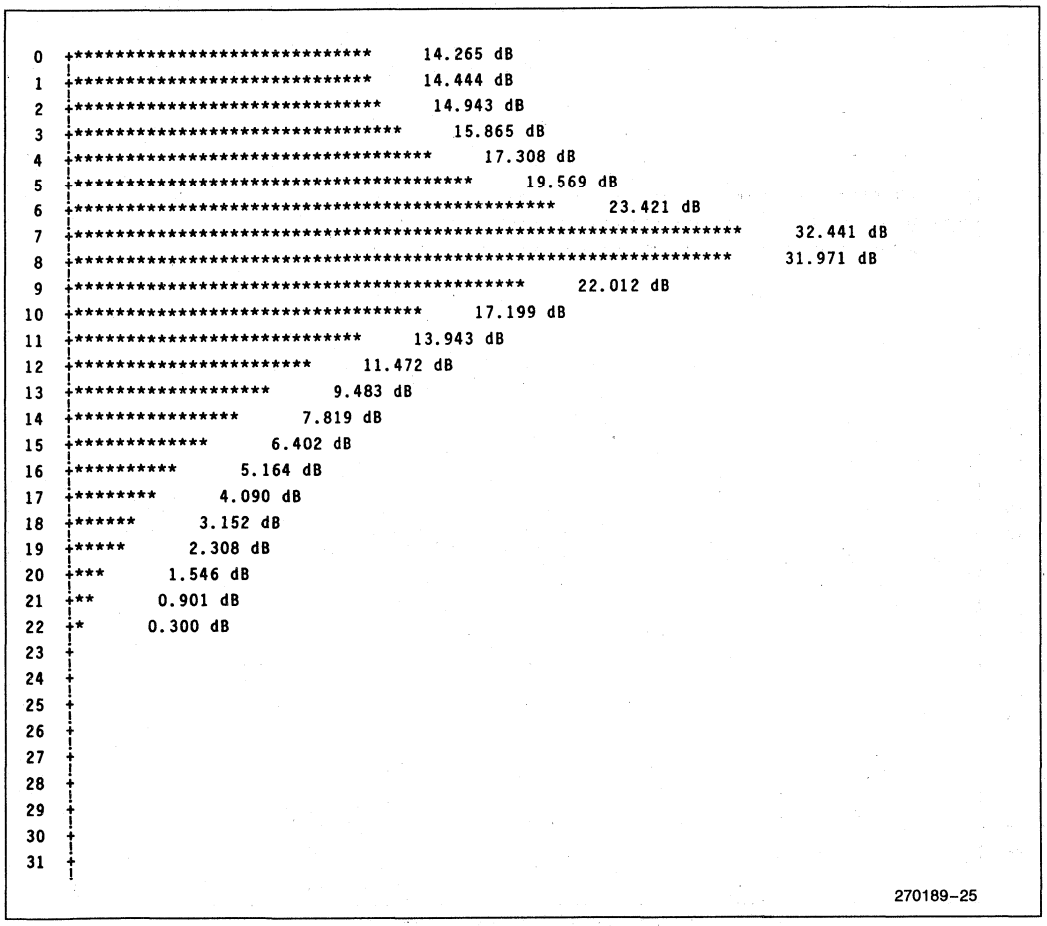
6



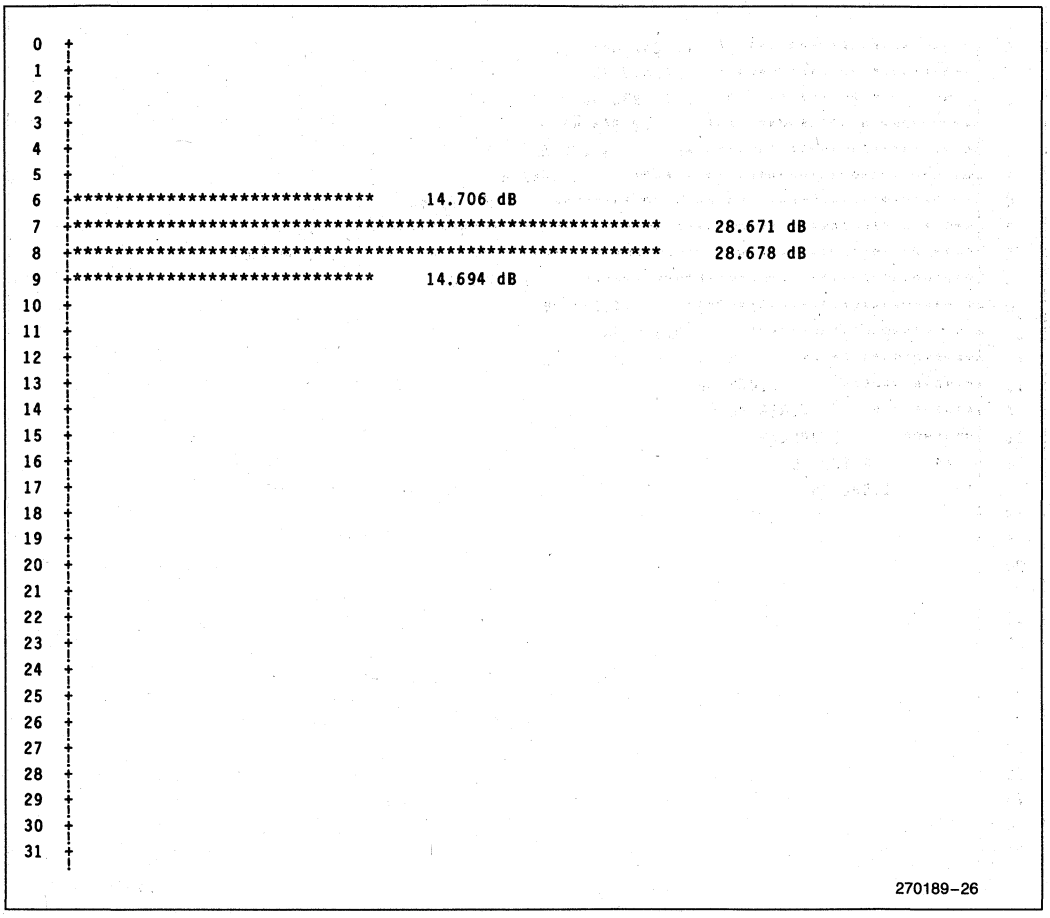
Plot 4—Sin (7.0X) without Window



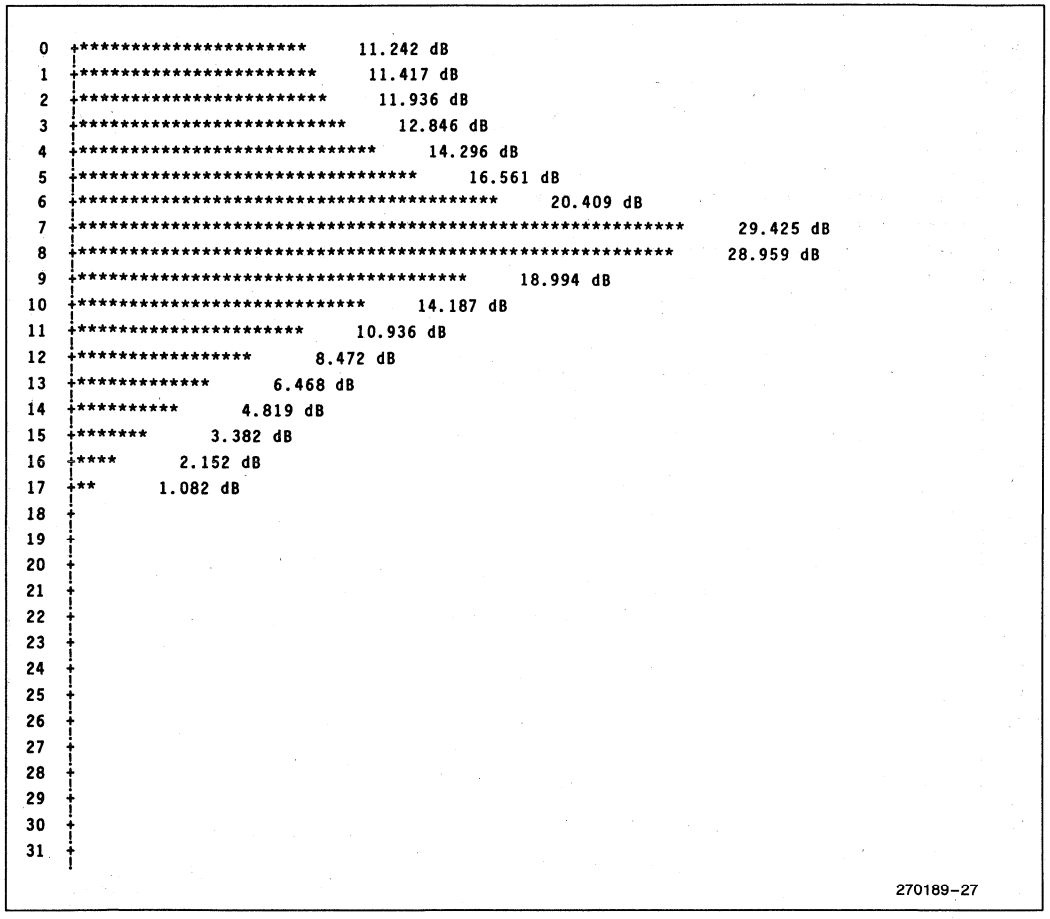
Plot 5—Sin (7.0X) with Window



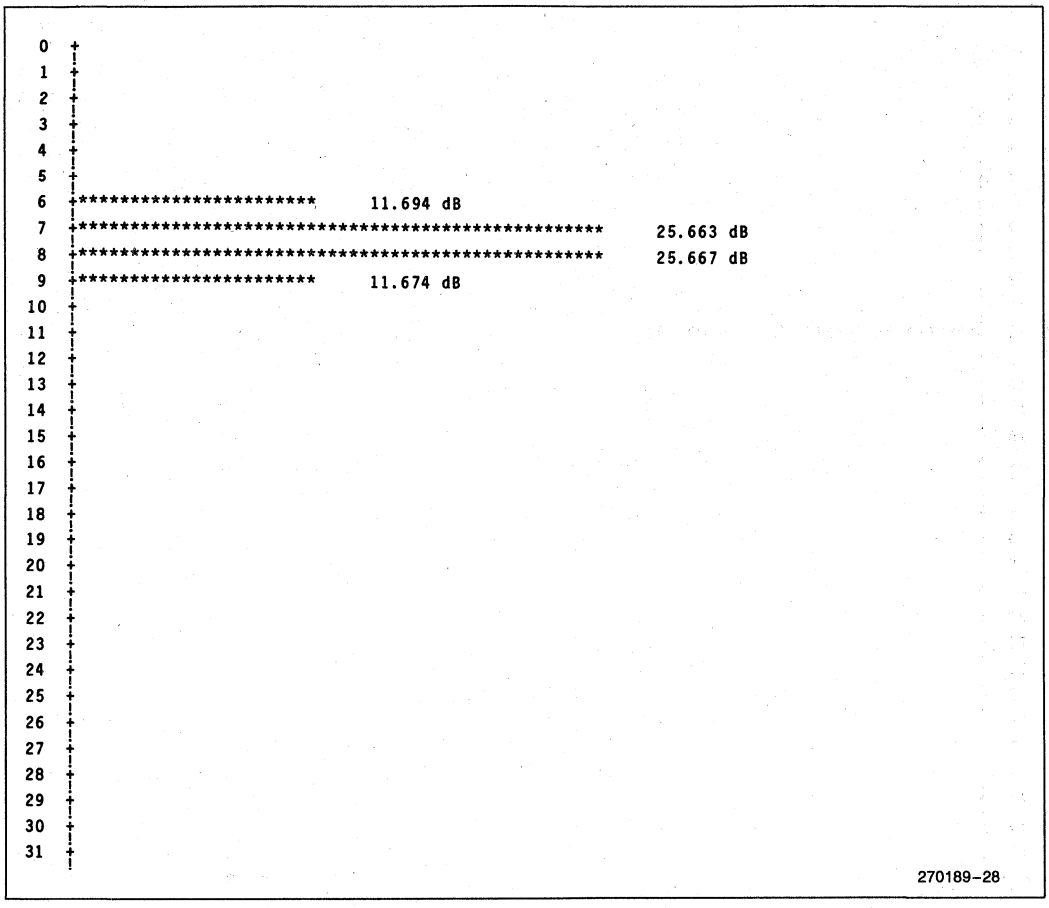
Plot 6—Sin (7.5X) without Window



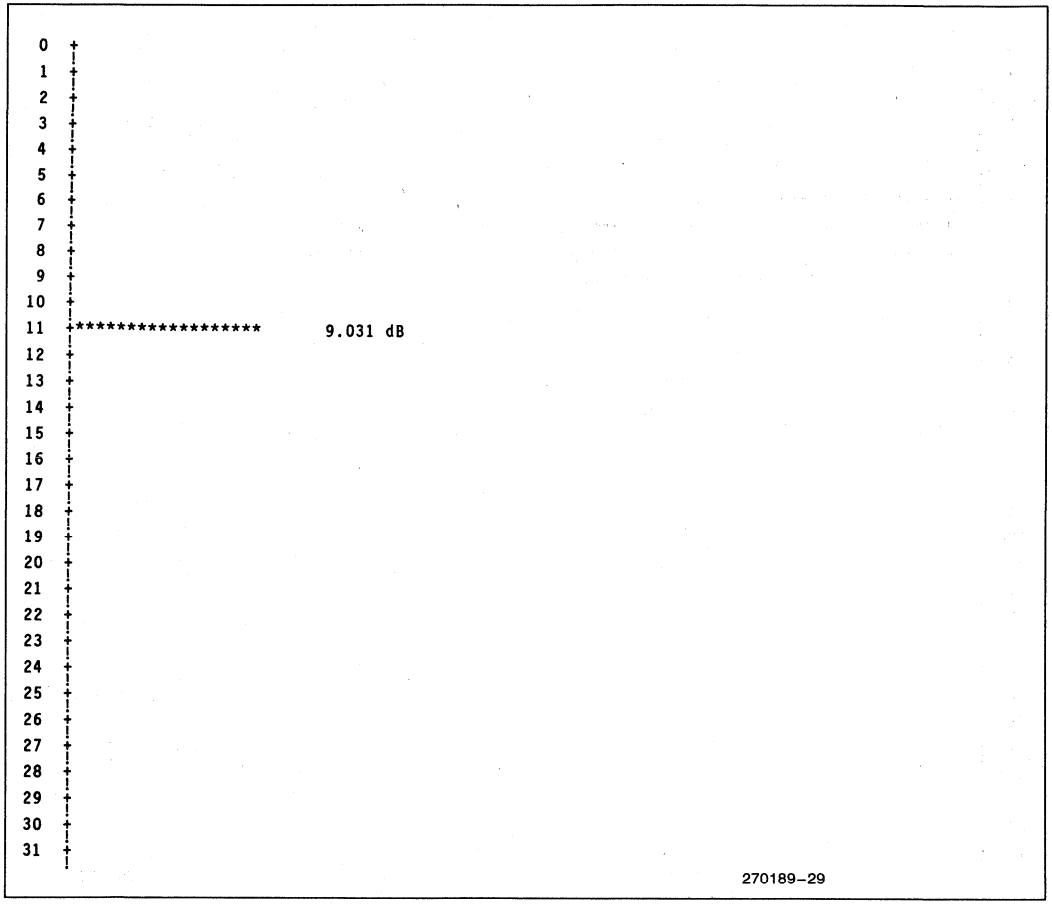
Plot 7—Sin (7.5X) with Window



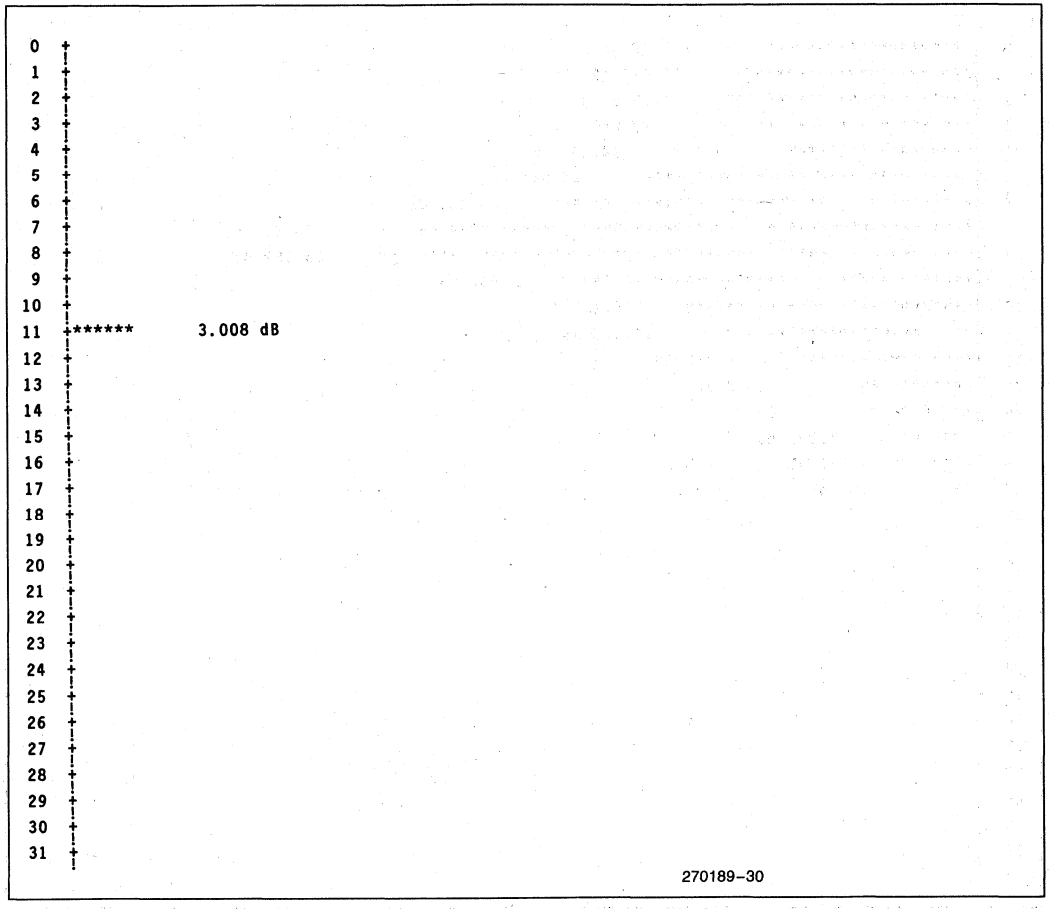
Plot 8—0.707 * Sin (7.5X) without Window



Plot 9—0.707 * Sin (7.5X) with Window

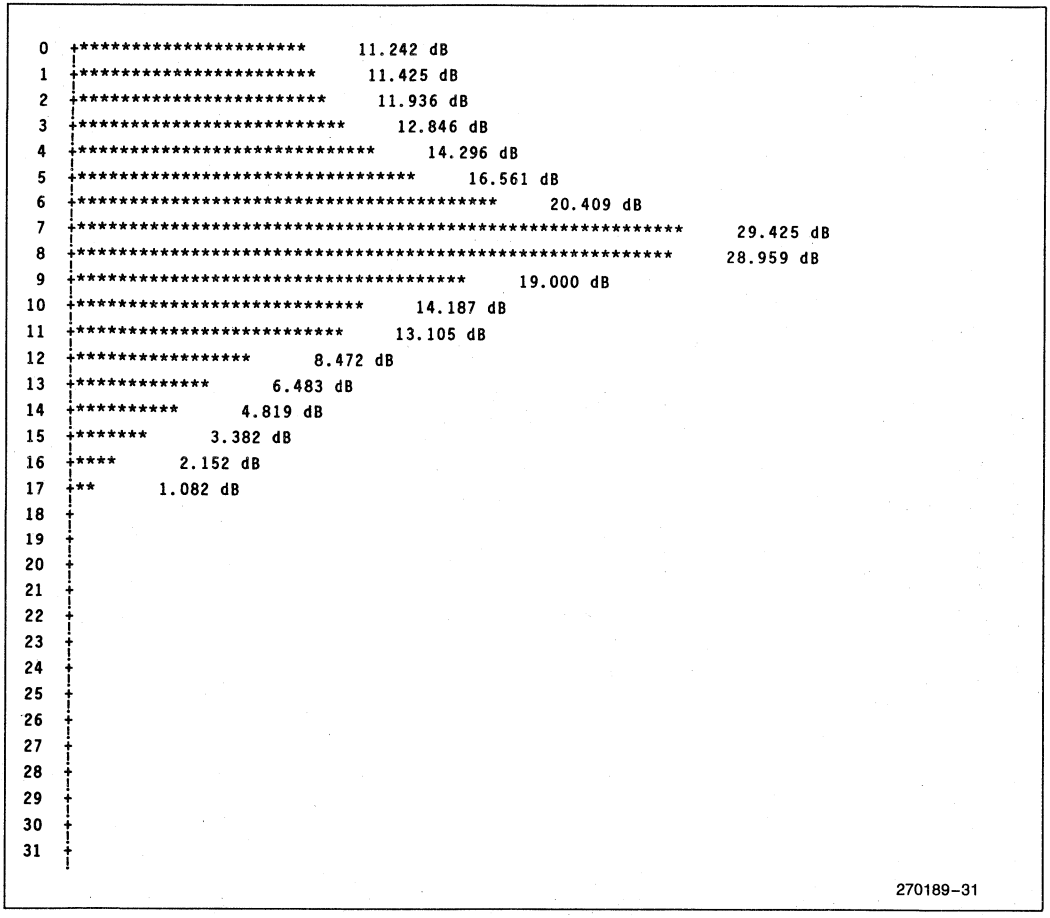


Plot 10—0.707/16 * Sin (11X) without Window

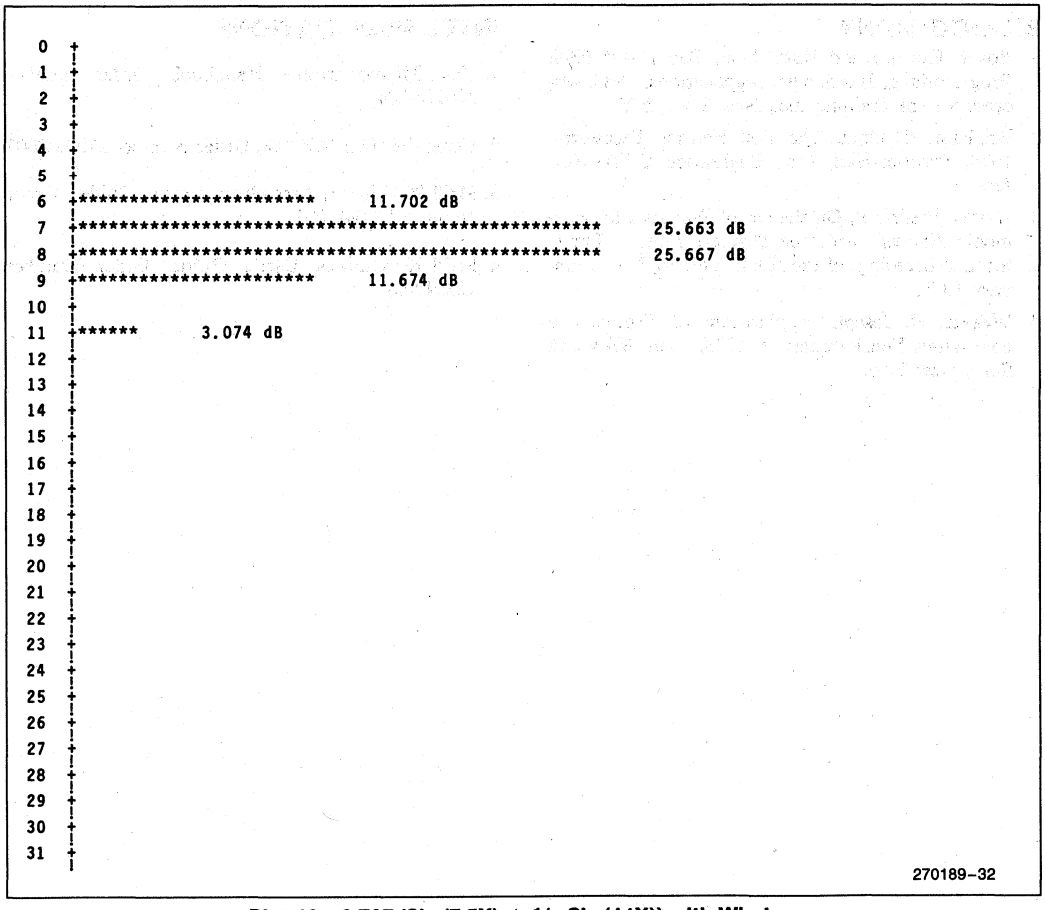


Plot 11—0.707/16 * Sin (11X) with Window

6



Plot 12—0.707 (Sin (7.5X) + 1/16 Sin (11X)) without Window



Plot 13—0.707 (Sin (7.5X) + 1/16 Sin (11X)) with Window

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April 1989

Upgrade Path from 8096-90 to 8096BH to 80C196

Order Number: 270521-001

UPGRADE PATH FROM 8096-90 TO 8096BH TO 80C196

CONTENTS

Converting applications that use an 8X9X-90 to use an 8X9XBH requires consideration of a few of the BH enhancements. Descriptions of each of the differences between the -90 and the BH follow, along with a discussion of the implications of the change.

$\overline{BHE}$ and INST are latched: The bus control signals $\overline{BHE}$ and INST are valid throughout the bus cycle on 8X9XBH devices. ON -90 devices, these signals need to be latched on the falling edge of ALE.

Byte Read following $\overline{RESET}$ rising: The bus control and buswidth options of 8X9XBH devices are selected by configuration of the chip immediately following the rising edge of $\overline{RESET}$. During the usual 10 state reset sequence, BH parts will perform a byte read of location 2018H to acquire configuration information prior to fetching the first opcode at location 2080H. The 8X9X-90 does not perform this read.

ALE is high while in reset: The ALE/$\overline{ADV}$ pin of the 8X9XBH is driven high while the $\overline{RESET}$ pin is held low. On -90 devices, ALE is driven low while in RESET. Circuits which rely on the state of ALE while RESET is low must be modified. The reset state of ALE was changed to enable implementation of the Chip Configuration Byte read from external memory following the rising edge of RESET.

$\overline{EA}$ is latched on $\overline{RESET}$ rising: The 8X9XBH latches the value of $\overline{EA}$ on the rising edge of $\overline{RESET}$. On -90 devices, $\overline{EA}$ was not latched and could be changed without placing the part in $\overline{RESET}$. This change was necessary to enhance ROM/EPROM security. Circuits that rely on $\overline{EA}$ not being latched must be modified.

A/D speed increased: The 8X95BH and 8X97BH A/D converters complete conversion in 88 state times. On -90 devices with A/D converters, a conversion takes 168 state times. This translates in an increased conversion speed from 42μs on -90 parts to 22μs on BH parts running at 12MHz. Software that relies upon the speed of conversion for timing must be changed. It is also recommended that MCS-96 software be written so as to not be impacted by further changes in A/D conversion speed.

Sample/Hold on A/D: The 8X95BH and 8X97BH have a sample/hold on the input of the A/D converter. 8X9X-90 devices with A/D converters do not have sample/hold circuitry. External analog circuitry which also includes a sample/hold must provide a settled analog input within the first four state times of 8X9XBH conversion.

Duplicate Fetches: The 8X9XBH bus controller was made more aggressive when it comes to instruction fetches in order to minimize the execution speed degradation of using an 8-bit bus. As a result, instruction fetches over a 16-bit bus sometimes occur when there is no space in the prefetch queue to store the fetched opcodes. This requires another instruction fetch from the same address when space in the prefetch queue opens up.

To the external system, these occurrences appear as duplicate instruction fetches. An estimated 10 percent of all instruction fetches will be "duplicates", while overall bus loading will be approximately 65 to 70 percent, compared to an 8X9X-90 bus loading of approximately 55 to 60 percent. Execution speed is not impacted by a duplicate fetch.

Write Pulse Width: The 8X9XBH 16-bit bus write pulse width is one T_{osc} longer than on the 8X9X-90, thus allowing slower memories and peripherals to be used. In order to widen the $\overline{WR}$ pulse width, the time between the end of $\overline{WR}$ and the next ALE was reduced by T_{osc}. Note that the signals $\overline{WRL}$, $\overline{WRH}$, and $\overline{WR}$ with an 8-bit bus are still the same width as on -90 parts.

V_{PP} Replaces V_{BB}: V_{PP} is the programming pin for EPROM devices. Systems that have this connected through a capacitor to ANGND (required on 8X9X-90 parts) do not need to change. ANGND must be held nominally at the same potential as V_{SS}, and V_{PP} must NOT be connected to V_{CC}. High voltage must NEVER be placed on the V_{PP} pin of a ROM device.

While there is almost no reason to do so, an application should not attempt to execute with the EA pin at logic zero and V_{CC} at 5.5 V_{DC} on an 879XBH EPROM device. Additionally, the design should always begin the "out of RESET" code execution from the internal EPROM, immediately after the power-on sequence.

Reserved location warning: Intel reserved addresses can not be used by applications which use 8X9XBH internal ROM/EPROM. The data read from a reserved location is not guaranteed, and a write to any reserved location could cause unpredictable results. When attempting to program Intel Reserved addresses, the data must be OFFFFH to ensure a harmless result.

Intel Reserved locations, when mapped to external memory, must be filled with OFFFFH to ensure compatibility with future parts.

A positive transition on NMI: The 8X9XBH does not clear the Watchdog Timer. The 8X9X-90 does clear the WDT on a positive transition of NMI, and both part vector to external address 0000H.

The following is the latest information on upgrading a NMOS 8096 to a CHMOS 80C196.

The chip which is the CHMOS 8096BH replacement is designated the 80C196. The part can be configured to be pin compatible with the 8096, but because of the process change and other enhancements, it may not be plug compatible in some designs. This is to say that you will not be able to arbitrarily swap out a NMOS 8096 and replace it with the 80C196. However, if a few rules are followed the changes required will be almost painless.

80C196 OVERVIEW

First, some background on the 80C196 is needed. The opcode set is a true superset of the 8096, but some enhancements have been made to the peripherals and timings. The crystal is divided by 2 on the 80C196, instead of 3, as on the 8096. This means that the 80C196 running at 8 MHz will have a 250 ns state time, Just like an 8096 running at 12 MHz.

An 80C196 running at 8 MHz will emulate an 8096 at 12 MHz except that some of the instructions and peripherals will operate faster. The instructions which will be speeded up include mul, div, interrupt, call, ret, and jumps. The serial port will require a different baud value and the A to D may not run at exactly the same speed. This means that timing loops which measure instruction speed or A to D completion speed may have to be modified. The bus timings, while not nanosecond for nanosecond compatible, will work in most systems.

DESIGN GUIDELINES

1. Do not use undefined register areas for storage or depend on them to return a specific value if it is not stated in the Embedded Controller. Undefined registers and locations on this, or any other, part should be considered off-limits and reserved for development systems, testing or future use.
2. Do not base timings loops on instruction execution times, as some instructions may execute faster on the 80C196 than on the 8096, even when the 80C196 is slowed down to 8 MHz, its 8096 compatible rate. Counter-type loops should be initialized with values that can easily be changed at compile time.
3. Do not base critical timings on interrupt responses, A to D completions, flag settings, etc. This is for the same reason as above; some of these responses may be slightly different from those on the 8096. Timer 1 is provided for critical timings. With an 8 MHz crystal, it will increment every 2 microseconds, just as an 8096 running at 12 MHz.
4. The serial port baud register values should be easily changeable at compile time. Since the serial port is now capable of running at a higher frequency, a different baud rate value will be needed.
5. The circuitry interfacing to the chip should be capable of interfacing to the 80C196. The I/O lines on 80C196 will look a lot like those on the 80C51.
6. The $\overline{BHE}/\overline{WRH}$ signal in eight bit and write strobe mode will go low for odd byte transfers and high for even byte transfers. The $\overline{WR}/\overline{WRL}$ signal will go low for odd byte transfers and high for even byte transfers. Normally, the $\overline{WR}/\overline{WRL}$ signal should go low for odd and even byte transfers since transfers are on the low byte of the data bus.
7. PUSH and POP operations addressed relative to the stack pointer work differently on the 80C196 than on the 8096. On the 8096, the address is calculated based on the un-updated stack pointer value, on the 80C196, the address is calculated based on the updated value. The only operations effected are: PUSH xx[sp], PUSH [sp], PUSH sp, POP xx[sp], POP [sp], POP sp.
8. The V_{PD} pin on the 8X9X parts is now the CDE (Clock Detect Enable) pin on the 80C196. When tied high, CDE enables a clock speed sensor and will reset the part if the Xtal1 frequency drops below a few hundred KHz. While this is perfect for most production boards, it may be desirable to have a jumper option on this function for evaluation boards.

April 1989

Memory Expansion for the 8096

DOUG YODER
ECO APPLICATIONS ENGINEER

Order Number: 270522-001

MEMORY EXPANSION FOR THE 8096

CONTENTS

This Application Brief presents two examples of a paging scheme for the 8096, allowing either 256K bytes of total memory, or 544K bytes of total memory. Both systems utilize PORT1 as the output for the upper address lines. Because Interrupt vectors, and other critical sections of code must always be present, addresses 0-7FFFH always refer to the same main page. The PORT1 upper addresses only affect addresses 8000-FFFFH, by slapping several 32K pages in and out.

THE 256K SYSTEM

Hardware

The hardware for the 256K system (see Figures 4 & 5, an example with 128K ROM and 128K RAM) utilizes a 74LS157 quad 2 to 1 multiplexer. The enable pin of the 74LS157 is tied to the inverted A15 signal, which is the latched addr/data 15 (AD15) signal from the 96. In this way, when A15 is low, the 74LS157 is disabled and all its outputs are low. Particularly, MA17 is low, which selects the 27512 and deselects the rams. Also, MA15 and MA16 are low, which guarantee that addresses 0-7FFFH of the 27512 are accessed.

When A15 is high, the 74LS157 is enabled to pass MA15 - MA17 values. The bank select pin of the 74LS157 is connected to the INST pin of the 96. When the INST pin is high, for a code access, INSTA15 - INSTA17 (PORT1.0 - PORT1.2) are used. When INST is low, for a data read or write, DATAA15 - DATAA17 (PORT1.3 - PORT 1.5) are used. This allows for the use of separate pages for code and data without having to change the upper address lines each time. Also, it is possible to select a ROM page for a data table, or load a RAM page with executable code downloaded from another source. PORT1.6 and PORT1.7 can still be used as I/O ports. If a -90 part were used, the INST pin would need to be latched since it is only valid during the address output on the bus pins.

This system was designed to get the maximum amount of memory with a minimum amount of hardware. The amount of ROM and RAM was picked arbitrarily, and could be reconfigured in various ways, however, this may require slight modifications or additions to the decoder circuitry. This setup has a main page at addresses 0-7FFFH, and upper pages 1-7 at addresses 8000-FFFFH. Note that upper page 0 is the same as the main page. The WRL and WRH feature of the BH part was used to allow for byte writes to RAM. If the -90 part were to be used, additional logic would be necessary to generate these signals from WR and BHE.

The RAM chips utilized were NEC uPD43256-15 32K x 8 static rams with an access time of 150ns. The ROMs were Intel 27512 64K x 8 EPROMs with an access time of 200ns. The decoder circuitry used was entirely LS TTL. Using an 8097BH running at 10MHz, there was ample time for address decoding and memory access. Timing analysis showed that 12MHz operation would also be accommodated easily. If slower memories are used, further analysis would be necessary. Also, it would be possible to switch to S TTL to greatly decrease the decoding response time.

Software

When using this system there are several things to keep in mind when preparing the software.

Since ASM96 will only allow addresses from 0-FFFFH, it is necessary to generate each page of code in a separate file. These pages should not be linked together, but rather should each be used to program the proper section of the EPROM associated with that page. The main page routine should be coded with addresses from 0-7FFFH, and each of the upper pages should be coded with addresses from 8000-FFFH. Because linking is not possible, each module should contain a table of constants which defines the symbols used in other modules. These values are easily obtained from the listing file, which can be created using zeros in the table the first time. The addresses of the pages in a 27512 after splitting low and high bytes into 2 EPROMs are shown in Figure 1.

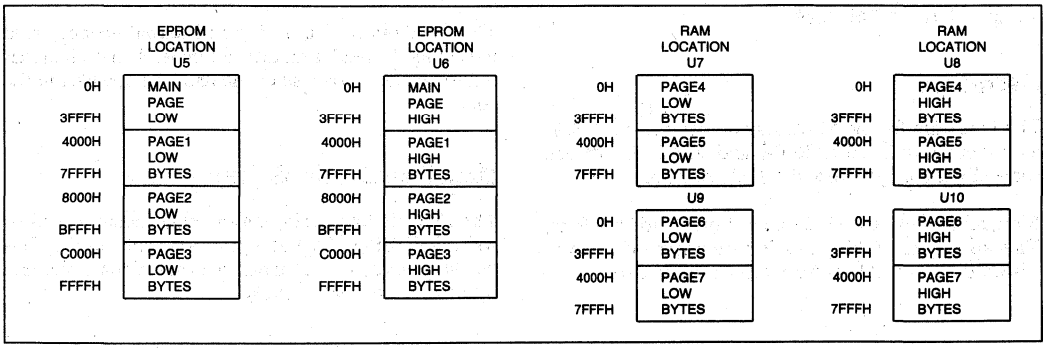

Figure 1. The Current System

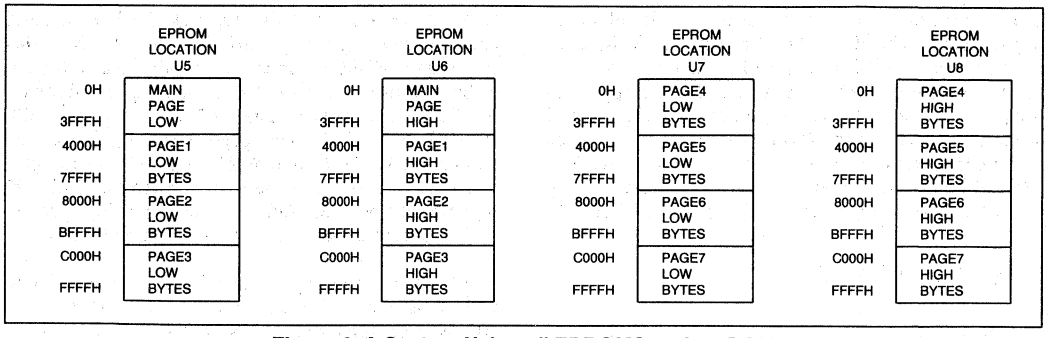

Figure 2. A System Using all EPROMS and no RAM

All changes to the upper instruction addresses of PORT1 must be made by code located in the main page. A listing of subroutines for use in the main page, and a listing of macros for use in all pages is provided. By invoking one of these macros the programmer can easily transfer from one page to another, or select a new data page. The subroutines should not be called directly, they should be entered by using the appropriate macro. The subroutines should be located at the addresses specified, otherwise the macros must be changed as they are written to call an absolute address in the main page. Also, any hardware changes may render the software inoperative.

Because the WRL-WRH feature of the 96BH is used, the correct Chip Configuration Register value of 0FBH must be loaded into the ROMs at address 2018H. This is done in the main code file with the following statements:

```
CSEG AT 2018H

CCR: DCB 0FBH   ;VALUE FOR CHIP
                 CONFIGURATION REGISTER
```

Finally, it is necessary to initialize the DATA address at the start of the program this can be done using the NEW_DATA_PAGE MACRO.

THE 544K SYSTEM

Hardware

The hardware for the 544K system (see Figures 6 & 7, an example with 288K ROM and 256K RAM) has some slight changes from the 256K system.

First, all pins of PORT1 are now in use as address lines. This allows for PORT1 to select 16 pages of memory, with a different address for instructions or data.

Second, 27128 16K x 8 EPROMS have been added for use as the main code page. In this system, the main page is physically separate from upper page 0. The 27128's are selected by A15 being low. The upper pages of memory are selected when A15 is high which enables the 74LS155 demultiplexer which is used for address decoding. When the 74LS155 is disabled, its outputs are all high, which disables all upper memories. The 74LS157 is enabled all the time, to speed up address decoding, as its outputs do not matter when the 74LS155 is disabled.

Software

All rules for the 256K system apply to the 544K system, except that the main page no longer overlaps page 0. However, because all of PORT1 is now in use, different macros and subroutines must now be used. These have been included also.

THE INST PIN

The instruction pin has been verified to work correctly on the 8X9X- 90, 8X9XBH, and the 80C196. The functionality of the INST pin is as follows.

Instruction Fetches

The INST pin is high during an external memory read indicating the read is an instruction fetch. This includes immediate data reads since the data is embedded in the code.

Data Reads and Writes

The INST is low during an external memory read or write indicating the bus cycle is a data cycle. This would be indirect and indexed instructions which are directed at external memory.

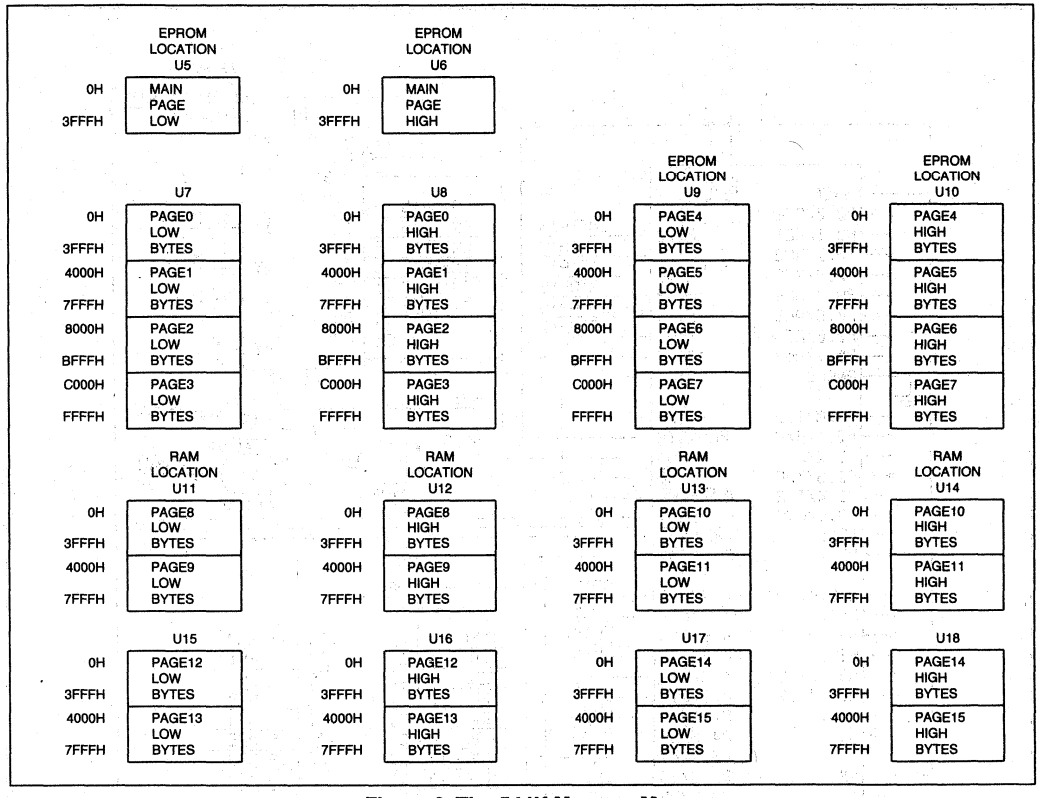

Figure 3. The 544K Memory Map

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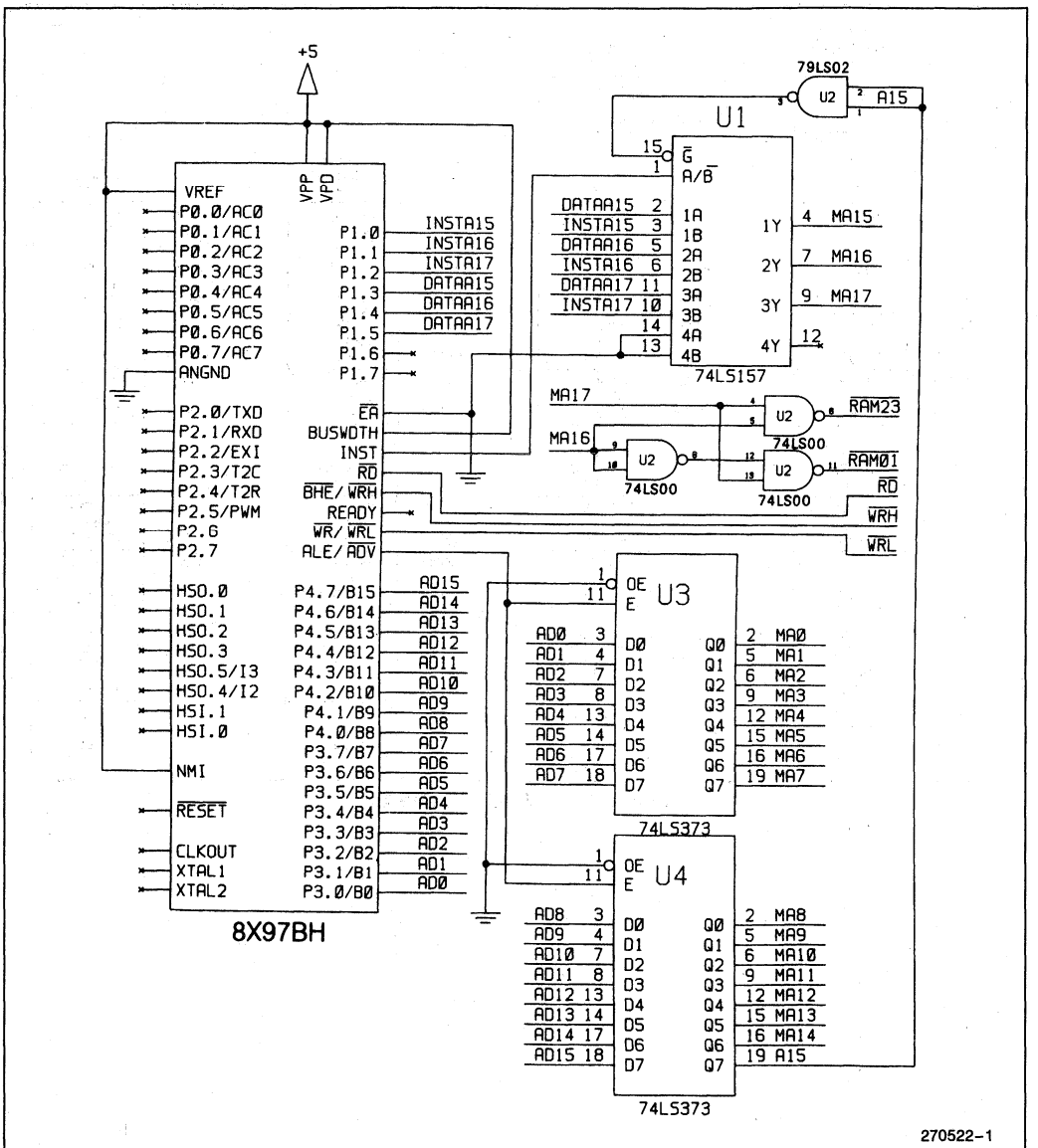
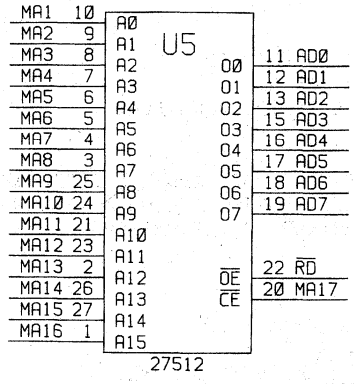
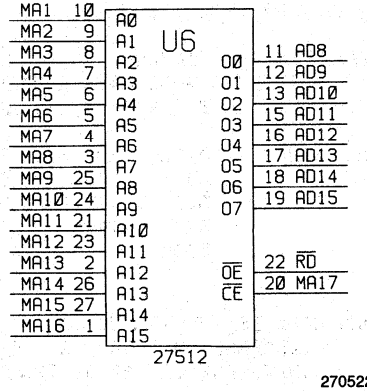


NOTE:
All other connections should be made as specified in current Embedded Controller Handbook.

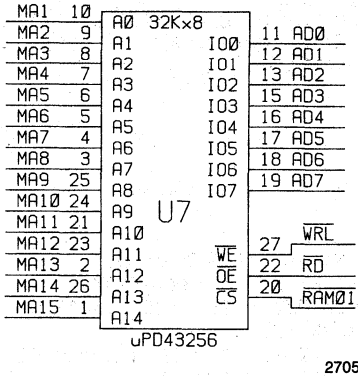
Figure 4. 128K ROM + 128K RAM Memory



270522-2



270522-5



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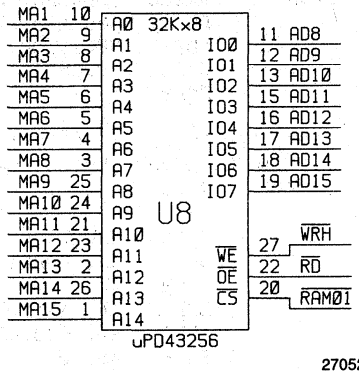
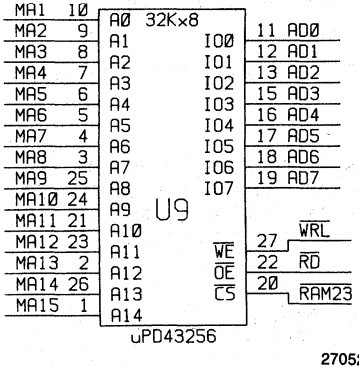
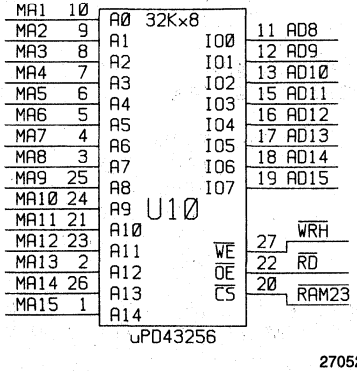


270522-6



270522-4



270522-7

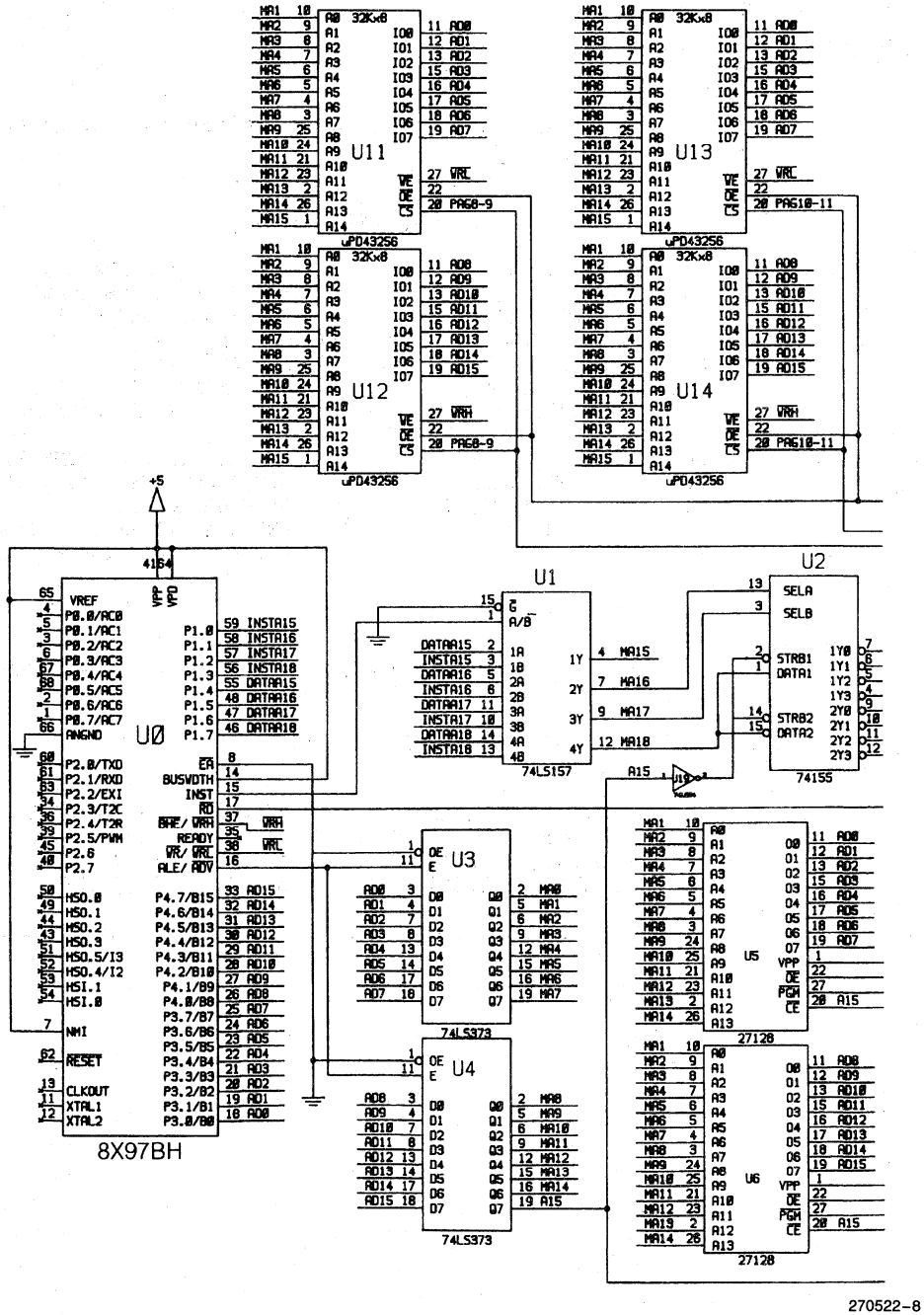
Figure 5. 128K ROM + 128K RAM Memory

6

```
;MACROS FOR 256K SYSTEM

;LONG_BRANCH IS INVOKED TO BRANCH FROM ONE PAGE TO ANOTHER.
       ;ADDRESS MUST HAVE A VALUE FROM 8000H TO FFFFH.
       ;NEW_PAGE CAN BE AN IMMEDIATE NUMBER OR A REGISTER NUMBER.

LONG_BRANCH     MACRO  ADDRESS, NEW_PAGE
                LD     CODE_ADDRESS, #ADDRESS ;SET UP CODE_ADDRESS REGISTER
                LDB    NEW_PAGE_NO, NEW_PAGE  ;SET UP NEW_PAGE_NO REGISTER
                BR     7FF0H                  ;BRANCH TO I_P_BRANCH
                ENDM


;LONG_CALL IS INVOKED TO CALL A SUBROUTINE IN ANOTHER PAGE.
       ;ADDRESS MUST HAVE A VALUE FROM 8000H TO FFFFH.
       ;NEW_PAGE CAN BE AN IMMEDIATE NUMBER OR A REGISTER NUMBER.

LONG_CALL       MACRO  ADDRESS, NEW_PAGE
                LD     CODE_ADDRESS, #ADDRESS ;SET UP CODE_ADDRESS REGISTER
                LDB    NEW_PAGE_NO, NEW_PAGE  ;SET UP NEW_PAGE_NO REGISTER
                CALL   7FC0H                  ;CALL I_P_CALL
                ENDM

;PUSH_OLD_DATAPAGE IS INVOKED TO INSTALL A NEW DATA PAGE AND SAVE
;THE OLD VALUE ON THE SYSTEM STACK.
       ;NEW_PAGE CAN BE AN IMMEDIATE NUMBER OR A REGISTER NUMBER.

PUSH_OLD_DAPAG MACRO  NEW_PAGE
                LDB    AL, PORT1              ;GET OLD PAGE NUMBER...
                PUSH   AX                     ;STORE IT ON THE STACK
                LDB    AL, NEW_PAGE           ;GET NEW DATA PAGE NUMBER...
                ANDB   AL, #00000111B         ;MASK IT...
                SHLB   AL, #3                 ;SHIFT IT TO PROPER POSITION...
                ANDB   PORT1, #11000111B      ;CLEAR THE OLD ONE...
                ORB    PORT1, AL              ;AND LOAD IN NEW ONE
                ENDM

;POP_OLD_DATAPAGE IS INVOKED TO REINSTALL AN OLD DATA PAGE THAT WAS SAVED
;ON THE SYSTEM STACK BY PUSH_OLD_DATAPAGE.

POP_OLD_DAPAG  MACRO
                POP    AX                     ;RECALL OLD PAGE NUMBER...
                ANDB   AL, #00111000B         ;MASK OLD ONE FOR DATA PAGE...
                ANDB   PORT1, #11000111B      ;CLEAR NEW DATA PAGE...
                ORB    PORT1, AL              ;AND LOAD IN OLD ONE
                ENDM

;NEW_DATA_PAGE IS INVOKED TO INSTALL A NEW DATA PAGE.
       ;NEW_PAGE CAN BE AN IMMEDIATE NUMBER OR A REGISTER NUMBER.

NEW_DATA_PAGE  MACRO  NEW_PAGE
                LDB    AL, NEW_PAGE           ;GET NEW DATA PAGE NUMBER...
                ANDB   AL, #00000111B         ;MASK IT...
                SHLB   AL #3                  ;SHIFT IT TO PROPER POSITION...
                ANDB   PORT1, #11000111B      ;CLEAR THE OLD ONE...
                ORB    PORT1, AL              ;AND LOAD IN NEW ONE
                ENDM
```

```
;SUBROUTINES FOR 256K SYSTEM

CSEG AT 7FC0H

;SUBROUTINE:   I_P_CALL
;       THIS SUBROUTINE ALLOWS FOR THE CALLING OF SUBROUTINES LOCATED IN
;       A DIFFERENT PAGE OF MEMORY.
;
;       PARAMETERS:     CODE_ADDRESS, NEW_PAGE_NO
;       SUBROUTINES:    ANY THAT ARE REQUESTED.
;
I_P_CALL:       LDB     AL, PORT1               ;GET OLD PAGE NUMBER...
                PUSH    AX                      ;STORE IT ON THE STACK
                ANDB    PORT1, #11111000B       ;CLEAR OLD INST PAGE...
                ANDB    NEW_PAGE_NO, #00000111B ;MASK NEW ONE...
                ORB     PORT1, NEW_PAGE_NO      ;AND LOAD IT IN
                PUSH    #I_P_RETURN             ;SAVE RETURN ADDRESS...
                BR      [CODE_ADDRESS]          ;CALL REQUESTED ROUTINE

I_P_RETURN:     POP     AX                      ;RECALL OLD PAGE NUMBER...
                ANDB    PORT1, #11111000B       ;CLEAR NEW INST PAGE...
                ANDB    AL, #00000111B          ;MASK OLD ONE...
                ORB     PORT1, AL               ;AND LOAD IT IN
                RET                             ;RETURN TO CALLING ROUTINE

CSEG AT 7FF0H

;SUBROUTINE:    I_P_BRANCH
;       THIS SUBROUTINE ALLOWS FOR BRANCHING TO LOCATIONS IN A DIFFERENT
;       PAGE OF MEMORY.
;
;       PARAMETERS:     CODE_ADDRESS, NEW_PAGE_NO
;       SUBROUTINES:    NONE
;
I_P_BRANCH:     ANDB    PORT1, #11111000B       ;CLEAR OLD INST PAGE...
                ANDB    NEW_PAGE_NO #00000111B  ;MASK NEW ONE...
                ORB     PORT1, NEW_PAGE_NO      ;AND LOAD IT IN
                BR      [CODE_ADDRESS]          ;BRANCH TO REQUESTED
ROUTINE
```

6



NOTE:
All other connections should be made as specified in current Embedded Controller Handbook.

Figure 6. 288K ROM + 256K RAM Memory

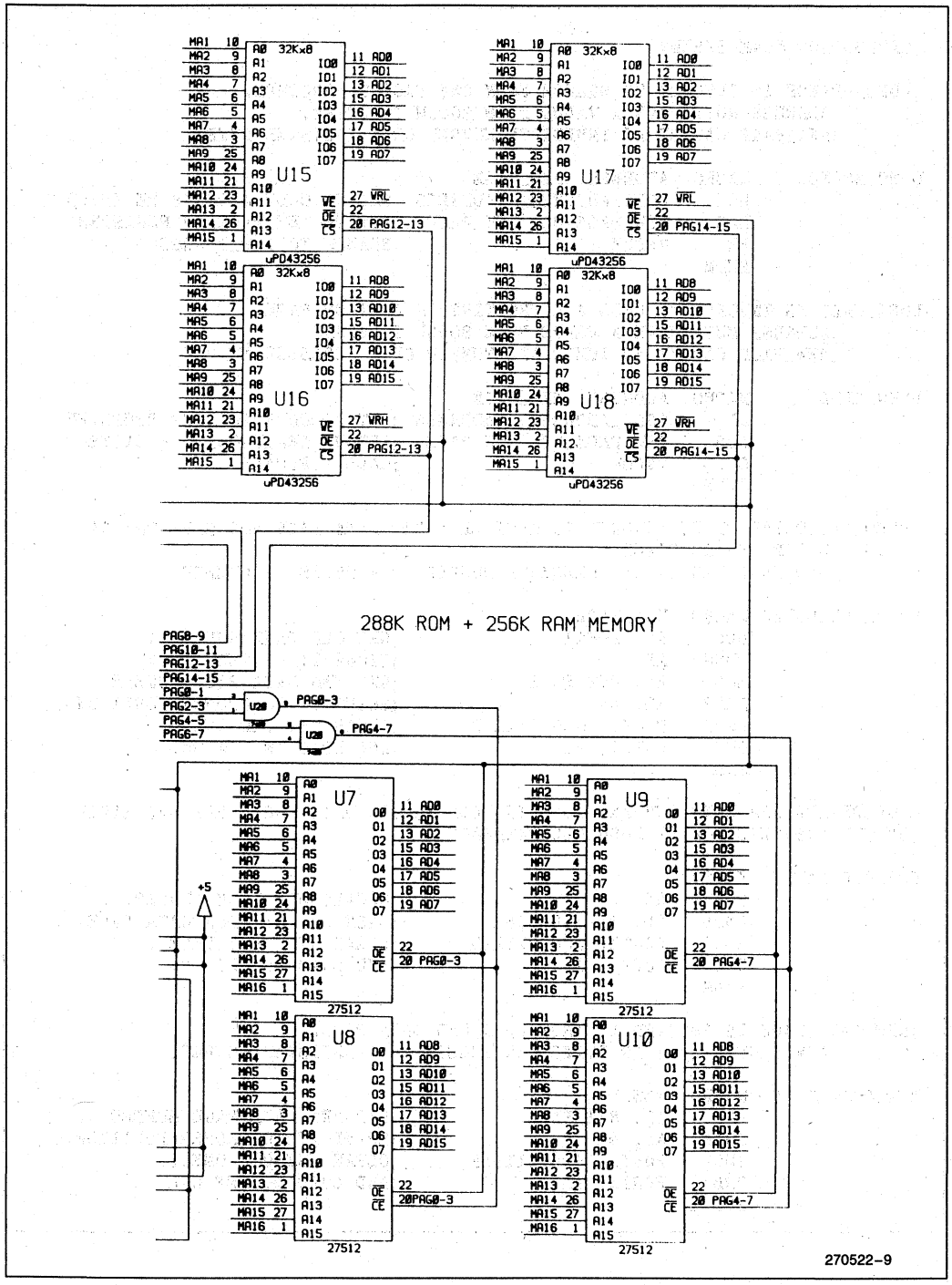


Figure 7. 288K ROM + 256K RAM Memory

```
;MACROS FOR 544K SYSTEM

;LONG_BRANCH IS INVOKED TO BRANCH FROM ONE PAGE TO ANOTHER.
       ;ADDRESS MUST HAVE A VALUE FROM 8000H TO FFFFH.
       ;NEW_PAGE CAN BE AN IMMEDIATE NUMBER OR A REGISTER NUMBER.

LONG_BRANCH     MACRO  ADDRESS, NEW_PAGE
                LD     CODE_ADDRESS, #ADDRESS ;SET UP CODE_ADDRESS REGISTER
                LDB    NEW_PAGE_NO, NEW_PAGE  ;SET UP NEW_PAGE_NO REGISTER
                BR     7FF0H                  ;BRANCH TO I_P_BRANCH
                ENDM

LONG_CALL IS INVOKED TO CALL A SUBROUTINE IN ANOTHER PAGE.
       ;ADDRESS MUST HAVE A VALUE FROM 8000H TO FFFFH.
       ;NEW_PAGE CAN BE AN IMMEDIATE NUMBER OR A REGISTER NUMBER.

LONG_CALL       MACRO  ADDRESS, NEW_PAGE
                LD     CODE_ADDRESS, #ADDRESS ;SET UP CODE_ADDRESS REGISTER
                LDB    NEW_PAGE_NO, NEW_PAGE  ;SET UP NEW_PAGE_NO REGISTER
                CALL   7FC0H                  ;CALL I_P_CALL
                ENDM

;PUSH_OLD_DATAPAGE IS INVOKED TO INSTALL A NEW DATA PAGE AND SAVE THE OLD
;VALUE ON THE SYSTEM STACK.
       ;NEW_PAGE CAN BE AN IMMEDIATE NUMBER OR A REGISTER NUMBER.

PUSH_OLD_DAPAG MACRO  NEW_PAGE
                LDB    AL, PORT1              ;GET OLD PAGE NUMBER...
                PUSH   AX                     ;STORE IT ON THE STACK
                LDB    AL, NEW_PAGE           ;GET NEW DATA PAGE NUMBER:..
                SHLB   AL, #4                 ;SHIFT IT TO PROPER POSITION...
                ANDB   PORT1, #00001111B      ;CLEAR THE OLD ONE...
                ORB    PORT1, AL              ;AND LOAD IN NEW ONE
                ENDM

;POP_OLD_DATAPAGE IS INVOKED TO REINSTALL AN OLD DATA PAGE THAT WAS SAVED
;ON THE SYSTEM STACK BY PUSH_OLD_DATAPAGE.

POP_OLD_DAPAG   MACRO
                POP    AX                     ;RECALL OLD PAGE NUMBER...
                ANDB   AL, #11110000B         ;MASK OLD ONE FOR DATA PAGE...
                ANDB   PORT1, #00001111B      ;CLEAR NEW DATA PAGE...
                ORB    PORT1, AL              ;AND LOAD IN OLD ONE
                ENDM

;NEW_DATA_PAGE IS INVOKED TO INSTALL A NEW DATA PAGE.
       ;NEW_PAGE CAN BE AN IMMEDIATE NUMBER OR A REGISTER NUMBER.

NEW_DATA_PAGE   MACRO  NEW_PAGE
                LDB    AL, NEW_PAGE           ;GET NEW DATA PAGE NUMBER...
                SHLB   AL, #4                 ;SHIFT IT TO PROPER POSITION...
                ANDB   PORT1, #00001111B      ;CLEAR THE OLD ONE...
                ORB    PORT1, AL              ;AND LOAD IN NEW ONE
                ENDM
```

```
;SUBROUTINES FOR 544K SYSTEM

CSEG AT 7FC0H

;SUBROUTINE:   I_P_CALL
;       THIS SUBROUTINE ALLOWS FOR THE CALLING OF SUBROUTINES LOCATED IN
;       A DIFFERENT PAGE OF MEMORY.
;
;       PARAMETERS:     CODE_ADDRESS, NEW_PAGE_NO
;       SUBROUTINES:    ANY THAT ARE REQUESTED.
;
I_P_CALL:       LDB     AL, PORT1               ;GET OLD PAGE NUMBER...
                PUSH    AX                      ;STORE IT ON THE STACK
                ANDB    PORT1, #11110000B       ;CLEAR OLD INST PAGE...
                ANDB    NEW_PAGE_NO, #00001111B ;MASK NEW ONE...
                ORB     PORT1, NEW_PAGE_NO      ;AND LOAD IT IN
                PUSH    #I_P_RETURN             ;SAVE RETURN ADDRESS...
                BR      [CODE_ADDRESS]          ;CALL REQUESTED ROUTINE

I_P_RETURN:     POP     AX                      ;RECALL OLD PAGE NUMBER...
                ANDB    PORT1, #11110000B       ;CLEAR NEW INST PAGE...
                ANDB    AL, #00001111B          :MASK OLD ONE...
                ORB     PORT1, AL               ;AND LOAD IT IN
                RET                             ;RETURN TO CALLING ROUTINE

CSEG AT 7FF0H

;SUBROUTINE:    I_P_BRANCH
;       THIS SUBROUTINE ALLOWS FOR BRANCHING TO LOCATIONS IN A DIFFERENT
;       PAGE OF MEMORY.
;
;       PARAMETERS:     CODE_ADDRESS, NEW_PAGE_NO
;       SUBROUTINES:    NONE
;
I_P_BRANCH:     ANDB    PORT1, #11110000B       ;CLEAR OLD INST PAGE...
                ANDB    NEW_PAGE_NO, #00001111B ;MASK NEW ONE...
                ORB     PORT1, NEW_PAGE_NO      ;AND LOAD IT IN
                BR      [CODE_ADDRESS]          ;BRANCH TO REQUESTED ROUTINE
```

intel®

APPLICATION BRIEF

AB-34

April 1989

Integer Square Root Routine for the 8096

LIONEL SMITH
ECO APPLICATIONS ENGINEER

Order Number: 270523-001

INTEGER SQUARE ROOT ROUTINE FOR THE 8096

CONTENTS

This Application Brief presents an example of calculating the square root of a 32-bit signed integer.

Theory

Newton showed that the square root can be calculated by repeating the approximation:

Xnew = (R/Xold + Xold)/2 ; Xold = Xnew

where: R is the radicand

Xold is the current approximation of the square root

Xnew is the new approximation

until you get an answer you like. A common technique for deciding whether or not you like the answer is to loop on the approximation until Xnew stops changing. If you are dealing with real (floating point) numbers this technique can sometimes get you in trouble because it's possible to hang up in the loop with Xnew alternating between two values. This is not the case with integers. As an example of how it all works, consider taking the square root of 37 with an initial guess (Xold) of 1:

Xnew = (37/1 + 1)/2 = 19; Xold = 19

Xnew = (37/19 + 19)/2 = 10; Xold = 10

Xnew = (37/10 + 10)/2 = 6; Xold = 6

Xnew = (37/6 + 6)/2 = 6; Xold = 6 – done!

Note that in integer arithmetic the remainder of a division is ignored and the square root of a number is floored (i.e. the square root is the largest integer which, when multiplied by itself, is less than or equal to the radicand).

Practice

The only significant problem in implementing the square root calculation using this algorithm is that the division of R by Xold could easily be a 32 by 32 divide if R is a 32 bit integer. This is ok if you happen to have a 32 by 32 divide instruction, but most 16-bit machines (including the 8096) only provide a 32 by 16 divide. However, a little bit of creative laziness will allow us to squeeze by using the 32 by 16 bit divide on the 8096.

The largest positive integer you can represent with a 32-bit two's complement number is 07fff$ffffh, or 2,147,483,647. The square root of this number is 0b504h, or 46,340. The largest square root that we can generate from a 32-bit radicand can be represented in 16-bits. If we are careful in picking our initial Xold we can do all of the divisions with the 32 by 16 divide instruction we have available. Picking the largest possible 16-bit number (0ffffh) will always work although it may slow the calculation down by requiring too many iterations to arrive at the correct result. The algorithm below takes a slightly more intelligent approach. It uses the normalize instruction to figure out how many leading zeros the 32-bit radicand has and picks an initial Xold based on this information. If there are 16 or more leading zeros then the radicand is less than 16 bits so an initial Xold of 0ffh is chosen. If the radicand is more than 16 bits then the initial Xold is calculated by shifting the value 0ffffh by half as many places as there were leading zeros in the radicand. To give credit where credit is due, I first saw this 'trick" in the January 1986 issue of Dr. Dobbs's Journal in a letter from Michael Barr of McGill University.

The routine was timed in a 12.0 Mhz 8096 as it calculated the square roots of all positive 32-bit numbers, the following numbers include the CALL and return sequence and were measured using Timer 1 of the 8096.

Minimum Execution Time:	24 microseconds
Maximum Execution Time:	236 microseconds
Average Execution Time:	102 microseconds

Comments

The program module which follows is part of a collection of routines which perform integer and real arithmetic on a software implemented tagged stack. The top element of the stack is call TOS and is in fixed locations in the register file. Since the square root operation only involves TOS, further details of the stack structure are not shown.

```
MCS-96 MACRO ASSEMBLER   SQRT                                    05/12/86 10:44:30 PAGE   1
DOS MCS-96 MACRO ASSEMBLER, V1.1
SOURCE FILE: ROOT2.A96
OBJECT FILE: ROOT2.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: NOSB
ERR LOC OBJECT        LINE        SOURCE STATEMENT
                        1  ;
                        2  sqrt module
                        3  ;
                        4  ; 32 bit integer square root for the 8096
                        5  ;
                        6  public qstk_isqrt            ;      TOP<-- SQUARE_ROOT(TOP)
                        7  extrn interr:entry           ; Integer error routine
                        8  ;
                        9  ;   id stags for stack integer routines
     0019               10  isqrt_id    equ     19h
                       11  ;
                       12  ; error codes
                       13  ;
     0000              14  overflow        equ     00h
     0001              15  paramerr        equ     01h
     0002              16  invalid_input   equ     02h
                       17
     001C              18      oseg at 1ch
                       19  ;   ==========
     001C              20  ax:     dsw 1
       001C            21   al equ ax:byte
       001D            22   ah equ (ax+1):byte
     001E              23  dx:     dsw 1
     0020              24  cx:     dsw 1
     0022              25  bx:     dsw 1
       0018            26  sp      equ 18h:word
                       27
                       28
     0030              29      oseg at 30h
                       30  ;   ==========
     0030              31  qstk_reg:
     0030              32      dsl   1                 ; make sure of alignment
       0030            33  next    equ qstk_reg:word   ; pointer to next element in the arg stack.
       0032            34  tos_tag equ (qstk_reg+2):word
     0034              35  tos_value:
     0034              36      dsl   1                 ; 32 bit integer
                       37  ;
     0000              38      cseg
                       39  ;   ====
                       40  bl  macro param
                       41      bnc   param
                       42      endm
                       43
                       44  bhe macro param
                       45      bc    param
                       46      endm
                       47  $eject
```

6

```
MCS-96 MACRO ASSEMBLER  SQRT                                    05/12/86 10:44:30 PAGE   2
ERR LOC  OBJECT           LINE       SOURCE STATEMENT
    0000                    48      cseg
                            49  ;   ====
                            50  ;
    0000                    51  qstk_isqrt:
                            52  ; Takes the square root of the long integer in TOS
                            53  ; TOS--> Top of argument stack
                            54  ;   iTOS - iSQRT(TOS)
                            55  ;
      0020                  56      Xold set cx
    0000 A0341C             57      ld      ax,tos_value
    0003 A0361E             58      ld      dx,(tos_value+2)
    0006 371F07             59      bbc     (dx+1),7,qsi05      ; if (TOS < 0)
    0009 C90119             60      push    #(isqrt_id*256+paramerr)
    000C EF0000         E   61      call    interr              ;   Call interr.
    000F F0                 62      ret                         ;   Exit
    0010                    63  qsi05:
    0010 0F221C             64      normal  ax, bx
    0013 DF3B               65      be      qstk_isqrt0
    0015 991022             66      cmpb    bx,#16              ; if (TOS < 2**16)
    0018 DA06               67      ble     qsil0
    001A A1FF0020           68      ld      Xold, #0ffh         ;   Use 0ffh as first estimate.
    001E 200A               69      br      qstk_isqrtloop
    0020                    70  qsil0:
    0020 180122             71      shrb    bx,#1               ; else
    0023 A1FFFF20           72      ld      Xold, #0ffffh       ;   Base the first estimate on the
    0027 082220             73      shr     Xold, bx            ;   number of leading zeroes in TOS.
    002A                    74  qstk_isqrtloop;
    002A A0341C             75      ld      ax,tos_value        ; do
    002D A0361E             76      ld      dx,(tos_value+2)    ;   if (The divide will overflow)
    0030 88201E             77      cmp     dx,Xold             ;      The loop is done.
                            78      bhe     qstk_isqrt_done
    0035 8C201C             80      divu    ax,Xold             ;   if ( (ax=TOS/Xold) >= Xold)
    0038 88201C             81      cmp     ax,Xold             ;      The loop is done.
                            82      bhe     qstk_isqrt_done
    003D 0122               84      clr     bx                  ;   Xold=(ax+Xold)/2
    003F 641C20             85      add     Xold,ax
    0042 A40022             86      addc    bx,0
    0045 0C0120             87      shrl    Xold,#1
    0048 27E0               88      br      qstk_isqrtloop      ; while (The loop is not done)
    004A                    89  qstk_isqrt_done:
    004A A02034             90      ld      tos_value,Xold      ; TOS=00:Xold
    004D A00036             91      ld      (tos_value+2),0
    0050                    92  qstk_isqrt0:
    0050 F0                 93      ret                         ; Exit
    0051                    94      end

ASSEMBLY COMPLETED.  NO ERROR(S) FOUND.
```

December 1987

MCS®-96 Analog Acquisition Primer

DAVID P. RYAN
INTEL CORPORATION

Order Number: 270365-001

ANALOG ACQUISITION PRIMER

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LISTING OF FIGURES

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THE MCS®-96 ANALOG ACQUISITION PRIMER

INTRODUCTION

As technology advances, embedded control applications continue to reduce chip-count and demand microcontrollers with increased features to assist system-cost reduction. Since every embedded control application interfaces with the physical world, and the physical world is an analog process, it was inevitable that microcontrollers would include integrated analog acquisition capabilities.

The first such integration of standard microcontroller and A/D converter occurred on Intel's 8022 in 1978. This opened the door to cost reduction of high volume applications that required analog inputs. The device fit well into applications that needed processing of analog data. But this chip, with its 8-bit CPU, could not perform in high-end applications requiring analog inputs, or in applications that had computationally demanding analog tasks.

With the introduction of the MCS®-96 family of 16-bit microcontrollers in 1982, the combined CPU and A/D performance became available to greatly reduce the system cost of mid- and high-performance embedded control applications. These are applications which were customarily implemented with 16-bit microprocessor chip-sets teamed with analog acquisition chip sets.

There are less obvious avenues for system cost reduction when a 16-bit CPU is teamed with an on-chip analog acquisition system. For example, closed-loop servo control had been implemented almost exclusively by using analog methods. When an MCS-96 device is designed into such an application, it is not only replacing a microcontroller or microprocessor, but it also replaces closed-loop analog circuitry which never before came in contact with the digital system.

To take full advantage of this new level of integration, digital designers must become familiar with analog acquisition, and analog designers must become familiar with digital methods of processing analog signals. This Application Note assists with the first task—understanding of an analog acquisition system.

Designers experienced with analog design, or analog acquisition systems, may find no revelations herein. To those unfamiliar with analog acquisition systems, this Ap Note provides a tutorial on the subject and will serve as a handy reference.

Answering the limitless number of analog circuit design questions is beyond the scope of this Ap Note. Suffice it to say that the effort placed on the design of analog circuits should increase with a decreasing error budget.

At a minimum, the applications literature of op-amp manufacturers and analog design manuals are a good place to start. Furthermore, the applications literature of monolithic analog acquisition system manufacturers should be consulted since the suggestions presented therein are largely transportable to any A/D system.

This Ap Note is organized in the following sections. The components of an analog acquisition system and the errors associated with each is first explained. Then, interfacing suggestions and ideas for getting more resolution are presented. Finally, a set of appendices provides back-up information, a bibliography, actual converter data and some program listings.

The definitions of terms used, and the examples presented, are drawn from the body of applications literature publicly available on the components of an analog acquisition system. There is usually no single meaning for a particular term or specification used to describe analog acquisition. However, there is, in most cases, a generally accepted definition which is most often used. To the extent possible, we have adopted the most used definition. To avoid any ambiguity, Appendix A lists the dictionary of terms as used to refer to the analog acquisition systems of MCS-96 devices.

For any users of an MCS-96 analog acquisition system (experienced or not), this document contains very useful information. It should be considered mandatory reading in addition to the latest Embedded Controller Handbook and MCS-96 data sheet for the actual device in use prior to the actual design.

WHAT IS AN ANALOG ACQUISITION SYSTEM?

An analog acquisition system is a collection of individual units which, when logically configured, form a system capable of converting an analog input to a digital value.

The typical components of an Analog Acquisition Unit (Figure 1) include an Analog-to-Digital Converter (A/D), a Sample-and-Hold (S/H) and an Analog Multiplexer (MUX). The A/D converts the infinitely varying analog voltage present on the S/H into a digital representation for use by the digital system. The S/H is required so a "snapshot" of a changing analog input can be stored for conversion by the A/D. The MUX is used to leverage the investment in the A/D by allowing a large number of isolated analog input channels to use the same converter.

The conversion result of an MCS-96 device is a 10-bit ratiometric representation of the input voltage. This produces a stair-stepped transfer function when the output code is plotted versus input voltage. See Figure 2.

The resulting digital codes can be taken as simple ratiometric information, or they can be used to provide information about absolute voltages or relative voltage changes on the inputs. The more demanding the application is on the A/D converter, the more important it is to fully understand the converter's operation. For simple applications, knowing the absolute error of the converter is sufficient. However, controlling a closed loop with analog inputs necessitates a detailed understanding of an A/D converter's operation and errors.

The errors inherent in an analog-to-digital conversion process are many: quantizing error; zero offset; full-scale error; differential non-linearity; and non-linearity. These are "transfer function" errors related to the A/D converter. In addition, the S/H and MUX may induce channel dissimilarities and sampling error (described later).

Fortunately, one "Absolute Error" specification is available which describes the sum total of all deviations between the actual conversion process and an ideal converter. The various sub-components of error are, however, important in many applications. These error components are described in Appendix A and in the text below where ideal and actual converters are compared.

A/D Converter

There are at least three well-recognized methods for converting an analog voltage to a digital value—flash, dual slope and successive approximation.

Flash A/Ds are the fastest, and most expensive converters for a given accuracy. Flash converters typically resolve bits of the result in parallel to achieve fast conversions. Flash converter speeds are measured in tens-of-nanoseconds.

Dual slope converters are the slowest, but most accurate. Dual slope conversion is rather insensitive to noise on the input, but conversion times are measured in milliseconds.

Successive approximation converters provide a balanced tradeoff between speed and accuracy. Successive approximation conversion times are measured in tens-of-microseconds, and converter implementations are very economical for a given accuracy.

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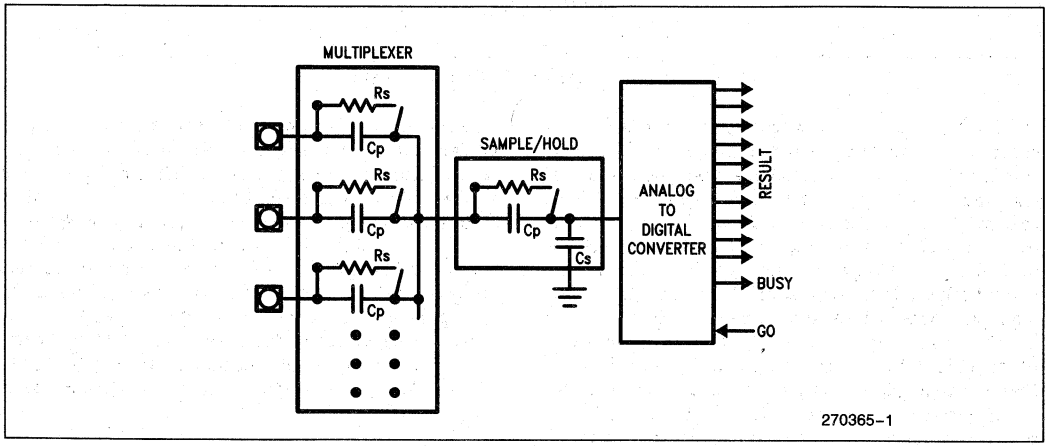

Figure 1. An Analog Acquisition System

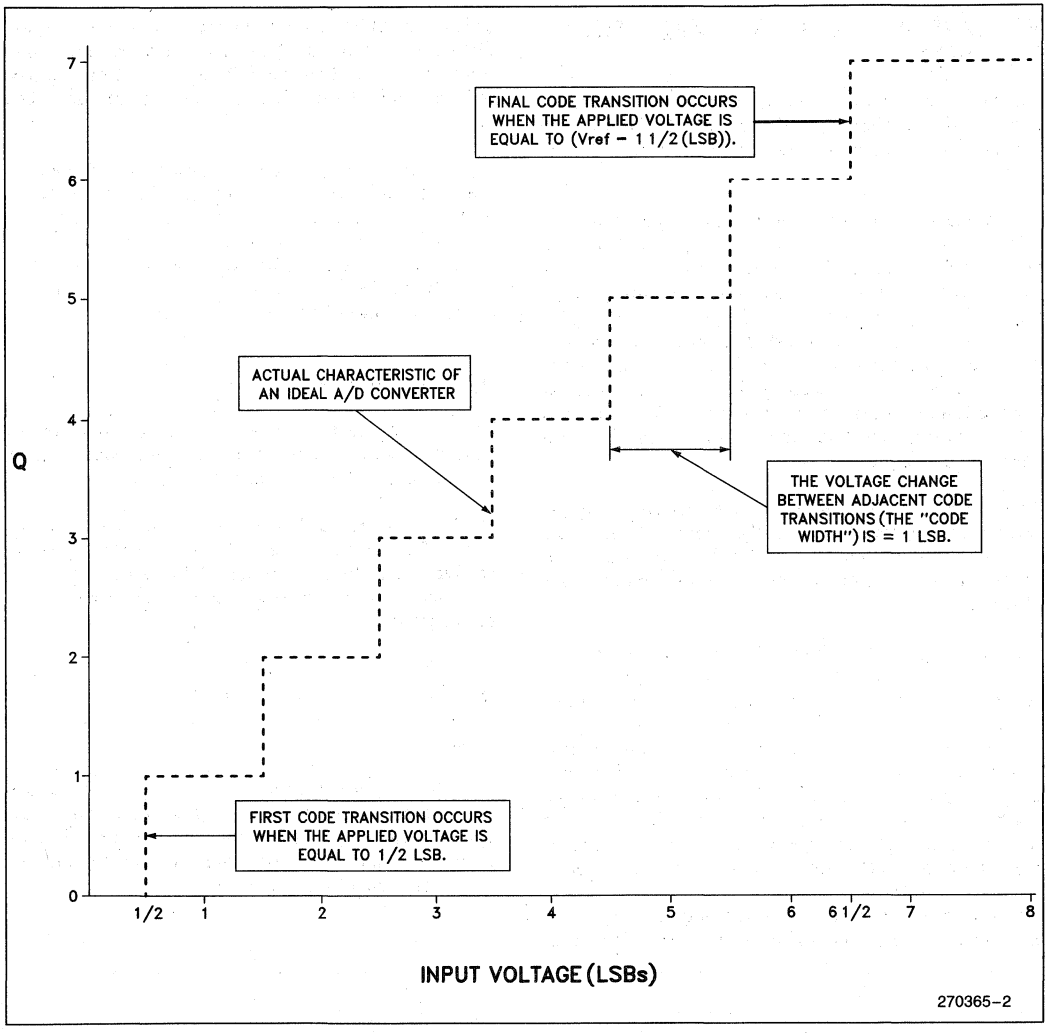

Figure 2. Ideal A/D Characteristic

MCS-96 converters use successive approximation. A successive approximation conversion is performed by comparing a sequence of reference voltages to the analog input in a binary search for the reference voltage that most closely matches the input. The ½ full-scale reference voltages is the tested first. This corresponds to a 10-bit result where the most significant bit is zero, and all other bits are ones (0111 1111 11b). If the analog input is less than the test voltage, bit 10 of the result is left a zero, and a new test voltage of ¼ full-scale (0011 1111 11b) is tried. If this test voltage is lower than the analog input, bit 9 of the result is set and bit 8 is cleared for the next test (0101 1111 11b). This binary search continues until 10 tests have occurred, at which time the valid 10-bit conversion result resides in a register where it can be read by software.

The voltages used during the binary search are generated from an internal Digital-to-Analog Converter similar to Figure 3. The figure shows eight resistors being used as a three-bit D to A. The first resistor tap is taken from the center of the first resistor to guarantee that a zero input voltage will always output a zero code. Each successive tap then provides a reference voltage $V_{REF}/8$ (one LSB) from the previous tap. When the analog input is above the voltage of the seventh tap, the A/D will resolve to its full-scale value of 111b. Therefore, an eighth tap is not needed, and the A/D's 110b to 111b code transition will occur when V_{ANIN} equals $V_{REF} - 1\ ½$ LSB.

The first error seen in this process is unavoidable, and results from the conversion of a continuous voltage to

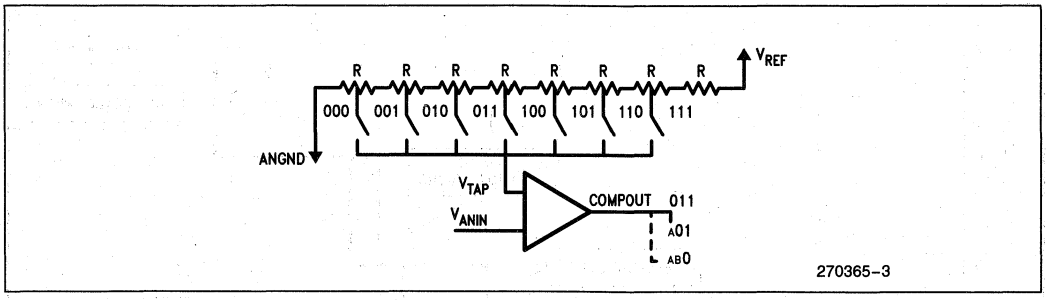

Figure 3. A Three-Bit D-to-A

an integer digital representation. This error is called quantizing error, and is always ±0.5 LSB. Quantizing error is the only error seen in a perfect A/D converter, and is obviously present in actual converters. Figure 2 shows the transfer function for an ideal 3-bit A/D converter (i.e. the Ideal Characteristic).

Note that in Figure 2 the Ideal Characteristic possesses unique qualities: it's first code transition occurs when the input voltage is 0.5 LSB; it's full-scale code transition occurs when the input voltage equals the full-scale reference minus 1.5 LSB; and it's code widths are all exactly one LSB. These qualities result in a digitization without offset, full-scale or linearity errors. In other words, a perfect conversion.

Figure 4 shows an Actual Characteristic of a hypothetical 3-bit converter which is not perfect. When the Ideal Characteristic is overlaid with the imperfect characteristic, the actual converter is seen to exhibit errors in the location of the first and final code transitions and code widths. The deviation of the first code transition from ideal is called "zero offset". The deviation of the final code transition from ideal is "full-scale error".

The deviation of the code widths from ideal causes two types of errors. Differential Non-Linearity and Non-Linearity. Differential Non- Linearity is a local linearity error measure, whereas Non-Linearity is an overall linearity error measure. For example, Figure 5a shows a transfer function with a large differential non-linearity and a little non-linearity. In contrast, Figure 5b shows a characteristic with small differential errors but a large overall linearity error.

Differential Non-Linearity is the degree to which actual code widths differ from the ideal width. Differential Non-Linearity gives the user a measure of how much the input voltage may have changed in order to produce a one count change in the conversion result.

If the absolute value of an input voltage is less important than the amount that the input changes, the differential non-linearity (DNL) specification of a converter is very important. For example, if the differential non-linearity of a converter is less than ± 0.5 LSB, a one count change in the digital result means that the input voltage changed at most 1.5 LSB (1 LSB ideal ± 0.5 LSB DNL). This is a much more accurate description of the input voltage change than would be available if the differential non-linearity of the converter was not known.

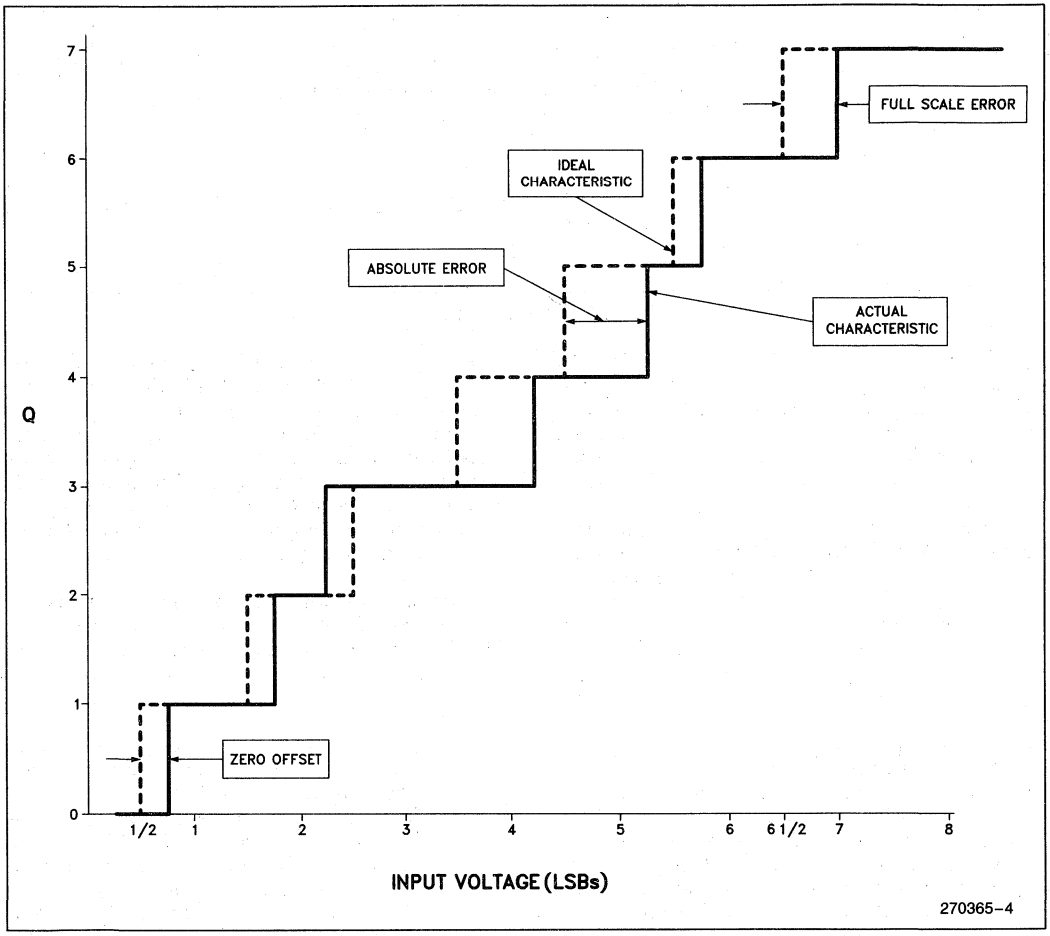

Figure 4. Actual and Ideal Characteristics

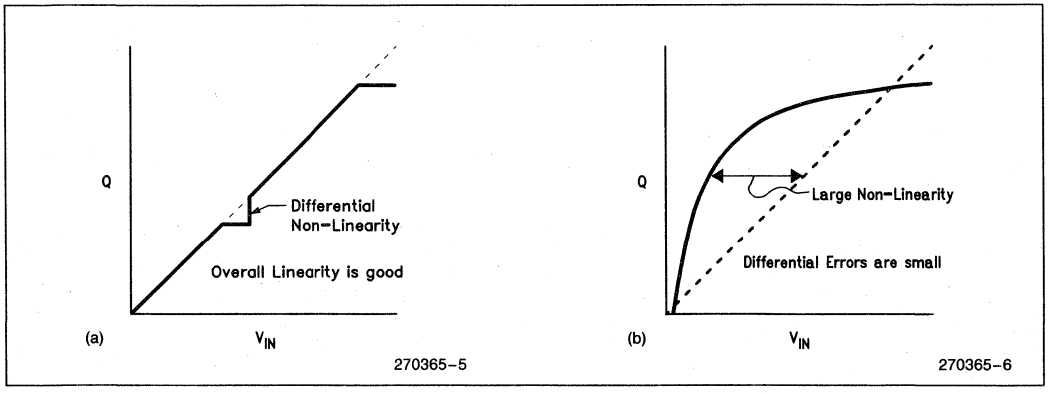

Figure 5. Types of Linearity Errors

Non-Linearity is the worst case deviation of code transitions from the corresponding code transitions of the Ideal Characteristic. Non- Linearity describes how much Differential Non-Linearities could add to produce an overall maximum departure from a linear characteristic.

If the Differential Non-Linearity errors are large enough, it is possible for an A/D converter to miss codes or exhibit non-monotonicity. Neither behavior is desirable in a closed-loop system. A converter has no missed codes if there exists for each output code a unique input voltage range that produces that code only. A converter is monotonic if every subsequent code change represents an input voltage change in the same direction. Figure 6a shows a converter with missed codes. Figure 6b shows a non-monotonic converter.

Differential Non-Linearity and Non-Linearity are quantified by measuring the Terminal Based Linearity Errors. A Terminal Based Characteristic results when an Actual Characteristic is shifted and scaled to eliminate zero offset and full-scale error (see Figure 7). The Terminal Based Characteristic is similar to the Actual Characteristic that would be seen if zero offset and full-scale error were externally trimmed away. In practice, this is done by using input circuits which include gain and offset trimming. (See the Application Hints section for more details.)

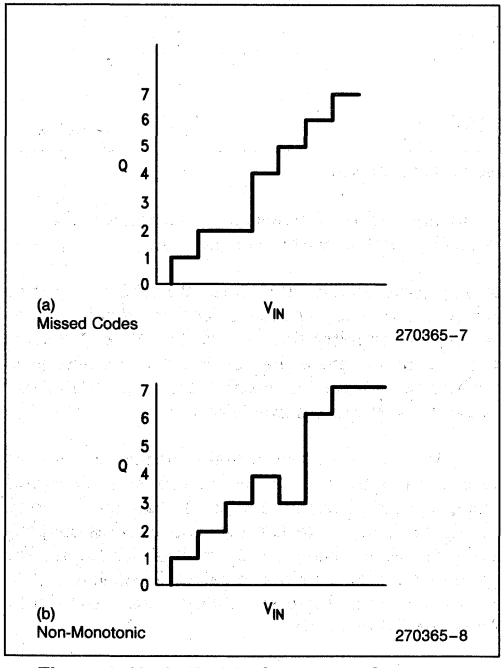

Figure 6. Undesirable Converter Operation

An often overlooked characteristic of A/D converters is that code transitions do not really occur instantaneously at some finite set of input voltages. Specific code transitions can be analyzed by doing repeated conversions around the transition point using a high accuracy input voltage. When this is done, we find that there is actually a range of voltages around code transitions where both the lower and upper codes occur for repeated conversions on the same input voltage.

Figure 8 shows this "repeatability" error. At the lower end of the region of repeatability error the lower code is most prevalent, but the upper code will occur in a small percentage of the conversion attempts. As the input voltage increases slightly, a point is reached where both lower and upper codes occur with 50 percent probability. As the input voltage moves slightly higher, the upper code occurs most often with the lower code showing up in a small percentage of conversions.

The repeatability error is due to the fundamental ability of the comparator in the A/D to resolve very similar voltages. Random noise also contributes to repeatability errors. On MCS-96 devices, the width of the region of repeatability error has been found to be typically 1 mV to 1.25 mV. Since this error is specified, all other errors are specified assuming the code transitions occur at the voltage where adjacent codes are equally likely.

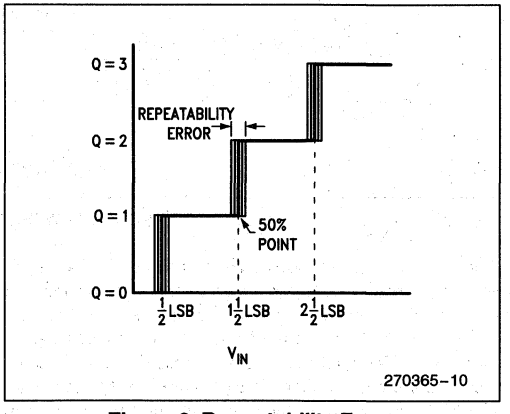

Figure 8. Repeatability Error

The Multiplexer

The eight channel multiplexer is implemented as a collection of eight MOS switches. Only one of eight can be closed at any instant in time. Figure 1 shows the multiplexer with the switches acting as resistors when closed and as small parasitic capacitors when open. The input protection devices on the analog input pins are also considered a part of the multiplexer.

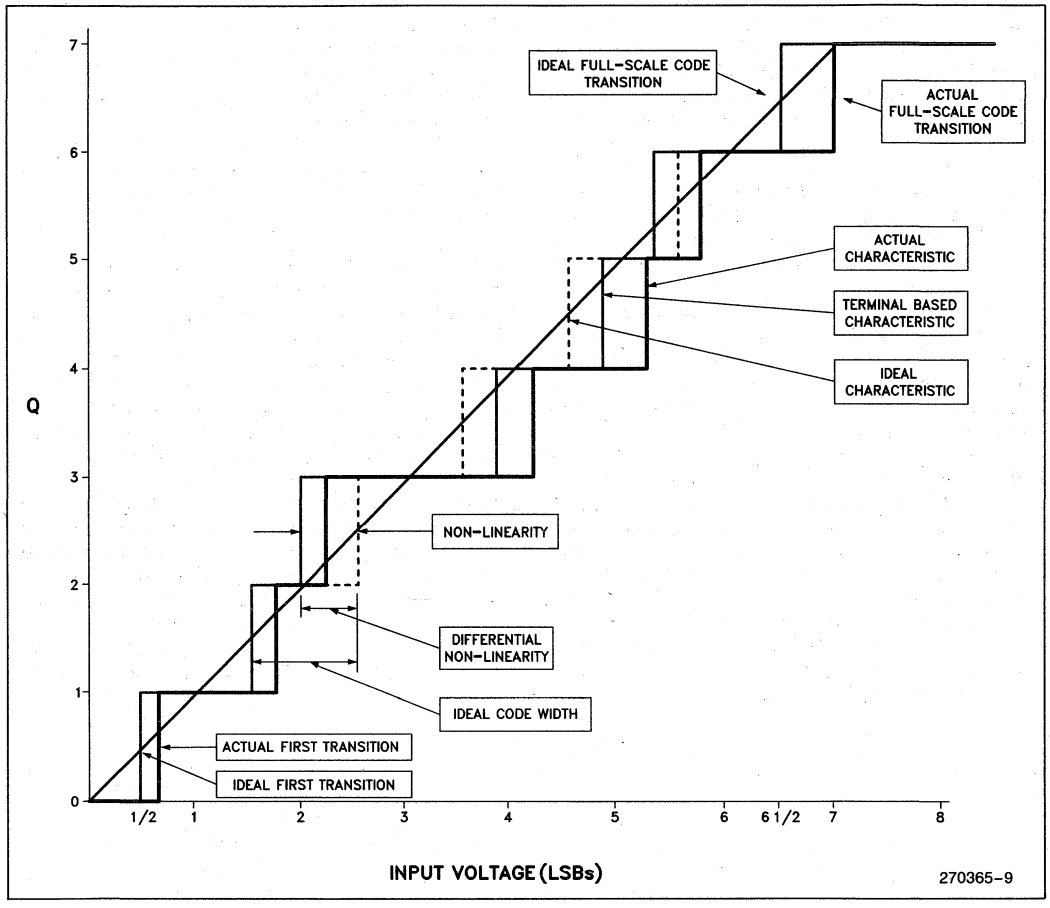

Figure 7. Terminal Based Characteristic

The resistance of a closed switch is typically 1K to 2K ohms and the D.C. leakage due to the input protection is typically 3 microamps maximum. Both values depend upon the process used and day-to-day fabrication variations. The channel resistance and the D.C. leakage can also vary from channel-to-channel on the same device. These variations can be seen in the conversion process and are described by the channel- to-channel matching specification.

Channel-to-channel matching specifies the input voltage differences induced by mismatched elements of the multiplexer. This error is quantified by measuring the difference between the input voltages necessary to cause the same code transition to occur through different multiplexer channels under identical test conditions.

Matching errors are more complex than a simple voltage offset between channels, and thus are difficult to externally cancel. Fortunately, multiplexer channels typically match to within one millivolt.

A multiplexer that has the potential to short two inputs together is not very attractive. To keep this from happening, the circuitry that selects the active channel is designed to guarantee that all channels are deselected before a new channel is selected. Thus, the multiplexer is said to be Break-Before-Make.

In addition to Break-Before-Make channel selection, an analog multiplexer must be able to keep deselected channels isolated from the selected channel. As shown in Figure 1, there are parasitic capacitances coupling every deselected channel to the multiplexer output. The quantification of coupling is called Off-Isolation. Off-isolation is the multiplexer's ability to attenuate signals on deselected channels.

Sample-and-Hold

The sample-and-hold of an analog acquisition system can be built using an analog switch and a sample capacitor. As with the multiplexer, there is also a parasitic capacitance coupling the switch input to the sample capacitor when the switch is open (Figure 1).

The resistance of the sample-and-hold switch combines with the series resistance of the multiplexer to impede the current necessary to charge the sample capacitor. For example, with a 5K ohm total input resistance from the pin to the 2 pf sample capacitor, the RC time constant is 10 nS (2 pf × 5K ohms).

During the one microsecond that the sample capacitor is connected to the input, 100 time constants elapse (1 microsecond/10 nS). This means that the sample capacitor is 100 percent of the voltage on the input pin ($1\text{-}e^{-100}$), assuming a zero source impedance.

If a source impedance of 2K ohms is assumed, the RC time constant of the sampling process would be 14nS (7K ohms × 2 pf). Thus, 71.4 time constants would pass in one microsecond resulting in the sample capacitor being charged to within 99.9 percent of its final value. Source impedances above 2K ohms would begin to degrade the conversion accuracy due to D.C. leakage (described later).

Figure 9 shows the actual input voltage and the sampled voltage approaching the input voltage. Once the sample-and-hold switch closes, the sample window begins. The sample window extends for four state times and ends with the sample-and-hold switch opening on MCS-96 devices (except 8X9X-90, which is 8 state times and has no sample-hold). Figure 9 also shows the sample delay, which is the delay from the time a start conversion signal is generated to the time a conversion process begins.

It is important to understand the uncertainties associated with the timing of the sample-and-hold. Digital signal processing algorithms rely upon the "spectral purity" of the sampling process. If the sample window jumps around with respect to the start conversion signal, or if the start conversion signal cannot be generated at precise times, consecutive samples of input data will not be equally spaced in time (i.e. sampling will be spectrally impure).

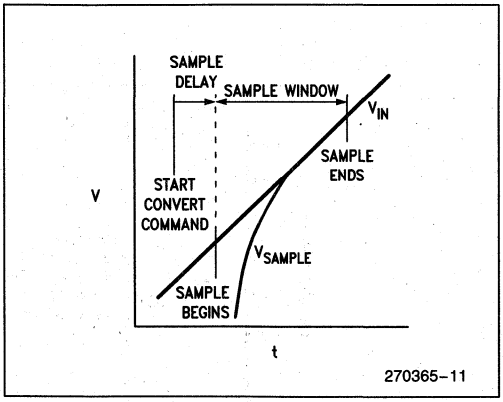

Figure 9. Sample-and-Hold Voltage

To improve the spectral purity of the sampling in digital signal processing applications, sequential MCS-96 start conversion signals can be generated with less than 50 nanoseconds of jitter using the HSO unit. The sample delay and sample time are also a constant number of state times to within 50 nanoseconds each.

Once the sample window closes, it is desired that all further changes on any input channel be isolated from the sample capacitor. The multiplexer's off-isolation is responsible for isolating deselected channels, while the sample-and-hold switch must attenuate changes on the selected channel. This source of error is described as Feedthrough. Feedthrough is quantified as the ability of the sample-and-hold to reject unwanted signals on its input.

Other factors that affect a real A/D Converter system include sensitivity to temperature. Temperature sensitivities are described by the change in typical specifications with a change in temperature.

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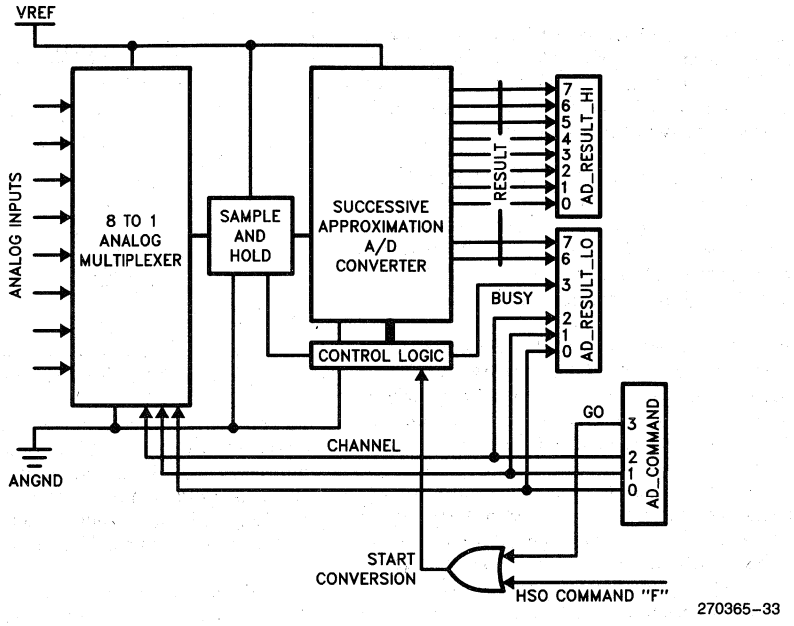
The MCS®-96 Conversion Sequence

The MCS-96 Analog Acquisition System includes an eight channel analog multiplexer, sample-and-hold circuit and 10-bit analog to digital converter (Figure 10). An MCS-96 device can therefore select one of eight analog inputs, sample-and-hold the input voltage and convert the voltage into a digital value. Each conversion takes 22 microseconds (8097BH), including the time required for the sample-hold (with XTAL1 = 12 MHz). The method of conversion is successive approximation.



NOTE:
1. Sample and hold not on 8X9X-90 devices.

Figure 10. A/D Converter Block Diagram

The conversion process is initiated by the execution of HSO command OFH, or by writing a one to the GO Bit in the A/D Control Register. Either activity causes a start conversion signal to be sent to A/D control logic. If an HSO command was used, the conversion process will begin when Timer 1 increments. This aids applications attempting to approach spectrally pure sampling, since successive samples spaced by equal Timer 1 delays will occur with a variance of about ±50 ns (assuming a stable clock on XTAL1). However, conversion initiated by writing a one to the ADCON register GO Bit will start within three state times after the instruction has completed execution, resulting in a variance of about 0.75 μs (XTAL1 = 12 MHz).

Once the A/D unit receives a start conversion signal, there is a one state time delay before sampling (sample delay) while the successive approximation register is reset and the proper multiplexer channel is selected. After the sample delay, the multiplexer output is connected to the sample capacitor and remains connected for four state times (sample time). After this four state time "sample window" closes, the input to the sample capacitor is disconnected from the multiplexer so that changes on the input pin will not alter the stored charge while the conversion is in progress. The sample delay and sample time uncertainties are each approximately ±50 ns, independent of clock speed.

To perform the actual analog-to-digital conversion the MCS-96 implements a successive approximation algorigthm. The converter hardware consists of a 256-resistor ladder, a comparator, coupling capacitors and a 10-bit successive approximation register (SAR) with logic that guides the process. The resistor ladder provides 20 mV steps (V_{REF} = 5.12V), while capacitive coupling is used to create 5 mV steps within the 20 mV ladder voltages. Therefore, 1024 internal reference voltages are available for comparison against the analog input to generate a 10- bit conversion result. Appendix B contains a detailed description of the method used to generate 1024 voltages from a 256-resistor chain.

The total number of state times required for a 10-bit conversion varies from one MCS-96 version to the next. Attempting to short-cycle the 10-bit conversion process by reading A/D results before the done bit is set may work on some versions of MCS-96 devices, however it is not recommended. Short-cycling is not tested, nor is it guaranteed. Furthermore, it may not work on future MCS-96 devices.

APPLICATION HINTS

The analog signals that must be converted by an analog acquisition system vary widely. The analog input may arrive at the controller as a voltage or current. The range may be 0 to 1 volt or ±30 volts, or some other arbitrary range. The input may be linear, logarithmic, non- linear, or perturbated in some bizarre fashion. Although interfacing to such signals could be considered an art form, some simple suggestions are contained in this section.

Analog Inputs

The external interface circuitry to an analog input is highly dependent upon the application, and can impact converter characteristics. In the external circuit's design, important factors such as input pin leakage, sample capacitor size and multiplexer series resistance from the input pin to the sample capacitor must be considered.

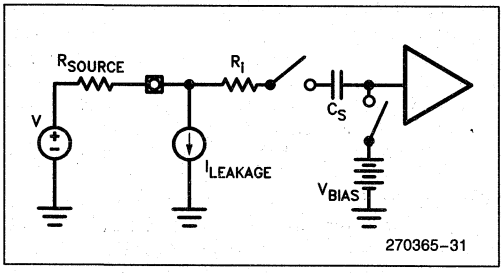


Figure 11. Idealized A/D Sampling Circuitry

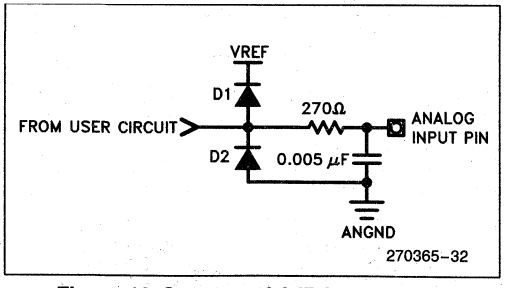


Figure 12. Suggested A/D Input Circuit

For the 8096BH, these factors are idealized in Figure 11. The external input circuit must be able to charge a sample capacitor (C_S) through a series of resistance (R_I) to an accurate voltage given a D.C. leakage (I_L). On the 8096BH, C_S is around 2 pF, R_I is around 5 KΩ and I_L is specified at 3 μA maximum. In determining the source impedance R_S, V_{BIAS} is not important.

External circuits with source impedances of 1 KΩ or less will be able to maintain an input voltage within a tolerance of about ±0.61 LSB (1.0 KΩ × 3.0 μA = 3.0 mV) given the D.C. leakage. Source impedances above 2 KΩ can result in an external error of at least one LSB due to the voltage drop caused by the 3 μA leakage. In addition, source impedances above 25 KΩ may degrade converter accuracy as a result of the internal sample capacitor not being fully charged during the 1 μs (12 MHz clock) sample window.

Placing an external capacitor on each analog input will reduce the sensitivity to noise, as the capacitor combines with source resistance in the external circuit to form a low-pass filter. In practice, one should include a small series resistance prior to an external low leakage capacitor on the analog input pin and choose the largest capacitor value practical, given the frequency of the signal being converted. This provides a low-pass filter on the input, while the resistor will also limit input current during over-voltage conditions.

Figure 12 shows a simple analog interface circuit based upon the discussion above. The circuit in the figure also provides limited protection against over-voltage conditions on the analog input (limits to 2.6 mA with 270Ω (0.7/270)). The circuit induces leakage from the diodes, which should be kept small.

The wide range of possible analog environments that must be interfaced to, or the existence of stringent accuracy requirements, makes the consideration of alternative input buffer configurations necessary. The most popular input buffer is a single op-amp in the non- inverting or inverting configurations of Figure 13.

In the non-inverting circuit of Figure 13 (a), the analog input is scaled by the buffer gain to output 5 volts when the input is at its maximum positive input. When the buffer input is 0 volts, the output will also be 0 volts.

In the inverting circuit of Figure 13 (b), a reference equal to the maximum possible input voltage is placed on the non-inverting input of the op-amp and the actual analog input is placed on the inverting input. The output voltage of the buffer is then proportional to the deviation of analog input from its maximum possible value. For example, when the analog input equals V_{MAX}, the buffer output will equal 0 zero volts. When the analog input equals its minimum value, the buffer output equals 5 volts. The digital result from the A/D converter might, of course, have to be complemented before being used.

The circuits of Figure 13 show only feedback resistors that set the gain of the buffer. In practice, it will often be necessary to include offset adjustments, gain trimming, temperature or frequency stability compensation, or components to build an active filter.

Figure 14 depicts a generalized non-inverting input buffer that offsets the analog input and scales the input

to a 5 volt range. The course offset is set by the ratio of R_{BIG1} and R_{BIG2}, while offset fine tuning is done by adjusting R_{TRIM}. The course gain is set by the ratio of R_{G1} and R_{G2} while gain trimming is done with R_{GTRIM}.

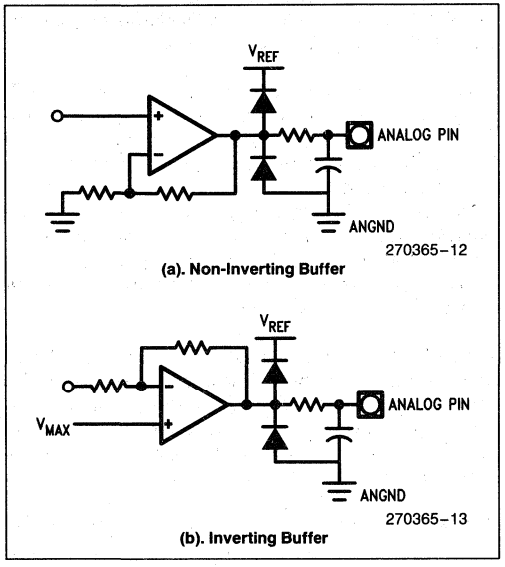


Figure 13

By trimming the offset and gain, not only can external component errors be zeroed out, but the offset and full scale error of the A/D converter can be nulled.

The procedure for nulling offset and gain is simple. First, a voltage is applied to V_{IN} which corresponds to the ideal first code transition of the A/D. R_{TRIM} is adjusted so that 50 percent of the conversion results are 0 while 50 percent are 1. Second, a voltage is applied to V_{IN} which corresponds to the ideal final code transition of the A/D converter. R_{GTRIM} is then adjusted until 50 percent of the conversion results are 3FEH and 50 percent are 3FFH. Once this adjustment is complete, the converter zero offset and full-scale errors are nulled, and could be ignored (except for temperature variation). This allows the system to rely upon the tighter, more descriptive converter specifications for Terminal Based Non- Linearity and Differential Non-Linearity.

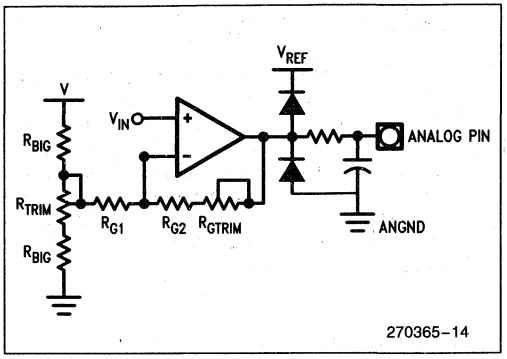


Figure 14. Trimming Offset and Gain

Analog References

Reference supply levels strongly influence the absolute accuracy of the conversion. For this reason, it is recommended that the ANGND pin be tied to a clean ground, as close to the power supply as possible. Bypass capacitors should also be used between V_{REF} and ANGND. ANGND should be connected to V_{SS} only at the chip. V_{REF} should be well regulated and used only for the A/D converter. The V_{REF} supply can be between 4.5V and 5.5V and needs to be able to source around 5 mA. Figure 15 shows all of these connections.

Note that if only ratiometric information is desired, V_{REF} can be connected to V_{CC}. In addition, if the A/D converter is not being used, V_{REF} must be connected to V_{CC} and ANGND to V_{SS} for Port0 to work as a digital port.

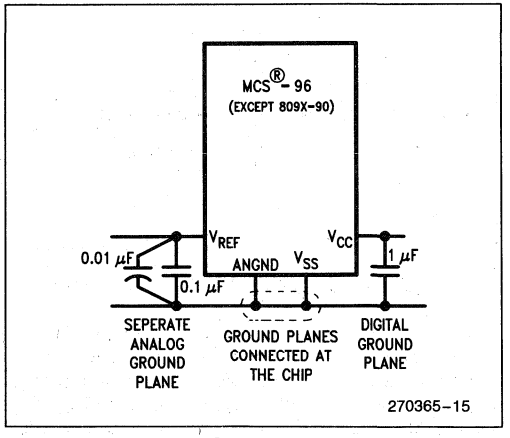


Figure 15. Supply Decoupling

Getting More Resolution

Given that the A/D converter can convert an analog input ranging from 0 volts to 5 volts into 1024 steps of 5 millivolts each, the desire for more resolution can come from three basic needs – need extra LSB, need extra MSB, need BOTH.

The configuration shown in Figure 16 can be used to solve each of the "more resolution" problems. This set-up requires the use of two input channels with different offsets and gains.

When the 5 millivolt step size of the A/D is too large for the application requirements, but the 5 volt range is sufficient, the system needs an "extra LSB". For example, an application requiring 2.5 millivolt steps over a 5 volt range needs an 11-bit conversion result. The 11th bit needs to be added to the least significant side of the 10- bit result (the "right"). This can be achieved using the circuit of Figure 16.

If both channels are set for a gain of 2, with channel 1 offset to 2.5 volts, the 5 volt input range is split into 2.5 volt ranges that are amplified by two before being input to the A/D. While V_{IN} is between 0 and 2.5 volts, channel 0 will be providing a proportional voltage between 0 volts and 5 volts to the A/D converter. Channel 1 will be clamped to 5 volts. When V_{IN} rises above 2.5 volts, channel 1 will begin to output a proportional voltage between 0 volts and 5 volts to the A/D converter and channel 0 will be clamped at 5 volts. Using this method, an 11-bit (2048 step) result is created with 2.5 millivolt steps (i.e. an extra LSB).

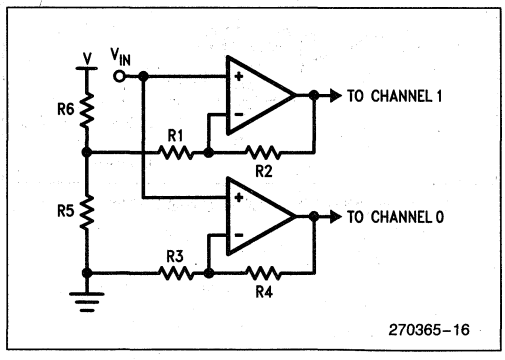


Figure 16. A Flexible Input Circuit

It is useful to note that only one conversion per sample will be required if the software keeps track of which channel is active. The only time that two conversions will be required for one sample is when the voltage crosses the midpoint.

The second reason that "more resolution" is requested is the need for an "extra MSB". When the converter's input voltage range is too small (5 volts when 10 volts is needed), but 5 millivolt steps over the actual input voltage range is sufficient, an extra bit is needed on the most significant ("left") side of the 10-bit result. The circuit of Figure 16 can also be used, with different gains and offsets, to satisfy this extra MSB need by splitting the 10 volt range into 5 volt ranges.

If both channels of Figure 16 are set for unity gain, and channel 1 is offset to 5 volts, an 11-bit conversion result with 5 millivolt steps is available. While V_{IN} is in the lower half of its range (0 volts to 5 volts), channel 0 will be active. While V_{IN} is in the upper half of its range (5 volts to 10 volts), channel 1 will be active. Thus, an extra MSB is created.

For applications requiring multiple extra bits of result, the solutions can become more "elegant" (i.e. elaborate). However, it is profitable to first squeeze the most out of the now familiar circuit in Figure 16.

Assume that the analog input, V_{IN}, ranges from 0 volts to 10 volts, and it is desired to measure this range in 2.5 millivolt steps. This requires two extra bits of result – one extra MSB and one extra LSB. A simple extrapolation of the preceding discussion of creating extra bits might have the designer planning to tieup four channels of the multiplexer needlessly. Needlessly, that is, if the application is a typical control application where the high accuracy requirements are only important in the "normal" operating range of the process. Outside of the normal operating range is the "possible" operating range which must be measured, but with less stringent requirements.

Since the requirements of the normal range set the necessary LSB weight, and the extent of the possible range sets the maximum voltage span, it follows that only two channels need to be used (Figure 16). Channel 0 would be set with a gain that compressed the possible V_{IN} range to 5 volts, while channel 1 would be offset to the normal operating range and would have a gain of two to expand this region of critical interest. With this ap-

proach, 100 percent of the normal operating range is digitized in 2.5 millivolt steps, while 100 percent of the possible range is digitized in 10 millivolt steps.

Unfortunately, not all high resolution applications can be described as a process with a small region of in-control operation, where the process is out-of-control outside of that small region. For example, it is necessary to measure airflow in an engine controlling carburetion. The air flow at idle is likely to be several orders-of-magnitude lower than the airflow at full RPM. The process needs to be in tight control over the entire range, not only when the engine is at half-speed.

When it is desired to measure a process with a fixed percent of error throughout a range spanning several orders-of-magnitude, a non- linear input buffer becomes attractive. For example, assume that the analog signal that needs to be digitized can vary from 1 millivolt to 25 volts and describes a physical process that must be represented digitally with 1 percent error at any point in the possible input range. A linear solution to this application would require a converter with a 10 microvolt LSB (1% × 1 mV), and a resolution of 22 bits (25 V/10 microvolts). This is clearly undesirable.

The use of a log input buffer to compress the 25 volt range logarithmically to 5 volts would satisfy the application requirements. The input would range from 1 millivolt to 25 volts with the output ranging from 0 volts to 5 volts proportionally to the log of V_{IN}/1mV. Each one-percent change in the input voltage would change the output voltage by 5 millivolts (one count). The antilog could be taken in software using a lookup table, or the control calculations could be performed in a log base.

Simple inexpensive log-amps can be built as in Figure 17, or high- accuracy, self-contained log-amps can be purchased. Which is chosen depends upon the application tradeoffs of price and performance.

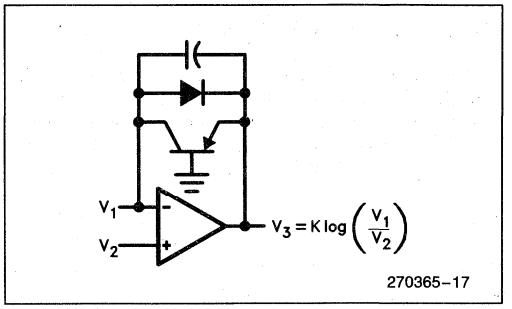


Figure 17. A Low-Cost Log Amplifier

Other techniques become available for consideration in systems that have slow sample rate requirements, but very high resolution requirements. In addition to the methods described above, which require external hardware, software filtering or other post-processing of the conversion results can be productive. Each method relies upon the ability to sample the analog input much faster than the system requires an analog input.

When resolution is limited by filterable noise, perhaps the most straightforward approach to post-processing is to oversample the input by a factor of N and digitally low-pass filter the data (i.e. weighted rolling average). A result would be reported to the rest of the system every N samples (Figure 18). A low-pass filter can increase the signal- to-noise ratio (SNR) by a factor of N (see bibliography). However, care must be taken to be certain that the input voltage varies slowly with respect to the sampling rate.

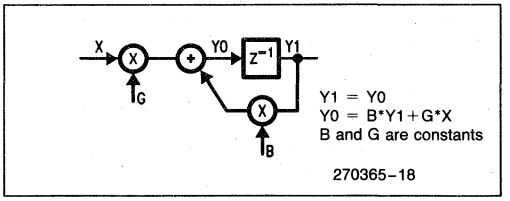


Figure 18. A Low Pass Filter

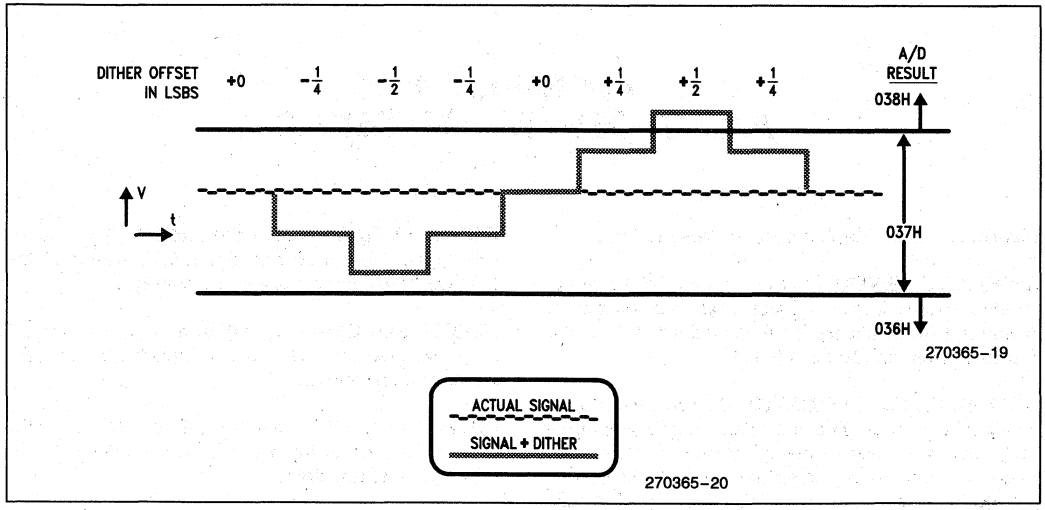


Figure 19. Dither

Another approach to creating more resolution is called "synchronized dither". Figure 19 shows an input voltage that is constant somewhere between two code transition points. This input is "dithered" by adding a small periodic waveform (1/4 LSB steps) to the input while performing an A/D conversion synchronized with each dither step. Every time the dither completes a full cycle, the eight conversion results are averaged to form one digitized value. Since the dither is periodic and symmetrical about 0 volts, its average impact on the input voltage is 0 volts.

The creation of extra resolution can be seen with the example shown in Figure 19. Without dither, the input voltage would always convert to 37H. With dither, one-eighth of the conversions would be 38H and 7/8 of the conversions would be 37H. If every eight conversions were averaged, the result would be 37H + 1/8 LSB. The possible results given a four level dither, where the input voltage was always within the 37H code width, would be

36H + 5/8
36H + 7/8
37H + 0
37H + 1/8
37H + 3/8

Hence, four new levels exist (two bits).

Dither will only create more resolution up to the limit of the A/D converter comparator's ability to distinguish voltages. Since MCS-96 converter repeatability error is typically around 1 millivolt to 1.25 millivolts, 1/4 LSB dither is the practical limit if no other processing is done. Figure 20 shows a simple method by which the input voltage could be dithered under software control.

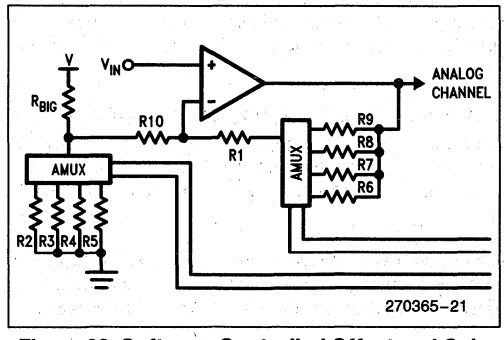


Figure 20. Software Controlled Offset and Gain

While only a few of the more obvious interfacing techniques were described here, there are as many innovative interfacing tricks as there are designers.

CONCLUSION

This application note provides a fundamental understanding of MCS-96 analog acquisition for the digital designer. Since answering the limitless number of analog circuit design questions is beyond the scope of this document, it is expected that analog design manuals and the large body of publicly available applications literature will be consulted for detailed design hints. Furthermore, the applications literature of monolithic analog acquisition system manufacturers should be consulted since the suggestions presented therein are largely transportable to any A/D system.

APPENDIX A
A/D GLOSSARY OF TERMS

Figures 2, 4 and 7 display many of these terms.

ABSOLUTE ERROR—The maximum difference between corresponding actual and ideal code transitions. Absolute Error accounts for all deviations of an actual converter from an ideal converter.

ACTUAL CHARACTERISTIC—The characteristic of an actual converter. The characteristic of a given converter may vary over temperature, supply voltage, and frequency conditions. An Actual Characteristic rarely has ideal first and last transition locations or ideal code widths. It may even vary over multiple conversions under the same conditions.

BREAK-BEFORE-MAKE—The property of a multiplexer which guarantees that a previously selected channel will be deselected before a new channel is selected. (e.g. the multiplexer will not short inputs together.)

CHANNEL-TO-CHANNEL MATCHING—The difference between corresponding code transitions of actual characteristics taken from different channels under the same temperature, voltage and frequency conditions.

CHARACTERISTIC—A graph of input voltage versus the resultant output code for an A/D converter. It describes the transfer function of the A/D converter.

CODE—The digital value output by the converter.

CODE CENTER—The voltage corresponding to the midpoint between two adjacent code transitions.

CODE TRANSITION—The point at which the converter changes from an output code of Q, to a code of Q + 1. The input voltage corresponding to a code transition is defined to be that voltage which is equally likely to produce either of two adjacent codes.

CODE WIDTH—The voltage corresponding to the difference between two adjacent code transitions.

CROSSTALK—See "Off-Isolation".

D.C. INPUT LEAKAGE—D.C. Leakage current of an analog input pin.

DIFFERENTIAL NON-LINEARITY—The difference between the ideal and actual code widths of the terminal based characteristic of a converter.

FEEDTHROUGH—Attenuation of a voltage applied on the selected channel of the A/D converter after the sample window closes.

FULL-SCALE ERROR—The difference between the expected and actual input voltage corresponding to the full-scale code transition.

IDEAL CHARACTERISTIC—A characteristic with its first code transition at V_{IN} = 0.5 LSB, its last code transition at V_{IN} = (V_{REF} − 1.5 LSB) and all code widths equal to one LSB.

INPUT RESISTANCE—The effective series resistance from the analog input pin to the sample capacitor.

LSB - LEAST SIGNIFICANT BIT—The voltage value corresponding to the full-scale voltage divided by 2n, where n is the number of bits of resolution of the converter. For a 10-bit converter with a reference voltage of 5.12 volts, one LSB is 5.0 mV. Note that this is different than digital LSBs, since an uncertainty of two LSBs, when referring to an A/D converter, equals 10 mV. (This has been confused with an uncertainty of two digital bits, which would mean four counts, or 20 mV.)

MONOTONIC—The property of successive approximation converters which guarantees that increasing input voltages produce adjacent codes of increasing value, and that decreasing input voltages produce adjacent codes of decreasing value.

NO MISSED CODES—For each and every output code, there exists a unique input voltage range which produces that code only.

NON-LINEARITY—The maximum deviation of code transitions of the terminal based characteristic from the corresponding code transitions of the actual characteristic of a converter.

OFF-ISOLATION—Attenuation of a voltage applied on a deselected channel of the A/D converter. (Also referred to as Crosstalk.)

REPEATABILITY—The difference between corresponding code transitions from different actual characteristics taken from the same converter on the same channel at the same temperature, voltage and frequency conditions.

RESOLUTION—The number of input voltage levels that the converter can unambiguously distinguish between. Also defines the number of useful bits of information which the converter can return.

SAMPLE DELAY—The delay from receiving the start conversion signal to when the sample window opens.

SAMPLE DELAY UNCERTAINTY—The variation in the Sample Delay.

SAMPLE TIME—The time that the sample window is open.

SAMPLE TIME UNCERTAINTY—The variation in the sample time.

SAMPLE WINDOW—Begins when the sample capacitor is attached to a selected channel and ends when the sample capacitor is disconnected from the selected channel.

SUCCESSIVE APPROXIMATION—An A/D conversion method which uses a binary search to arrive at the best digital representation of an analog input.

TEMPERATURE COEFFICIENTS—Change in the stated variable per degree centigrade temperature change. Temperature coefficients are added to the typical values of a specification to see the effect of temperature drift.

TERMINAL BASED CHARACTERISTIC—An Actual Characteristic which has been rotated and translated to remove zero offset and full-scale error.

V_{CC} REJECTION—Attenuation of noise on the V_{CC} line to the A/D converter.

ZERO OFFSET—The difference between the expected and actual input voltage corresponding to the first code transition.

APPENDIX B
CAPACITIVE INTERPOLATION

A successive approximation A/D converter needs an internal D/A converter of the same resolution as the desired A/D result. A 10-bit D/A could have been made using a string of 1024 resistors connected from the analog reference at one end to ground at the other end. Although this would be technically ideal, such a circuit would be enormous. Therefore, a method was developed to generate the needed reference voltages using a small area of silicon so that an on-chip 10-bit A/D converter would be economical.

The method used relies upon a 256-resistor chain to generate reference voltages in 20mV (5.12V/256) steps while two ratioed capacitors are used to capacitively "interpolate" voltages in-between the resistor tap voltages. The area of the 256-resistor chain together with the capacitors is one-fourth the area of the would-be 1024 resistor chain.

Before beginning a detailed description of the capacitive part of the conversion process, it is necessary to understand a few details about the resistor chain.

There are 256 resistors connected in series from the analog reference to analog ground. The actual value of the resistors only impacts the current through the reference pin. If every resistor in the chain is the same value the converter will function properly.

To reduce resistor-to-resistor variation, the chain is folded in half, and then in an accordion fashion to produce a 16 × 16 block of resistors. This minimizes the sensitivity of the array to processing gradients, while also allowing the array to be addressed roughly similar to a 16 × 16 memory array.

As explained earlier, it is desired for the A/D converter to have its first code transition at ½ LSB followed by subsequent code widths 1 LSB wide.

To accomplish this, each resistor is tapped in its center rather than between resistors. For example, the first resistor tap is half-way up the first resistor. This means that the zero resistor tap will output 10mV (20mV/2). When calculating the voltage on a certain resistor tap, you must add 10mV to the product of the tap number and 20mV.

The internal connections while an analog input is being sampled are shown in Figure B1a. Once sampling is complete, the analog input is disconnected and the comparator inputs are no longer clamped to V_{BIAS} (Figure B1b).

During the sample window (Figure B1a), V_{ANIN} and V_{OFS} control the amount of charge stored in C_A and C_B (V_{OFS} controls the converter offset). Once the sample window closes (Figure B1b), voltages applied to V_{IN} and V_{IN2} will add or subtract charge proportional to ($V_{ANIN} - V_{IN}$) on C_A and ($V_{OFS} - V_{IN2}$) on C_B. Unless a voltage is applied to V_{IN} and V_{IN2}. The inverting comparator input of Figure B1b will remain at V_{BIAS} due to the charges on C_A and C_B. The non-inverting comparator input will always remain at V_{BIAS} and serves as a reference.

If a V_{IN}, V_{IN2} combination is applied which causes the non-inverting input to drop below V_{BIAS} the comparator will output to a 1 to indicate that the applied voltage was lower than the original V_{ANIN}. To better understand how the circuit works, Figure B2 shows the superposition analysis used to form the equation for V_{OUT}, given initial charge on C_A and C_B and new input voltages V_{IN} and V_{IN2}.

Adding the independent effects shown in Figure B2 we have:

$$V_{OUT} = V1 + V2 + V3 + V4$$

$$V_{OUT} = V_{IN}\left(\frac{C_A}{C_A+C_B}\right) + V_{IN2}\left(\frac{C_B}{C_A+C_B}\right) + V_{AI}\left(\frac{C_A}{C_A+C_B}\right) + V_{BI}\left(\frac{C_B}{C_A+C_B}\right)$$

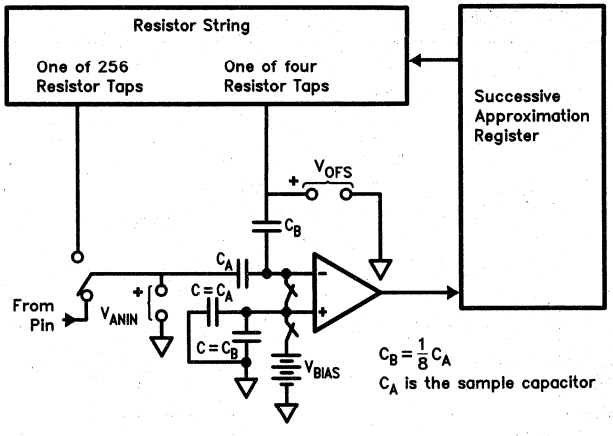
$$V_{OUT} = (V_{IN} + V_{AI})\frac{C_A}{C_A + C_B} + (V_{IN2} + V_{BI})\frac{C_B}{C_A + C_B} \quad \text{(I)}$$

The initial conditions on C_A and C_B are set-up as shown in Figure B3.

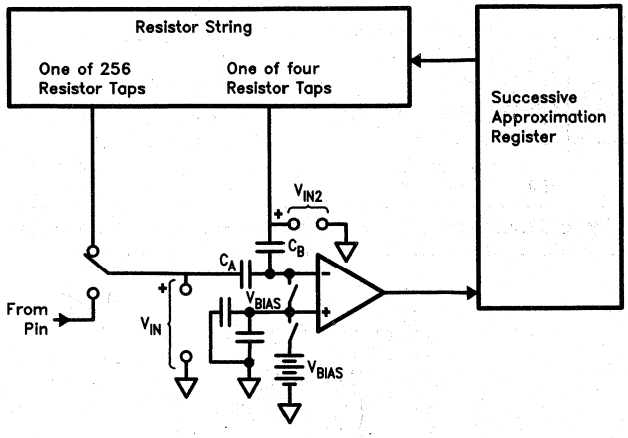
We can see that:

$$V_{AI} = V_{BIAS} - V_{ANIN} \quad \text{(II)}$$

$$V_{BI} = V_{BIAS} - V_{OFS} \quad \text{(III)}$$



(a). Connections during the sample window



(b). Connections after the sample window closes

Figure B1

Substituting II and III into I we get:

$$V_{OUT} = (V_{IN} + V_{BIAS} - V_{ANIN})\frac{C_A}{C_A + C_B} + (V_{IN2} + V_{BIAS} - V_{OFS})\frac{C_B}{C_A + C_B} \quad \text{(IV)}$$

V_{OUT} becomes the input voltage to the comparator which ideally presents no load. The only way to make V_{OUT} approach the value of V_{BIAS} (after V_{BIAS} is removed) is to apply a voltage combination which makes equation IV evaluate to V_{BIAS}. If we had an infinitely variable internal voltage reference to use, we could just set the reference on V_{IN} to the value of V_{ANIN} and make $V_{INZ} = V_{OFS}$.

We would then have, from IV:

$$V_{IN} = V_{ANIN},\ V_{IN2} = V_{OFS}$$

However, using a 256-resistor chain to provide references, we can find a V_{IN}, V_{INZ} combination which can bring V_{OUT} close to the value of V_{BIAS}. The 256-resistor chain provides a reference voltage in 20 mV steps. We can then take separate taps of the resistor chain and connect them to V_{IN} and V_{IN2}. The voltage attached to V_{IN} will couple to V_{OUT} by a factor of $C_A/(C_A + C_B) = 8/9$ from EQN IV. The voltage attached to V_{IN2} will couple to V_{OUT} by a factor of $C_B/(C_A + C_B)$. The ratio of the impacts on V_{OUT} of V_{IN} versus V_{IN2} is:

$$\left(\frac{\partial V_{OUT}}{\partial V_{IN}}\right) \div \left(\frac{\partial V_{OUT}}{\partial V_{IN2}}\right) = (8/9)/(1/9) = 8$$

Therefore, a voltage change on V_{IN} will affect the voltage seen at V_{OUT} eight times more than the same change placed on V_{IN2}.

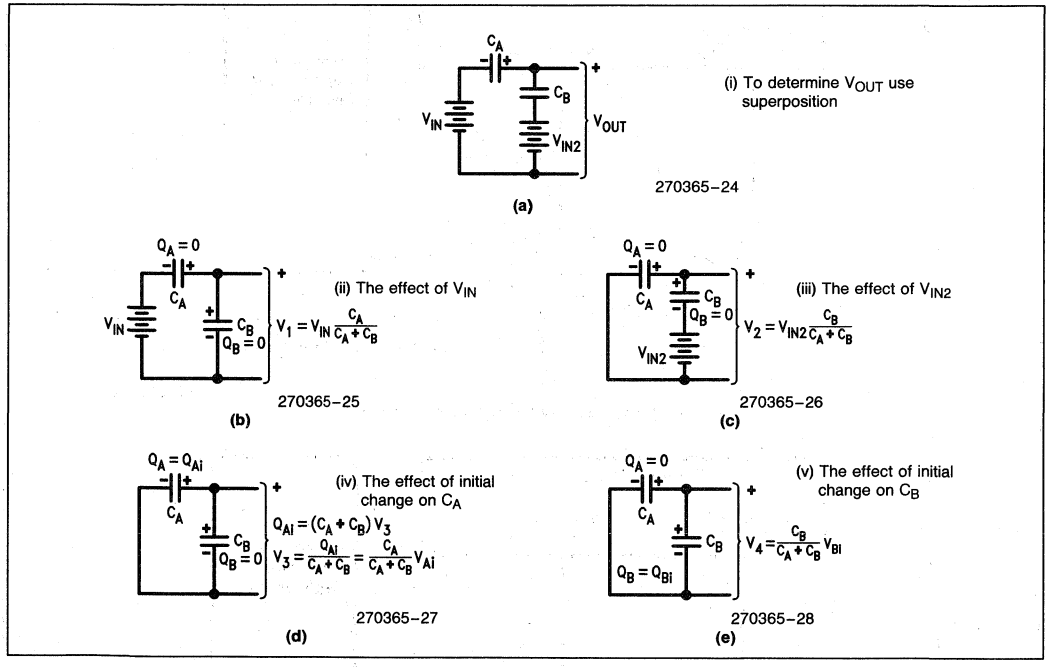


Figure B2. Superposition Analysis of comparator input voltage

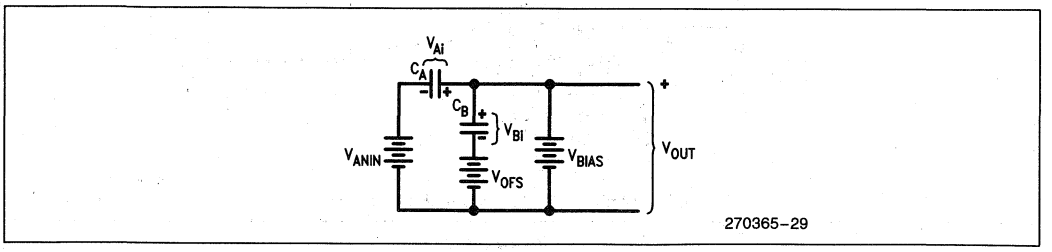


Figure B3. Initial Conditions

For example, assume the actual input voltage V_{ANIN} was 2.50mV during the sample window. Using EQN IV, and assuming V_{BIAS} = 3V and V_{OFS} = 70mV, we substitute and find:

$$V_{OUT} = (V_{IN} + 2.9975) \times (8/9) + (V_{IN2} + 2.93) \times (1/9) \quad (V)$$

Using successive approximation, the first trial input voltage attempted corresponds to the digital code 0111 1111 11b (127 × 20mV + 10mV). This means that the voltage applied to V_{IN} will be the 0111 1111b tap and the voltage applied to V_{IN2} will be the 0110b tap (6 × 20mV + 10mV = 3 LSB). Substituting these values into EQN V we have:

$$V_{OUT} = (2.550 + 2.9975) \times (8/9) + (0.130 + 2.93) \times (1/9) \quad (V)$$

$$V_{OUT} = 4.931 + 0.34 = 5.271$$

Since the 3V reference is lower than V_{OUT} with these inputs, the comparator will output a 0 which is placed in the MSB of the successive approximation register. The next most significant bit of the SAR is then zero'd and the new ladder tap applied to V_{IN}. The result of this second comparison, and the subsequent comparisons are shown in Table B1. The C program used to generate Table B1 is listed in Listing B1.

The value selected for V_{OFS} during the sample window may not be obvious. The purpose of V_{OFS} is to inject a constant offset in the sampling process so that the converter's first code transition will occur at 2.5mV.

Using EQN IV we can quickly see why V_{OFS} is chosen to be the fourth resistor tap (4 × 20mV + 10mV = 70mV). For V_{ANIN} = 2.5mV, we want V_{OUT} to evaluate to V_{BIAS} when the SAR is OH.

$$V_{OUT} = \{(0.20\ mV + 10\ mV) + (V_{BIAS} - 2.5\ mV)\} \times (8/9) + \{(0.20\ mV + 10mV) + (V_{BIAS} - 70\ mV)\} \times (1/9)$$

$$V_{OUT} - V_{BIAS} = 7.5\ mV \times (8/9) - 60\ mV \times (1/9) = 0$$

Therefore, if V_{OFS} = 70 mV, the converter's first code transition will be when V_{ANIN} = 2.5 mV.

Table B1. Conversion Simulation

```
A to D simulator. (center taps) . . With
VIN = 0.002500
VCENT = 3.000000 VOFF = 0.070000
SAR = 1FFH ( 511)   VOUT = 5.271111
SAR =  FFH ( 255)   VOUT = 4.133333
SAR =  7FH ( 127)   VOUT = 3.564444
SAR =  3FH (  63)   VOUT = 3.280000
SAR =  1FH (  31)   VOUT = 3.137778
SAR =   FH (  15)   VOUT = 3.066667
SAR =   7H (   7)   VOUT = 3.031111
SAR =   3H (   3)   VOUT = 3.013333
SAR =   1H (   1)   VOUT = 3.004444
SAR =   0H (   0)   VOUT = 3.000000
SAR =   1H (   1)    which means 0.005000 volts
```

6

```
#include "CTYPE.H"
#include "STDIO.H"
/* example invocation lines

  a2dsim 0.0025  3.0    0.07          p
         Vin    Vbias   Vofs    print to screen and lp

  a2dsim 0.0075  3.0    0.07
         Vin    Vbias   Vofs    print to screen only
*/


int main(k, argv)
int k;
char *argv[];
        {                                       /* main */
        FILE *fp, *fopen();
        double initial_conditions, vin, vout, vcent, voff, v89, v19;
        unsigned int sar = 0x3FF;
        unsigned int mask = 0x200;
        unsigned int count = 0;
        unsigned int printon;
        if (strcmp(argv[0], "run") == 0)
                count++;
        if ((k != (4 + count)) & (k != (5 + count)))
                {
                printf("\nInvocation error!\n");
                return;
                }
        count++;
        sscanf(argv[count++], "%lf", &vin);
        sscanf(argv[count++], "%lf", &vcent);
        sscanf(argv[count++], "%lf", &voff);
        if (count == k)
                printon = 0;
        else printon = 1;

        printf("A to D simulator.(center taps)..");

        if (printon)
                {
                if ((fp = fopen("\prn:", "w")) == 0)
                        {
                        printf("\nCan't open printer\n");
                        return;
                        }
                }
        if (printon)
                fprintf(fp, "A to D simulator..");

        printf(" with \nVin = %f\nVcent = %f\nVoff = %f\n", vin, vcent, voff);
        if (printon)
                fprintf(fp, " with \nVin = %f\nVcent = %f\nVoff = %f\n",
                        vin, vcent, voff);

        initial_conditions = ((8.0 / 9.0) * (vcent - vin))
            + ((1.0 / 9.0) * (vcent - voff));
        v89 = 8.0 / 9.0;
        v19 = 1.0 / 9.0;
```

270365-A5

Listing B1. A/D Converter Simulator

```
sar ^= mask;
printf("SAR = %3xH (%4d)\t", sar, sar);
if (printon)
        fprintf(fp, "SAR = %3xH (%4d)\t", sar, sar);
for (count = 0;  count < 10;  count++)
        {

        vout = (v89 * (((double) (sar >> 2)) * 0.02 + 0.01))
             + (v19 * (((double) ((sar & 3) << 1)) * 0.02 + 0.01))
             + initial_conditions;
        if (vout < vcent)
                sar |= mask;
        mask >>= 1;
        sar ^= mask;
        printf("Vout = %f\nSAR = %3xH (%4d)\t", vout, sar, sar);
        if (printon)
                fprintf(fp, "Vout = %f\nSAR = %3xH (%4d)\t",
                        vout, sar, sar);
        }
printf(" which means %f volts\n\n", (double) sar * 0.005);
if (printon)
        fprintf(fp, " which means %f volts\n\n", (double) sar * 0.005);
return;
}                                       /* main */
```

270365-A6

Listing B1. A/D Converter Simulator (Continued)

6

APPENDIX C
ERROR FORMULAS

The following C program listing contains the routines used to calculate A/D performance in the Embedded Controller Applications lab. Most of the routines require floating point arrays to operate upon. In the listings, the array x[ ] contains the input voltages corresponding to each code transition of the converter. The array dx[ ] contains the width of the region in which each code transition of the converter could occur. For example, an input voltage of 0.003V may cause code 0 and code 1 to be equally likely outputs. x[0] would then contain 0.0030000. However, 0-to-1 code transitions might be observed infrequently through a range of input voltages from 0.0025V to 0.0035V. dx[0] would then contain 0.0010000 to indicate that there is a 1 millivolt window in which either code could occur. x[ ] and dx[ ] are generated by hardware doing repeated conversions using precision voltage standards to provide the input voltages. The array dd[ ] is used throughout as temporary storage.

Generally, typical data is drawn from x[ ] only. When minimum and maximum data is desired, x[ ] and dx[ ] are used to find the range of possible input voltages that could cause each code. For example, typical zero offset is found by simply subtracting 0.5 LSB from the value of x[0]. But, the minimum and maximum zero offset would be calculated as x[0] - 0.5 LSB ± dx[0]/2.

The listings are provided to show exactly how performance data is calculated. They are not meant to be compiled by the reader. In fact, they are too incomplete to compile correctly, as some support routines and global data structures are not provided.

```
#include "\DPR\ADTMAC.H"
#include "\DPR\TDBASE.H"
#include "\DPR\RDBASE.H"
#define LSB (nov.avcc/(pow(2,nbits)))
#define FCT (int)(pow(2,nbits) - 2)
#undef min
#undef max
#undef abs

double pow(a, b)
int a, b;
        {                                       /* pow */
        double temp;
        int i;
        temp = 1.0;
        for (i = 1;  i <= ((int) b);  i++,  temp = temp * a)
                ;
        return (temp);
        }                                       /* pow */

double fabs(a)
double a;
        {
        if (a < 0)
                return (-a);
        else return (a);
        }

int min(a, b)
double a, b;
        {
        if (a < b)
                return (1);
        else if (a > b)
                return (2);
        else return (0);
        }

int max(a, b)
double a, b;
        {
        return (min(b, a));
        }

double typzoff(x, dx)
float x[], dx[];
        {
        double pow();
        return (x[0] - (0.5 * LSB));
        }

double maxzoff(x, dx)
float x[], dx[];
        {
        double pow();
        return (x[0] + (dx[0] / 2.0) - 0.5 * LSB);
        }

double minzoff(x, dx)
```

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Listing C1. Error Formulas

```
float x[], dx[];
        {
        double pow();
        return (x[0] - (dx[0] / 2.0) - 0.5 * LSB);
        }

double typfse(x, dx)
float x[], dx[];
        {
        double pow();
        return (x[FCT] - (nom.avcc - (1.5 * LSB)));
        }

double minfse(x, dx)
float x[], dx[];
        {
        double pow();
        return ((x[FCT] - (dx[FCT] / 2.0)) - (nom.avcc - (1.5 * LSB)));
        }

double maxfse(x, dx)
float x[], dx[];
        {
        double pow();
        return ((x[FCT] + (dx[FCT] / 2.0)) - (nom.avcc - (1.5 * LSB)));
        }

int xabserror(x, dx, dd, start, stop)   /* transition absolute error */
float x[], dx[], dd[];
unsigned int start, stop;
        {
        double pow(), fabs();
        int i, worst;
        for (i = worst = start;  i <= stop;  i++)
                {
                dd[i] = x[i] - ((double) i + 0.5) * LSB;
                if (fabs(dd[i]) > fabs(dd[worst]))
                        worst = i;
                }
        return (worst);
        }

int xabserrordx(x, dx, dd, start, stop) /* transition absolute error w/dx */
float x[], dx[], dd[];
unsigned int start, stop;
        {
        double pow(), fabs();
        int i, worst;
        double t1, t2;
        for (i = worst = start;  i <= stop;  i++)
                {
                t1 = (x[i] - (dx[i] / 2.0)) - (((double) i + 0.5) * LSB);
                t2 = (x[i] + (dx[i] / 2.0)) - (((double) i + 0.5) * LSB);
                if (fabs(t1) > fabs(t2))
                        dd[i] = t1;
                else dd[i] = t2;
                if (fabs(dd[i]) > fabs(dd[worst]))
                        worst = i;
                }
        return (worst);
        }
```

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Listing C1. Error Formulas (Continued)

```
int tbnonlin(x, dx, dd, start, stop)    /* tb nonlin using x only */
float x[], dx[], dd[];
unsigned int start, stop;
        {
        int i, worst;
        double pow(), typzoff(), typfse(), fabs();
        double oadj, qadj;

        oadj = typzoff(x, dx);
        qadj = 1.0 / ((typfse(x, dx) - oadj) / x[stop]);

        for (i = worst = start;  i <= stop;  i++)
                {
                dd[i] = (x[i] - oadj) * qadj - (((double) i + 0.5) * LSB);
                if (fabs(dd[i]) > fabs(dd[worst]))
                        worst = i;
                }
        return (worst);
        }

int tbnonlindx(x, dx, dd, start, stop)  /* tb nonlin using x and dx */
float x[], dx[], dd[];
unsigned int start, stop;
        {
        int i, worst;
        double pow(), typzoff(), typfse(), fabs();
        double oadj, qadj, t1, t2;

        oadj = typzoff(x, dx);
        qadj = 1.0 / ((typfse(x, dx) - oadj) / x[stop]);
```

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Listing C1. Error Formulas (Continued)

6

```
        for (i = worst = start;  i <= stop;  i++)
                {
                t1 = (x[i] - (dx[i] / 2.0) - oadj) * gadj - (((double) i + 0.5) * LSB);
                t2 = (x[i] + (dx[i] / 2.0) - oadj) * gadj - (((double) i + 0.5) * LSB);
                if (fabs(t1) > fabs(t2))
                        dd[i] = t1;
                else dd[i] = t2;
                if (fabs(dd[i]) > fabs(dd[worst]))
                        worst = i;
                }
        return (worst);
        }

int xdnl(x, dx, dd, start, stop)        /* using x only */
float x[], dx[], dd[];
int start, stop;
        {
        int i, worst;
        double pow(), fabs();
        double oadj, gadj;
        double typfse(), typzoff();

        oadj = typzoff(x, dx);
        gadj = 1.0 + ((typfse(x, dx) - oadj) / x[stop]);

        worst = start;
        if (start == 0)
                {
                dd[0] = 0.0;
                start++;
                }
        for (i = start;  i <= stop;  i++)
                {
                dd[i] = (x[i] - oadj) * gadj
                        - (x[i - 1] - oadj) * gadj
                        - LSB;
                if (fabs(dd[i]) > fabs(dd[worst]))
                        worst = i;
                }
        return (worst);
        }

int xdnldx(x, dx, dd, start, stop)      /* using x and dx */
float x[], dx[], dd[];
int start, stop;
        {
        int i, worst;
        double pow(), fabs();
        double t1, t2;
        double oadj, gadj;
        double typfse(), typzoff();

        oadj = typzoff(x, dx);
        gadj = 1.0 + ((typfse(x, dx) - oadj) / x[stop]);


        worst = start;
        if (start == 0)
                {
                dd[0] = dx[0] / 2.0;
```

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Listing C1. Error Formulas (Continued)

```
                start++;
                }
        for (i = start;  i <= stop;  i++)
                {
                t1 = (x[i] - (dx[i] / 2.0) - oadj) * gadj
                -(x[i - 1] + (dx[i - 1] / 2.0) - oadj) * gadj
                - LSB;
                t2 = (x[i] + (dx[i] / 2.0) - oadj) * gadj
                -(x[i - 1] - (dx[i - 1] / 2.0) - oadj) * gadj
                - LSB;
                if (fabs(t1) > fabs(t2))
                        dd[i] = t1;
                else dd[i] = t2;
                if (fabs(dd[i]) > fabs(dd[worst]))
                        worst = i;
                }
        return (worst);
        }

int reslevels(x, dx)    /* finds resolution in levels */
float x[], dx[];
        {
        int i, levels, n;
        double pow();

        levels = 1;
        n = (int) pow(2, nbits) - 1;
        if ((x[0] - (dx[0] / 2.0) > 0.0))
                levels++;

        for (i = 1;  i < n;  i++)
                if ((x[i - 1] + (dx[i - 1] / 2.0))
                        < (x[i] - (dx[i] / 2.0) - tparms.fine_step))
                        levels++;
        return (levels);
        }
```

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Listing C1. Error Formulas (Continued)

6

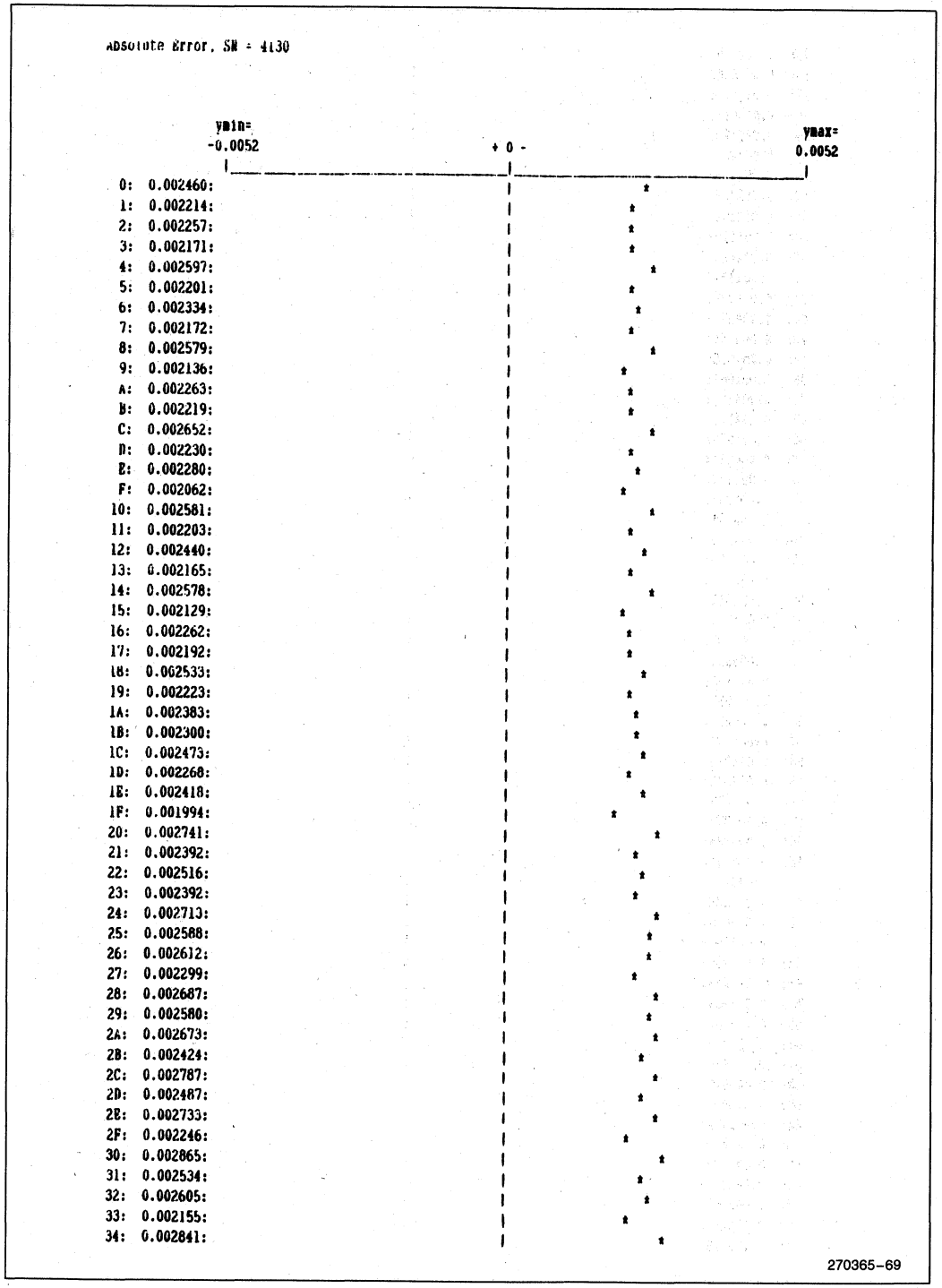
APPENDIX D
SAMPLE CONVERTER DATA

The following pages include printouts describing the performance of an 8097BH. The data shown is for one device and is provided for illustrative purposes only. Users should only rely upon data sheet specifications for the exact device they are designing with.

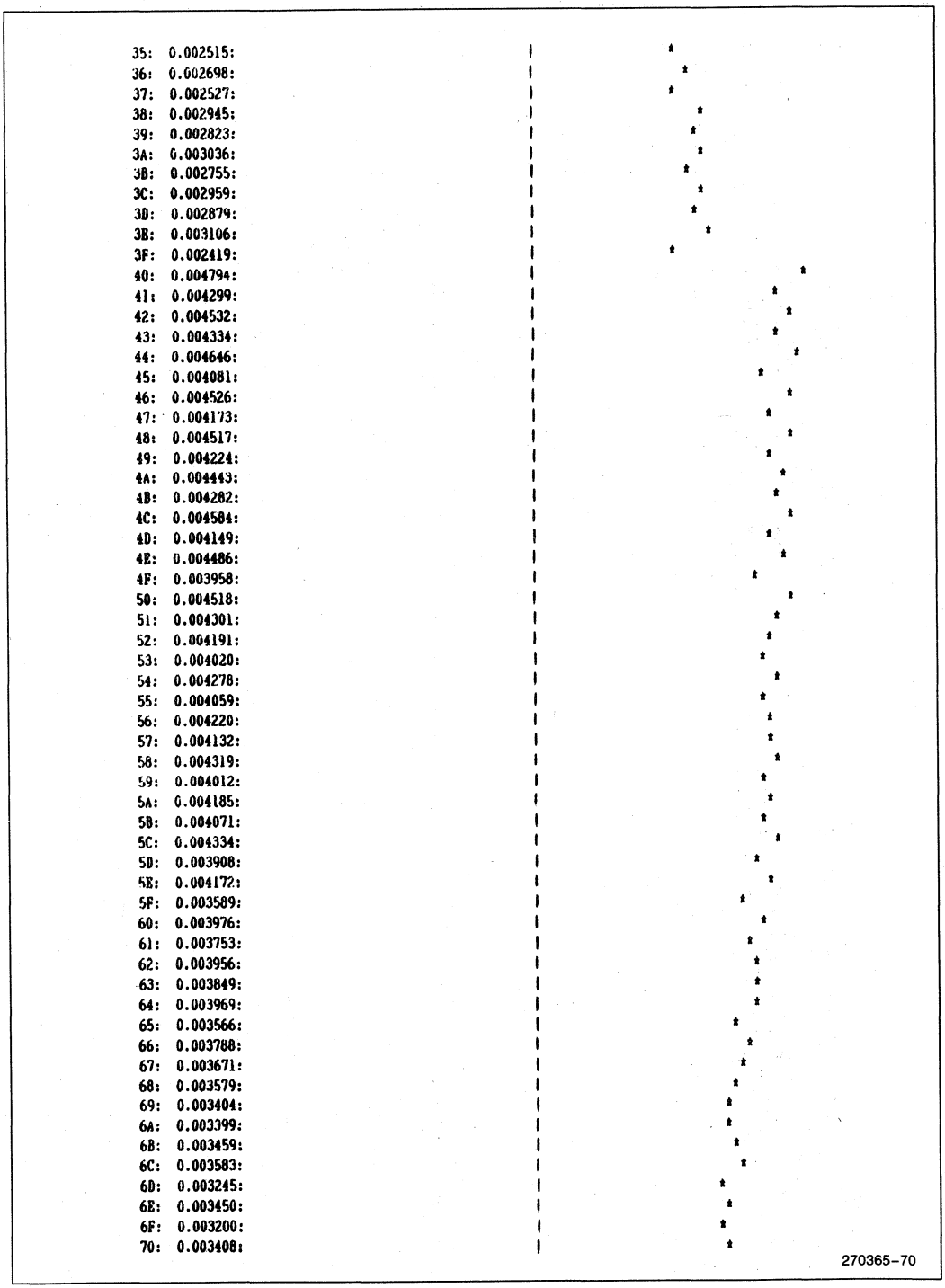
Table D1 summarizes many performance measures for one converter at 25 C, 12 MHz, V_{CC} = 5.00 volts and V_{REF} = 5.120 volts. Following Table D2 are several error plots that describe Absolute Error, Terminal-based Non-Linearity, Differential Non-Linearity and Repeatability for the test device code-by-code. The y-axis in the plots is the error in volts for each code transition, where code transitions make up the x-axis.

Table D1. Sample Converter Data

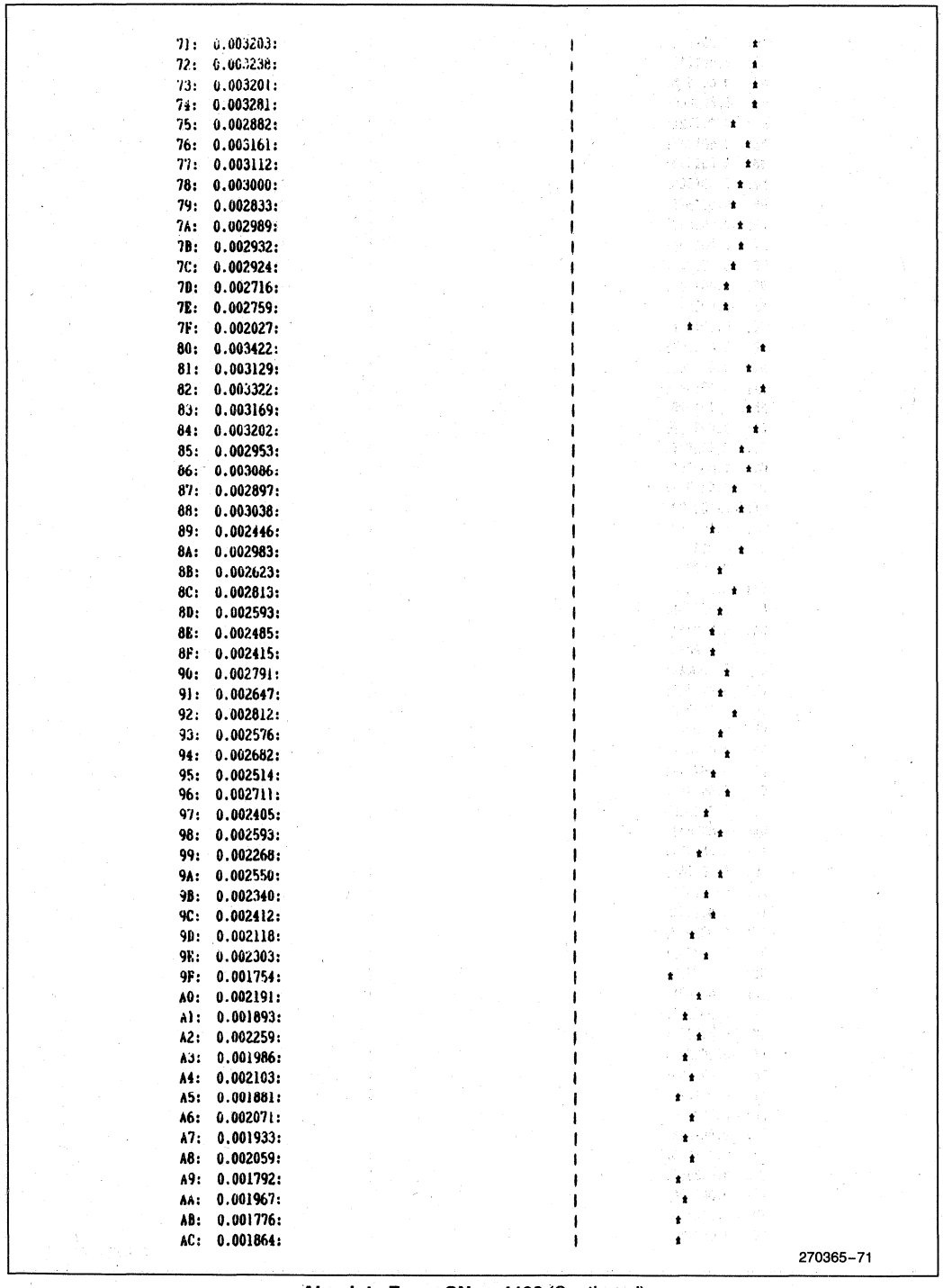
```
Test ID = D0H
sN: 4130 (1022H)
T = 25.000000
VCC = 5.000000, AVCC = 5.120000
Freq = 12.000000
Chan. = 3
States = 188   Mode = 0H
X0.15 1/28/87
Transition Characterization Parameter Listing
Large Step = 0.001000 V
Small Step = 0.000100 V
Endpoints when (1/100) are wrong

Center is 50 percent

Typical Offset Error = -0.001923
Maximum Offset Error = -0.002460
Maximum Offset Error = -0.001385

Typical FS Error = -0.000566
Maximum FS Error = -0.001254
Minimum FS Error = -0.000120

Absolute Error (typ) 40  = 0.004157
Absolute Error (max) 40  = 0.004795
Absolute Error (min) 325 = 0.001111

Diff. Non. Lin. Error (max) 40 = 0.003747
Diff. Non. Lin. Error (min) FF = -0.001071

Term. Non. Lin. Error (max) 325 = -0.004102
Term. Non. Lin. Error (min) 40 = 0.002148

Maximum Reliability Error 3D1 = 0.001875
Minimum Reliability Error 3A7 = 0.000974

Resolution is 1024 levels.
```



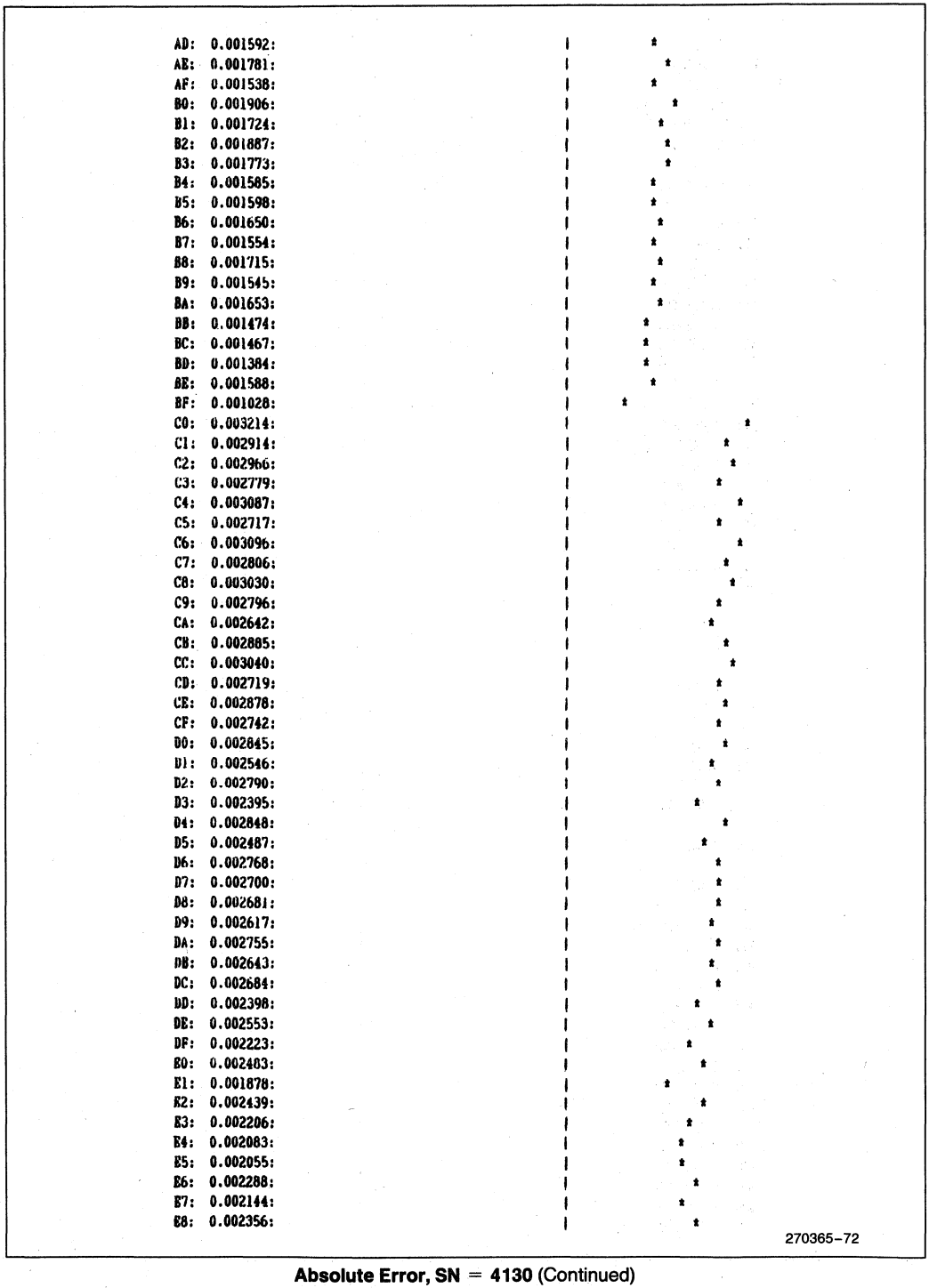
Absolute Error, SN = 4130



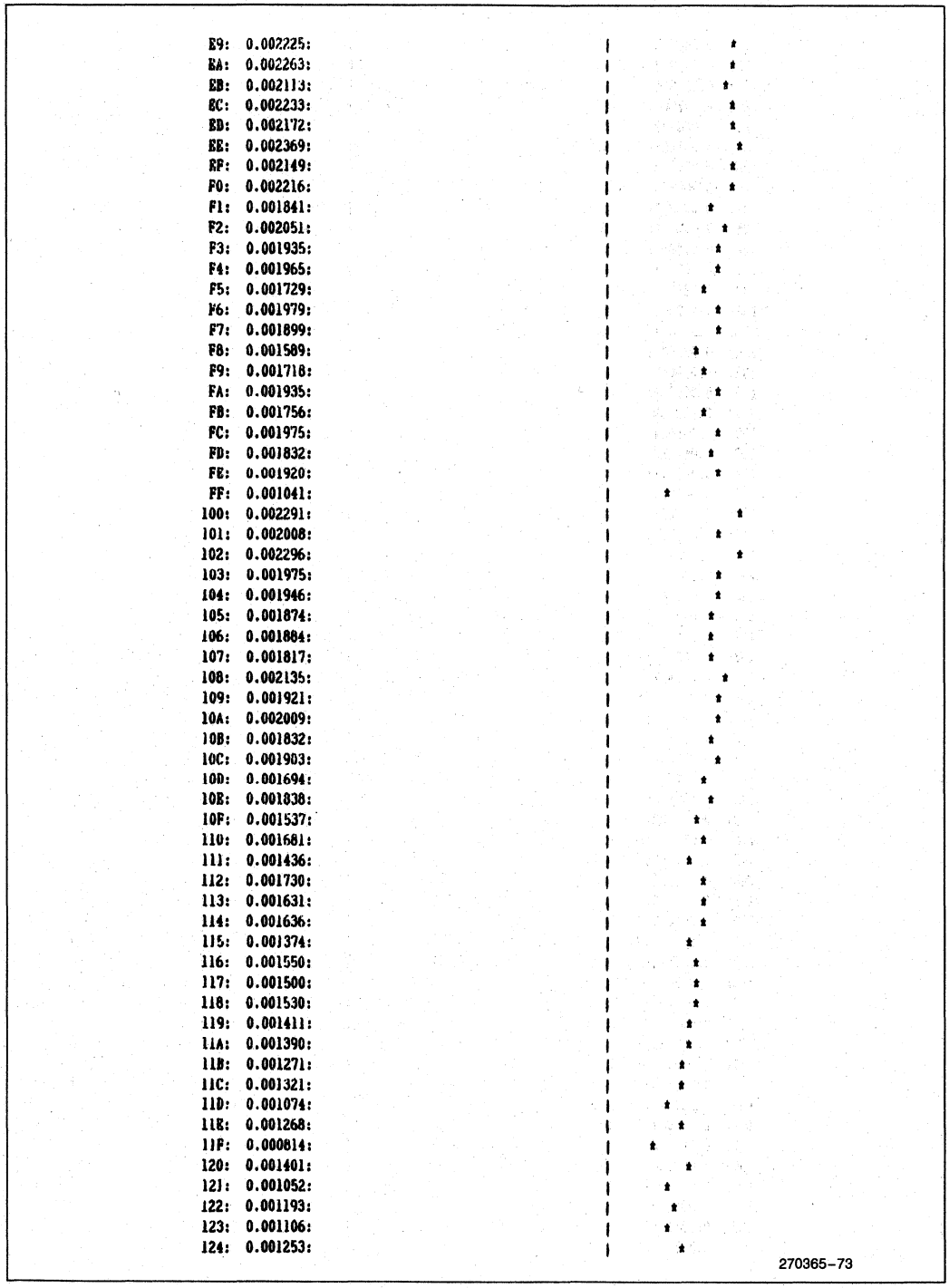
Absolute Error, SN = 4130 (Continued)



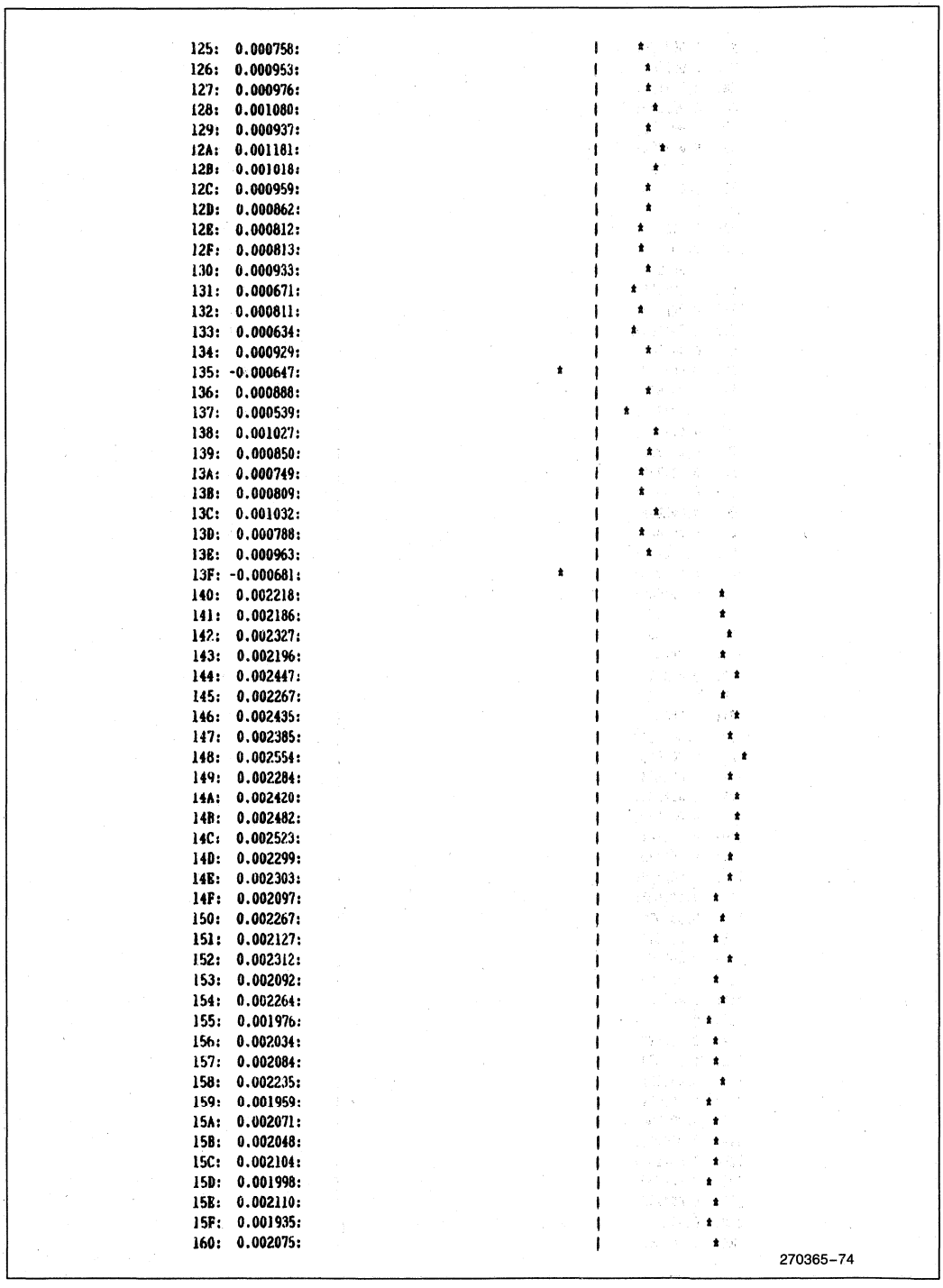
Absolute Error, SN = 4130 (Continued)



Absolute Error, SN = 4130 (Continued)



Absolute Error, SN = 4130 (Continued)



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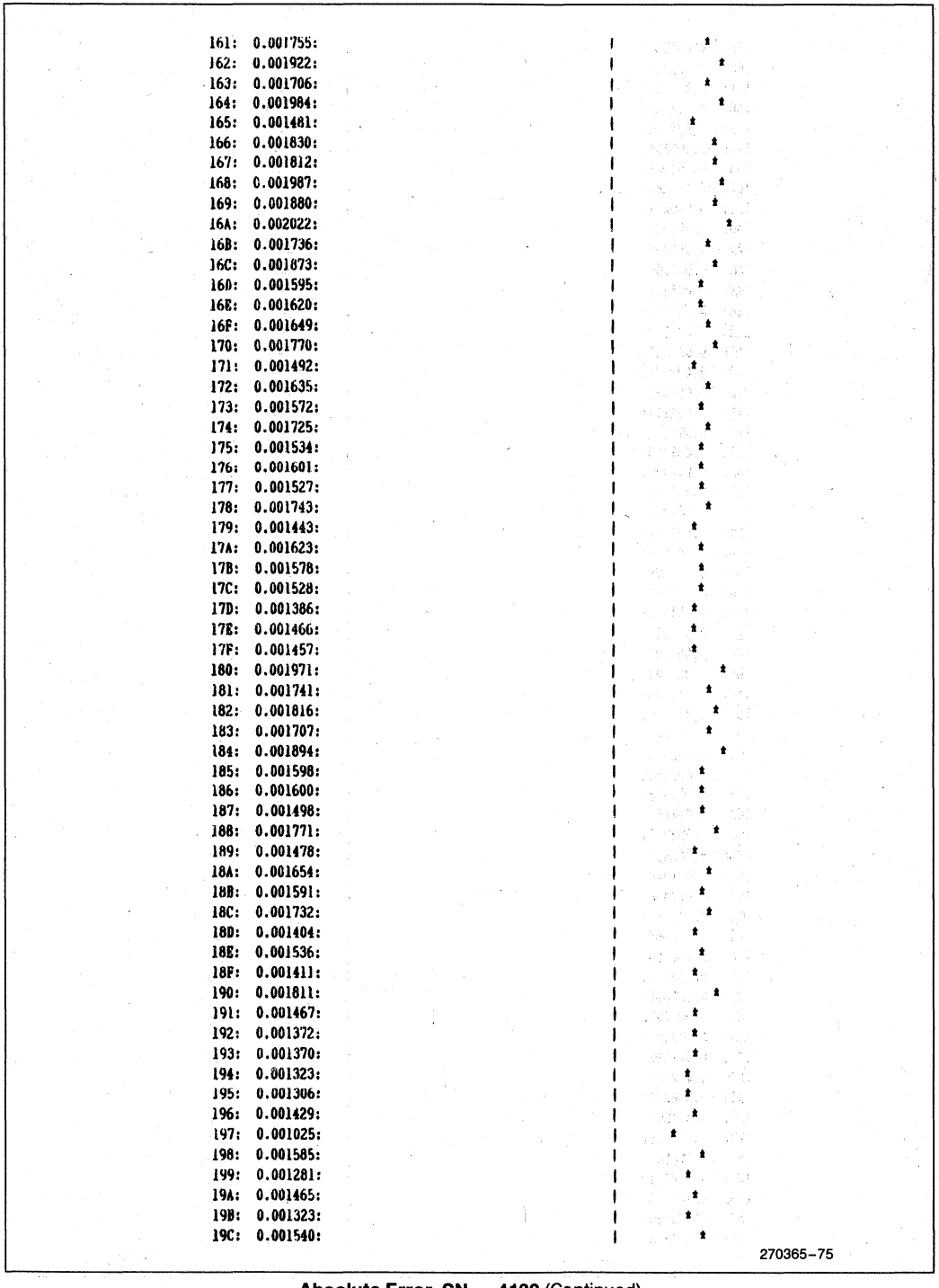
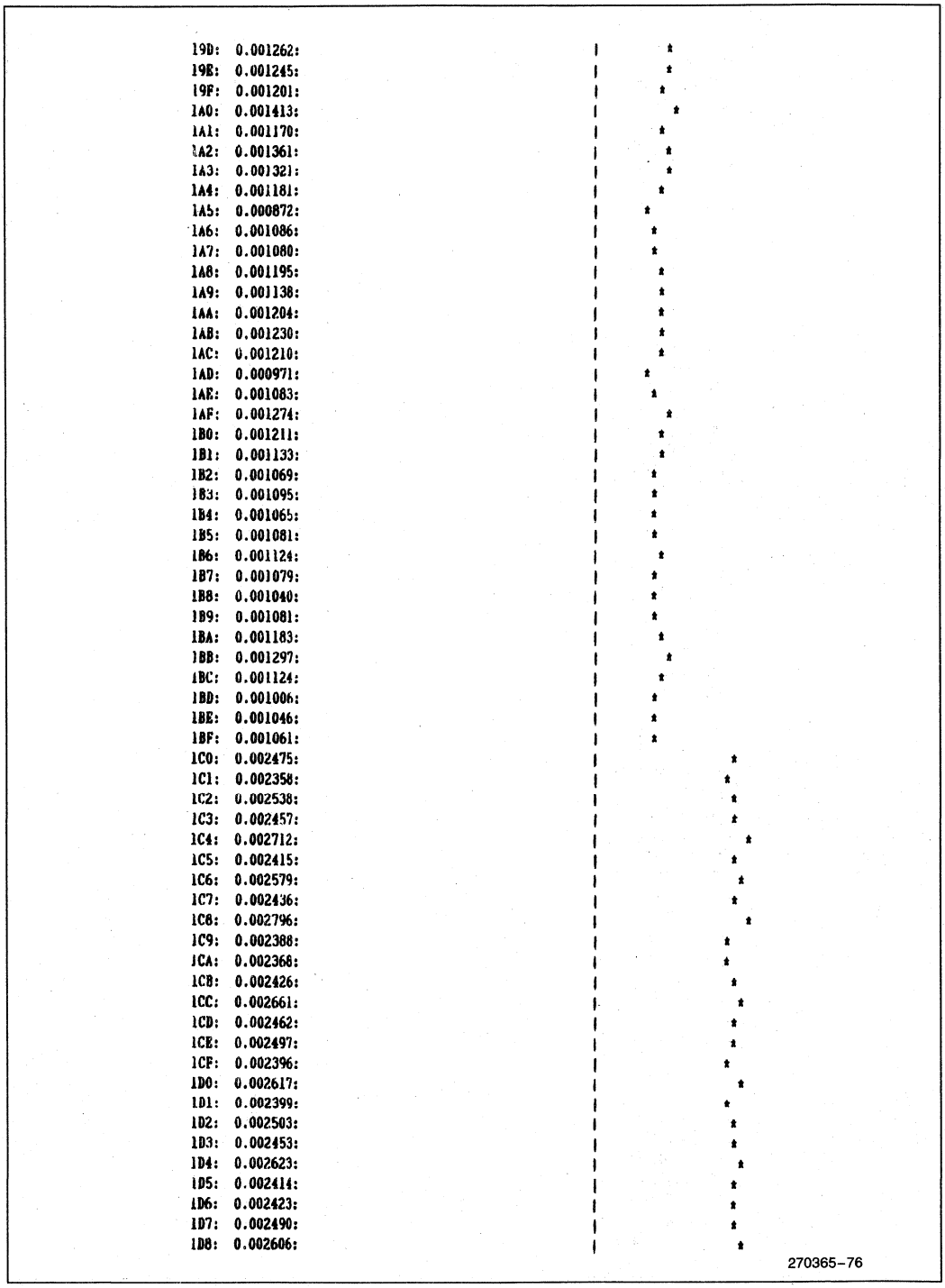
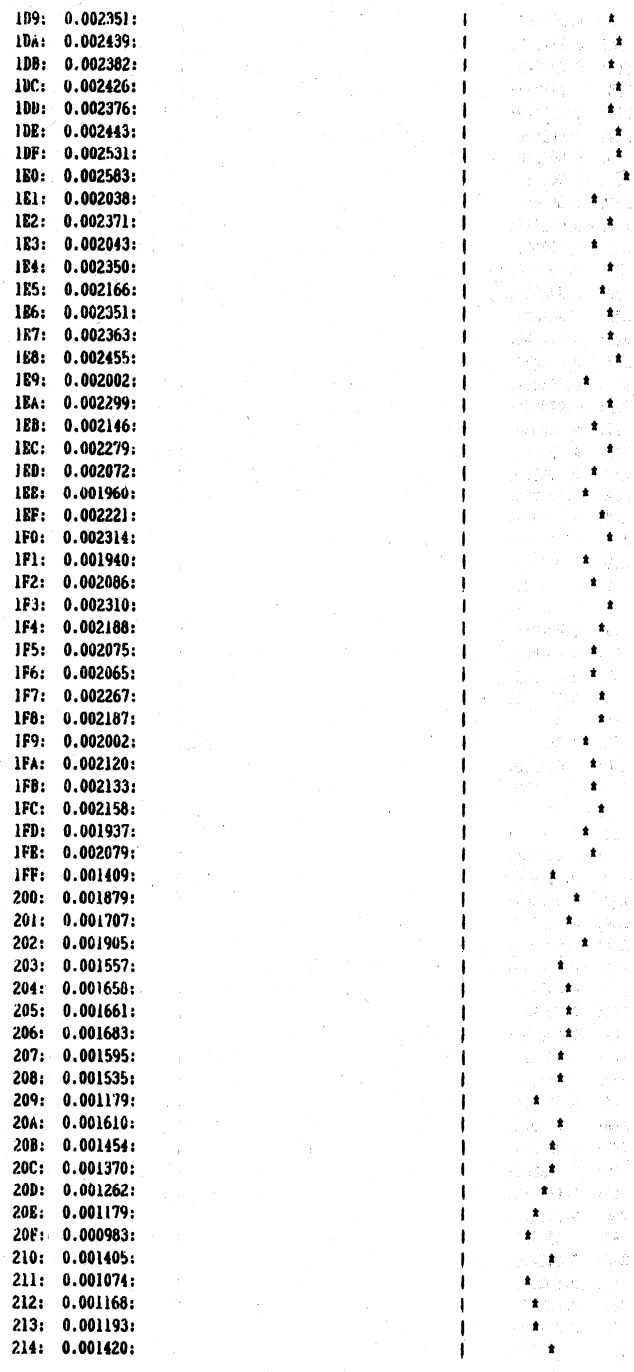
Absolute Error, SN = 4130 (Continued)



Absolute Error, SN = 4130 (Continued)



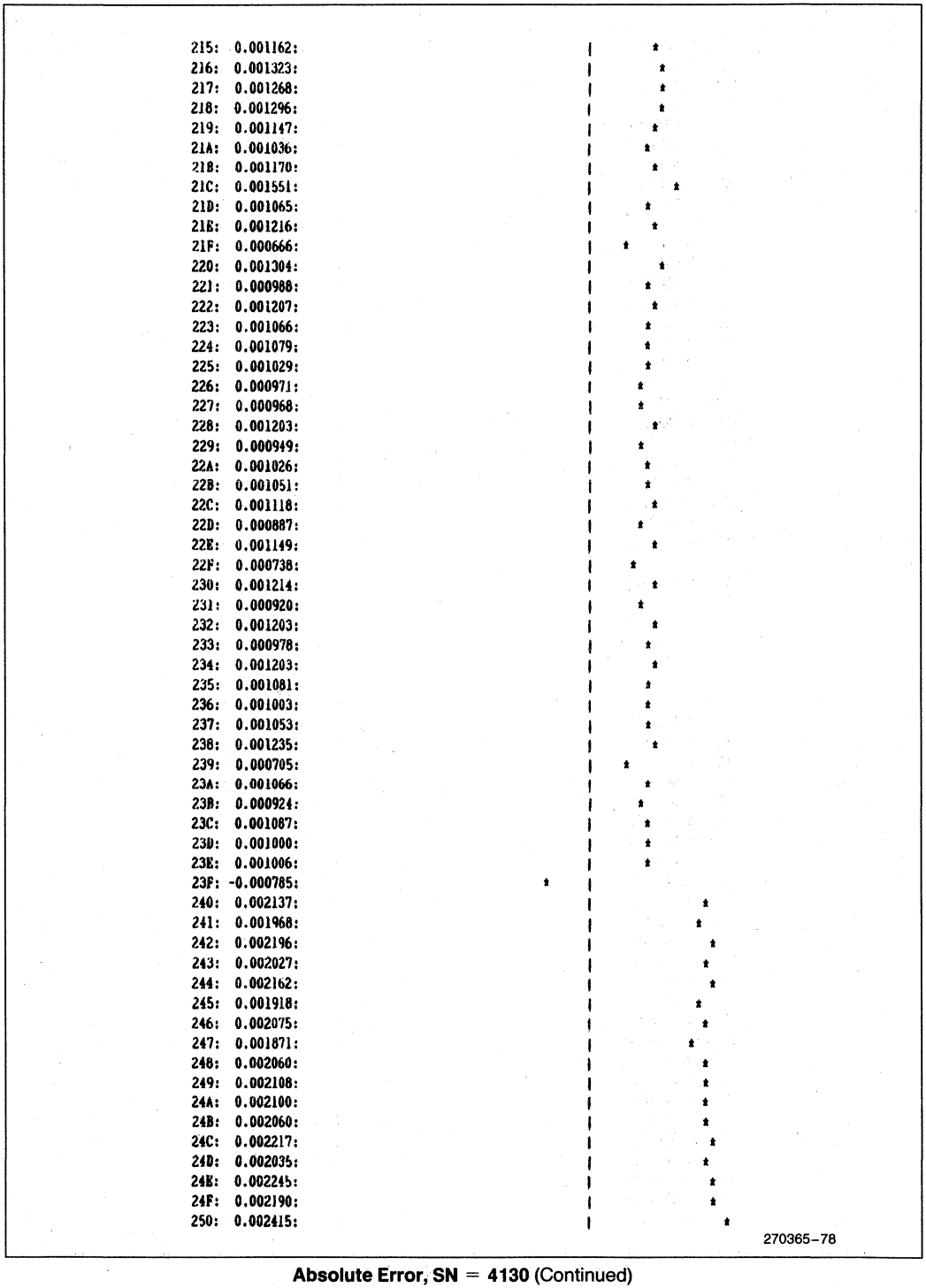
Absolute Error, SN = 4130 (Continued)



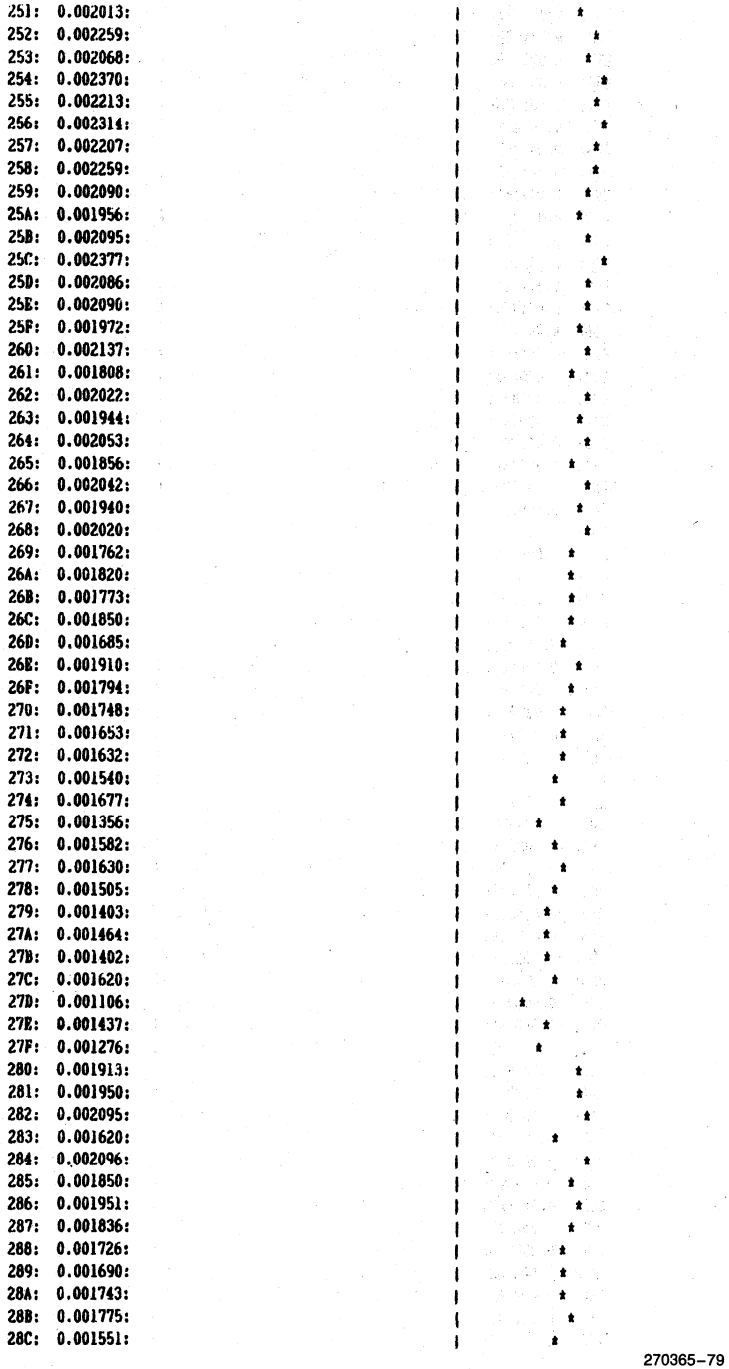
270365-77

Absolute Error, SN = 4130 (Continued)

6

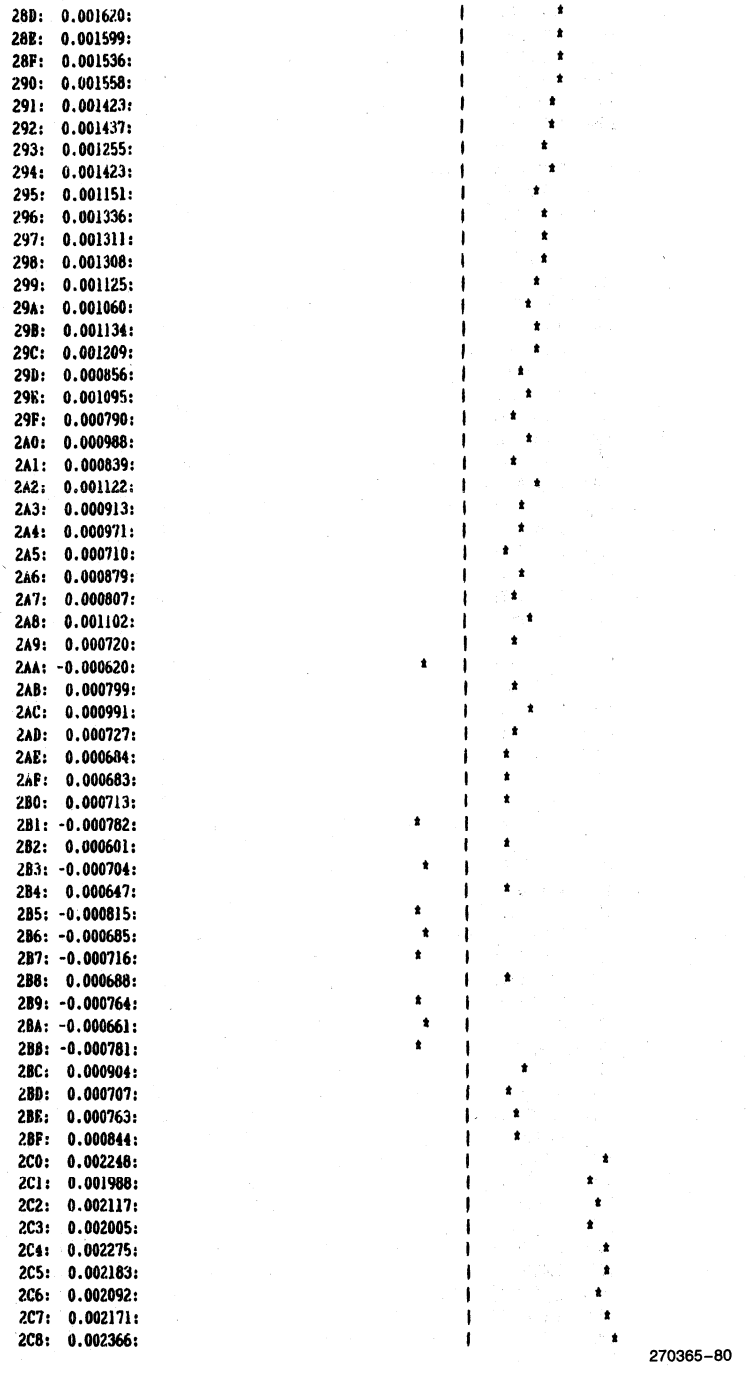


Absolute Error, SN = 4130 (Continued)

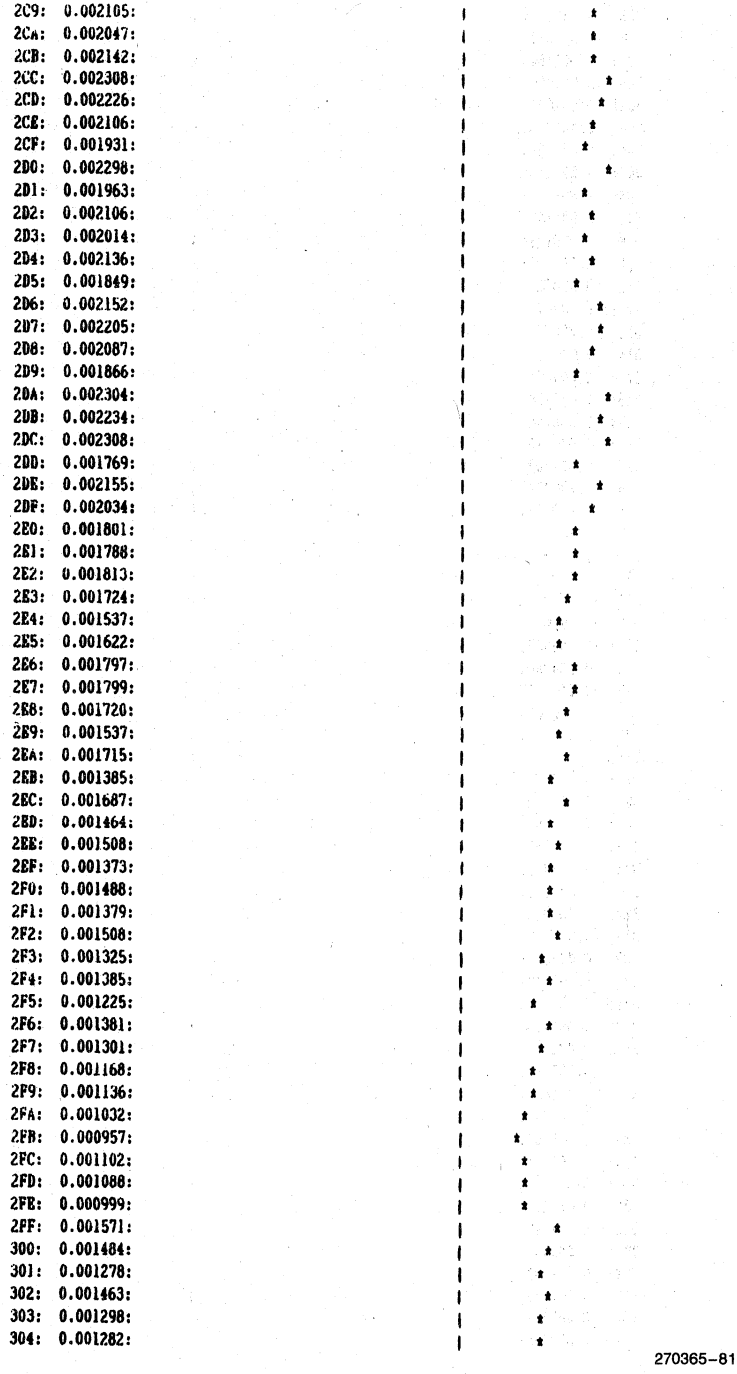


270365-79

Absolute Error, SN = 4130 (Continued)

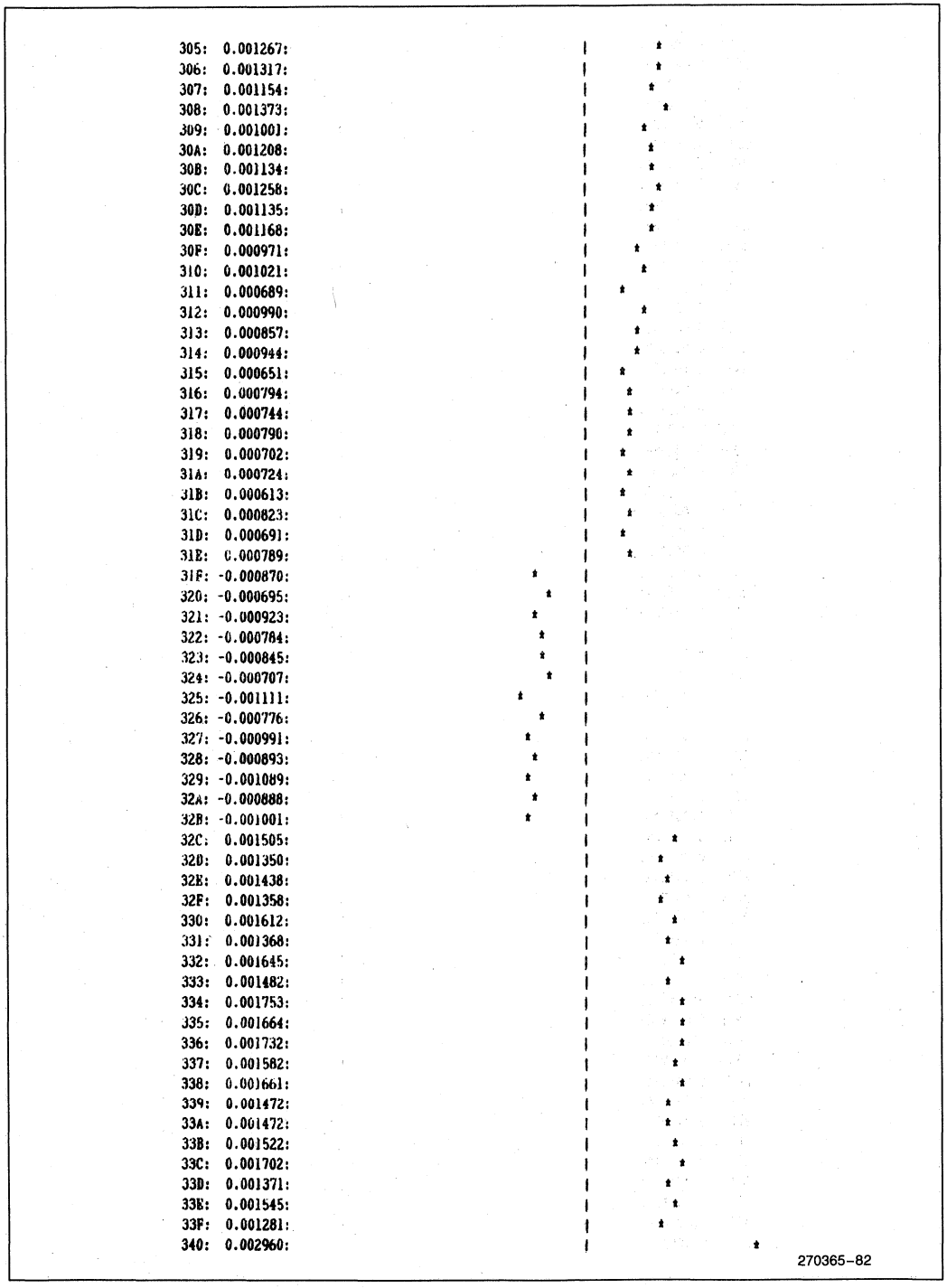


Absolute Error, SN = 4130 (Continued)



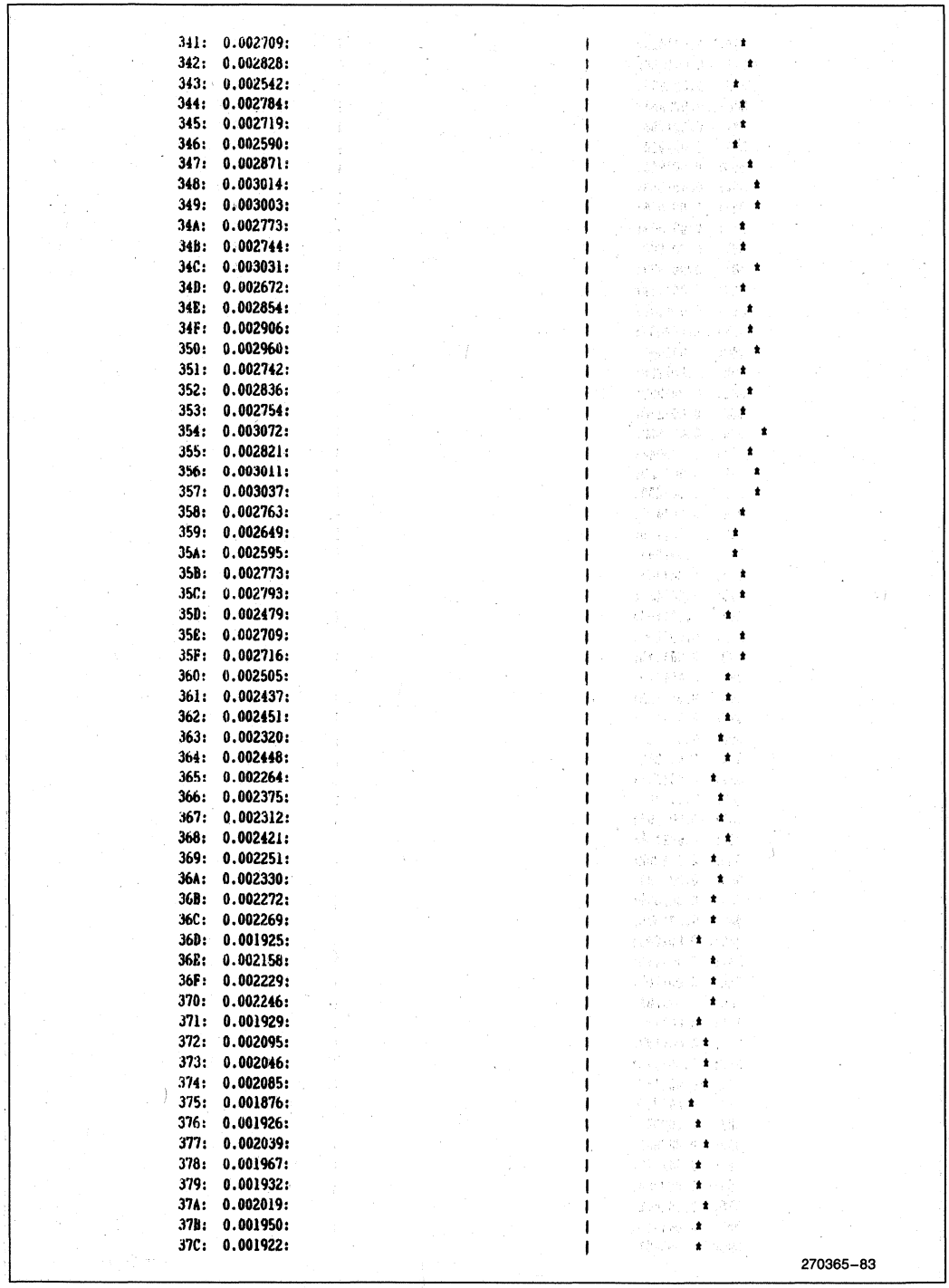
270365-81

Absolute Error, SN = 4130 (Continued)



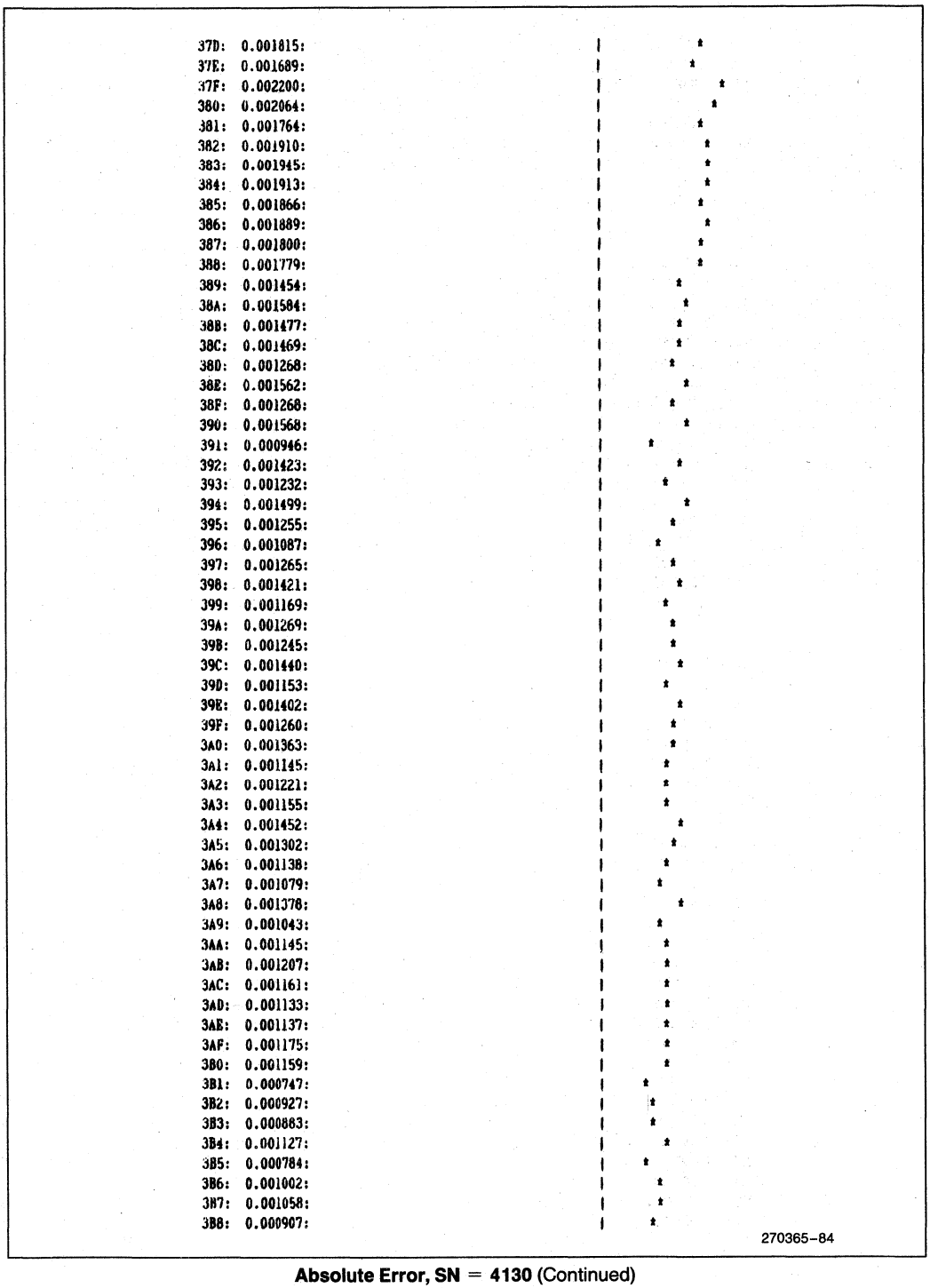
270365-82

Absolute Error, SN = 4130 (Continued)

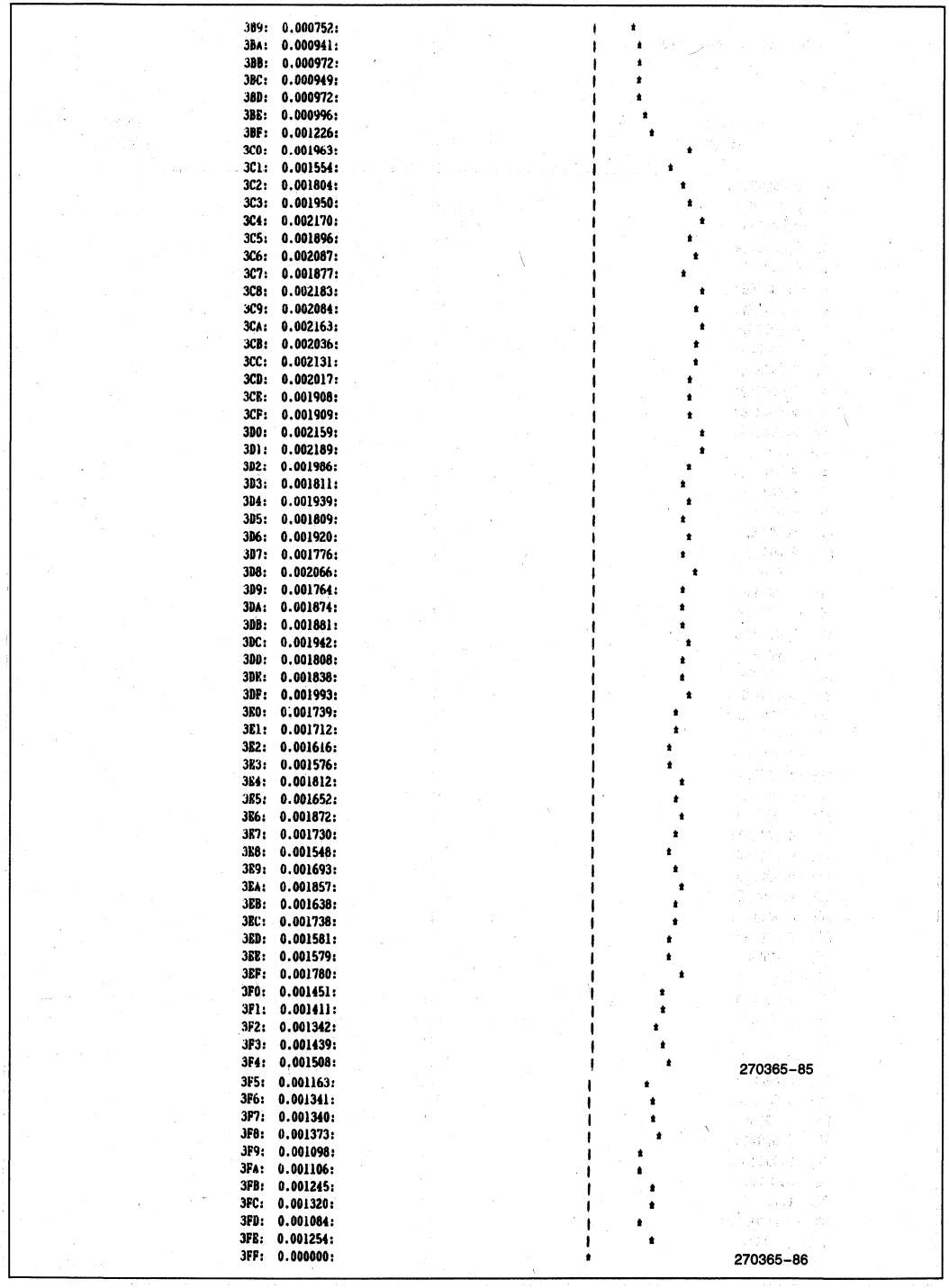


Absolute Error, SN = 4130 (Continued)

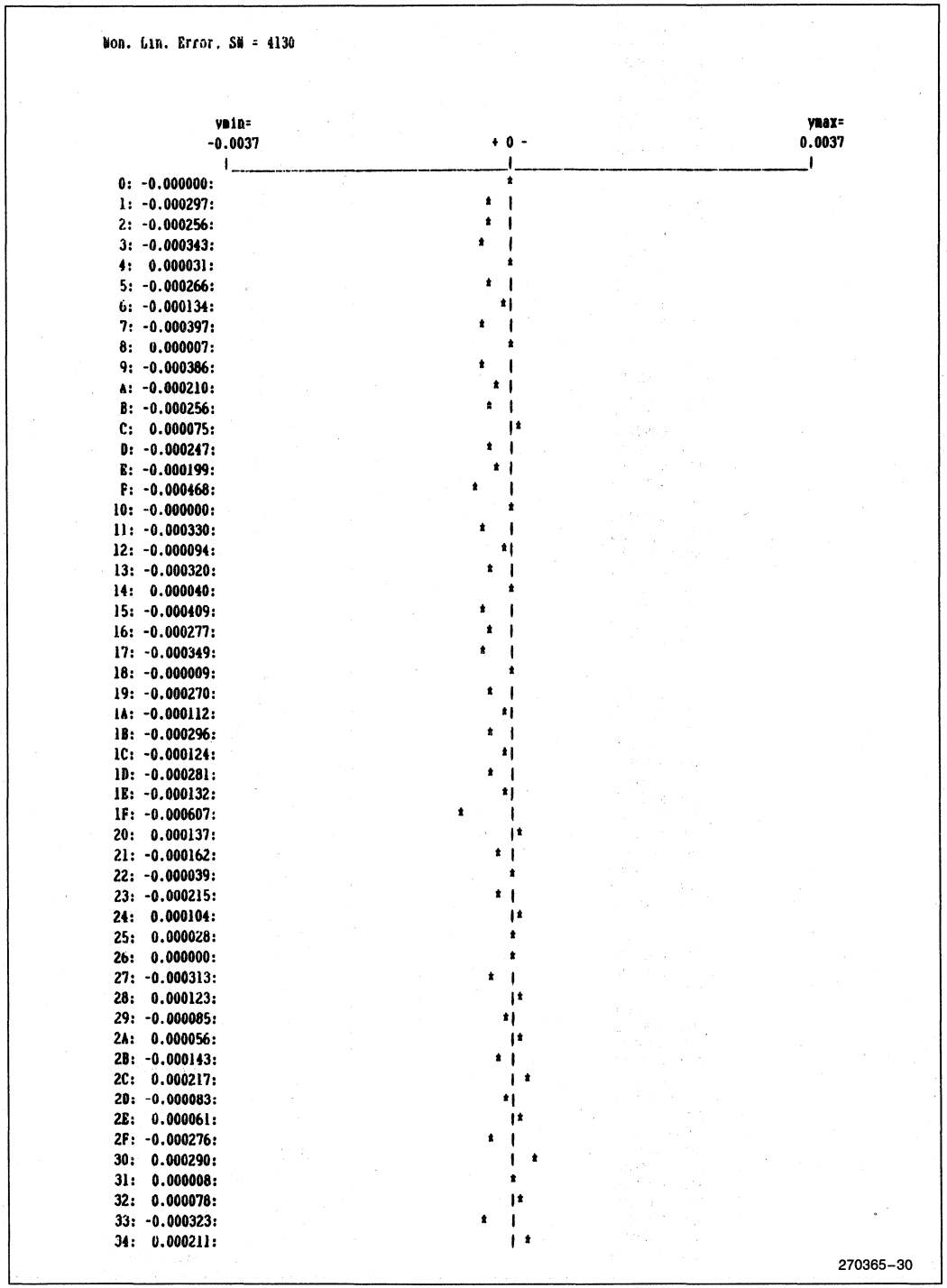
6



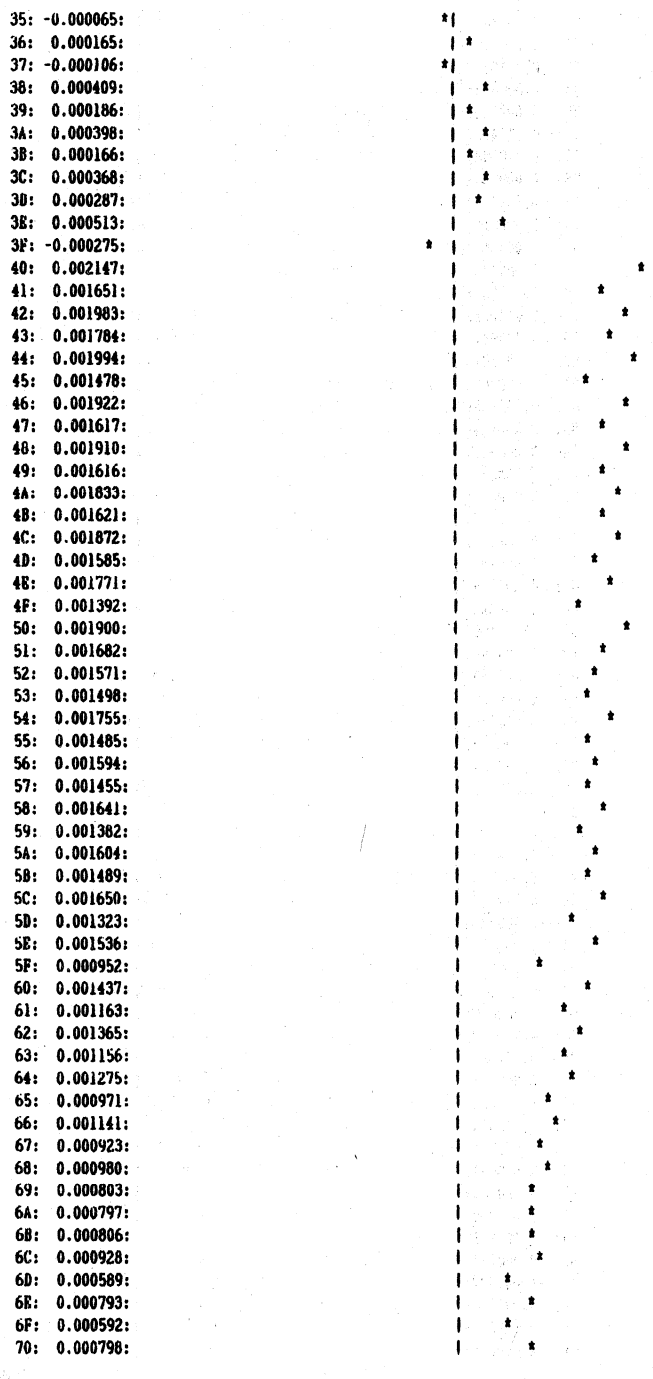
Absolute Error, SN = 4130 (Continued)



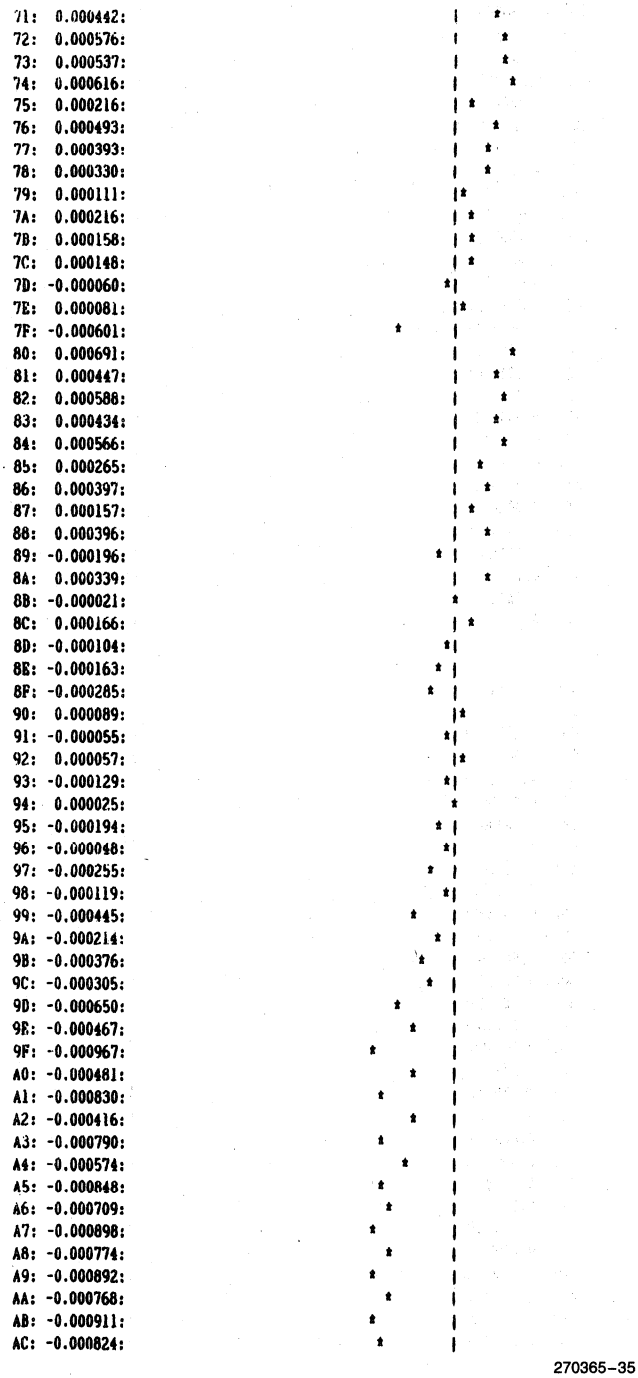
Absolute Error, SN = 4130 (Continued)



Non. Lin. Error, SN = 4130

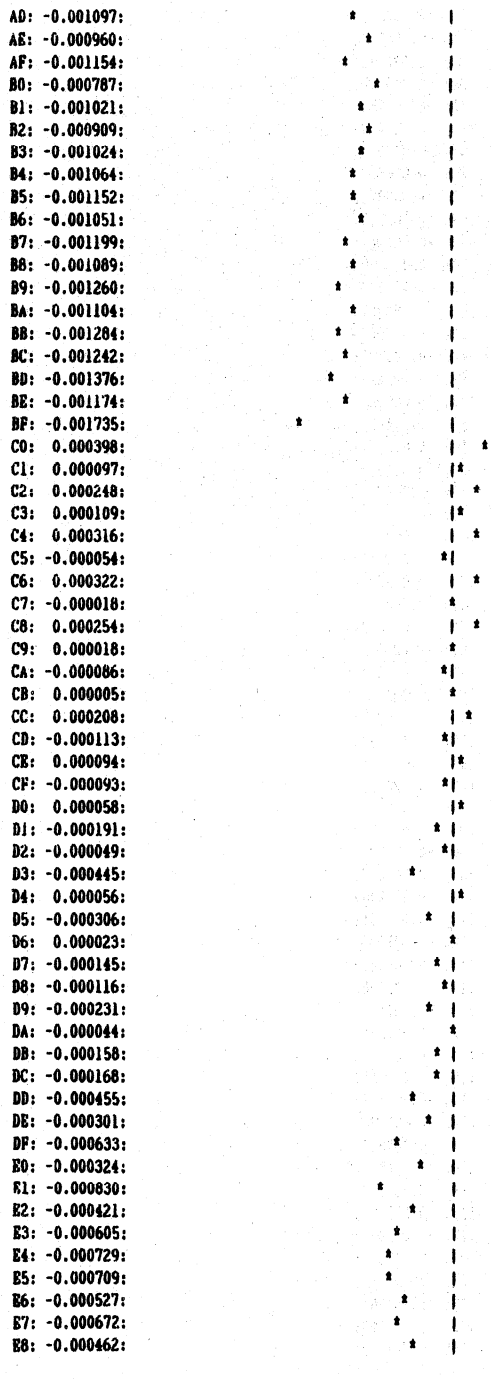


Non. Lin. Error, SN = 4130 (Continued)



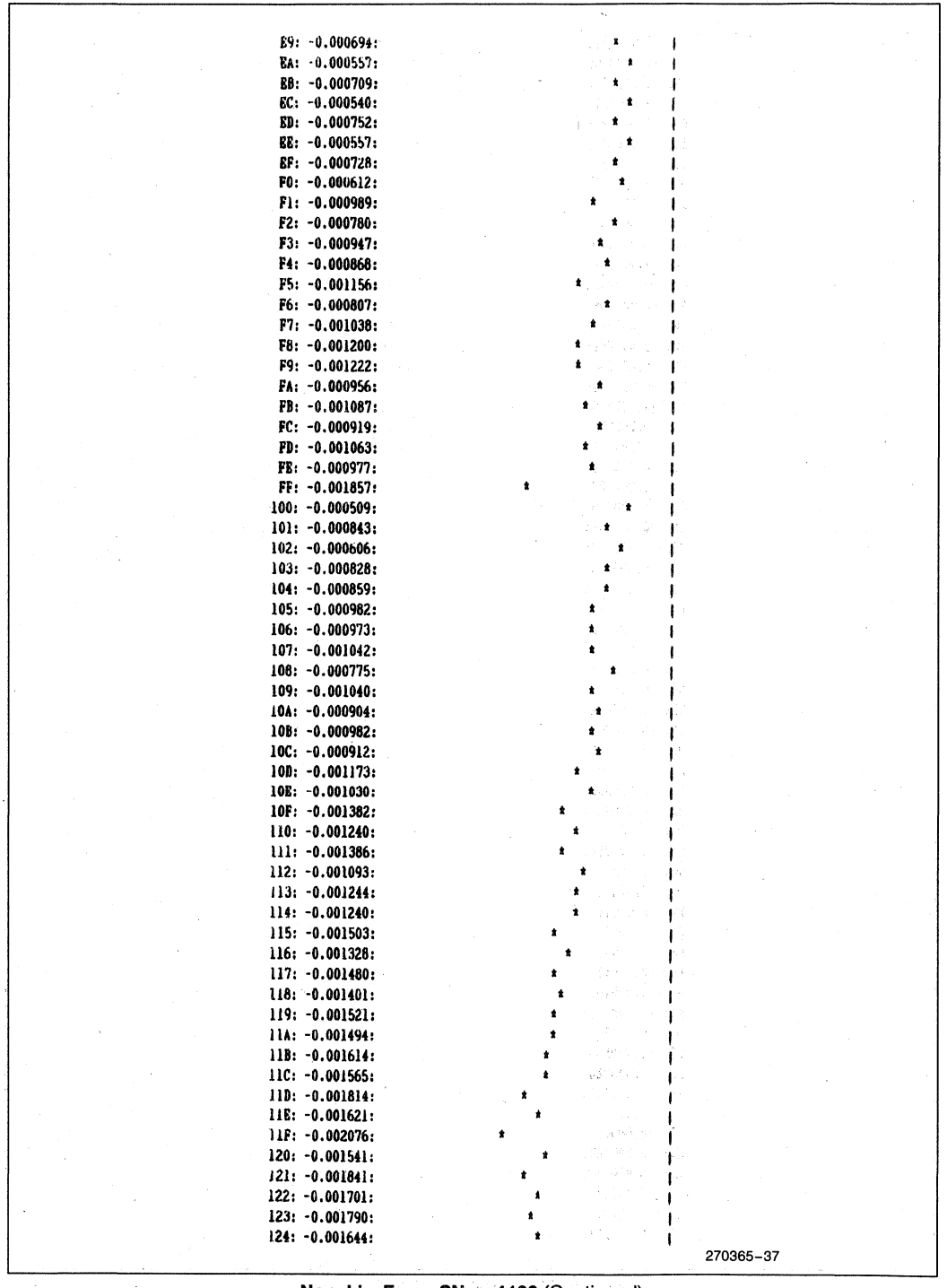
270365-35

Non. Lin. Error, SN = 4130 (Continued)



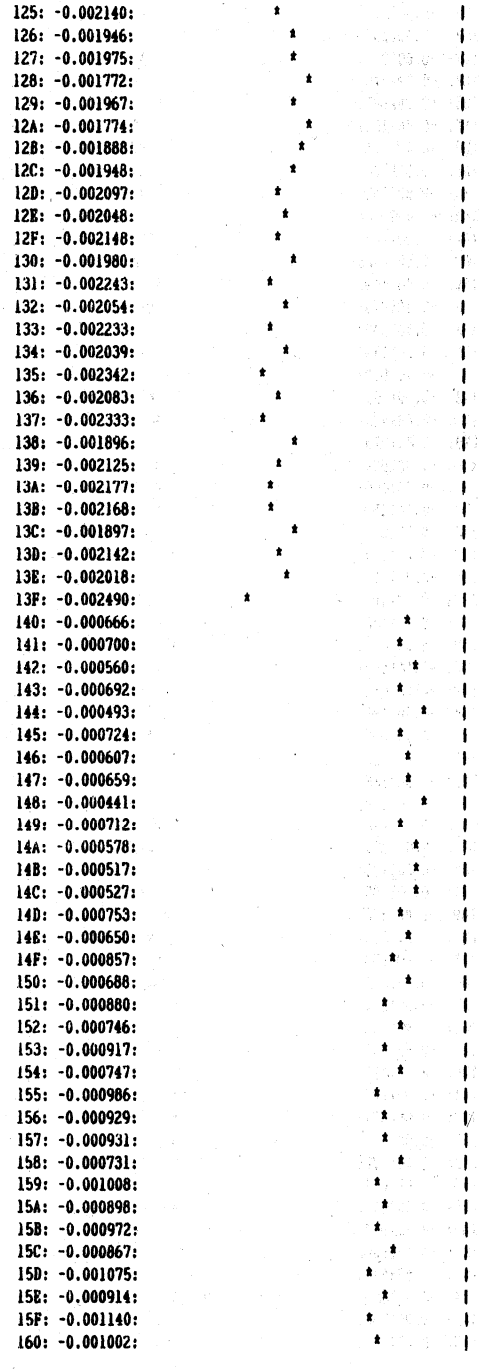
270365-36

Non. Lin. Error, SN = 4130 (Continued)



270365-37

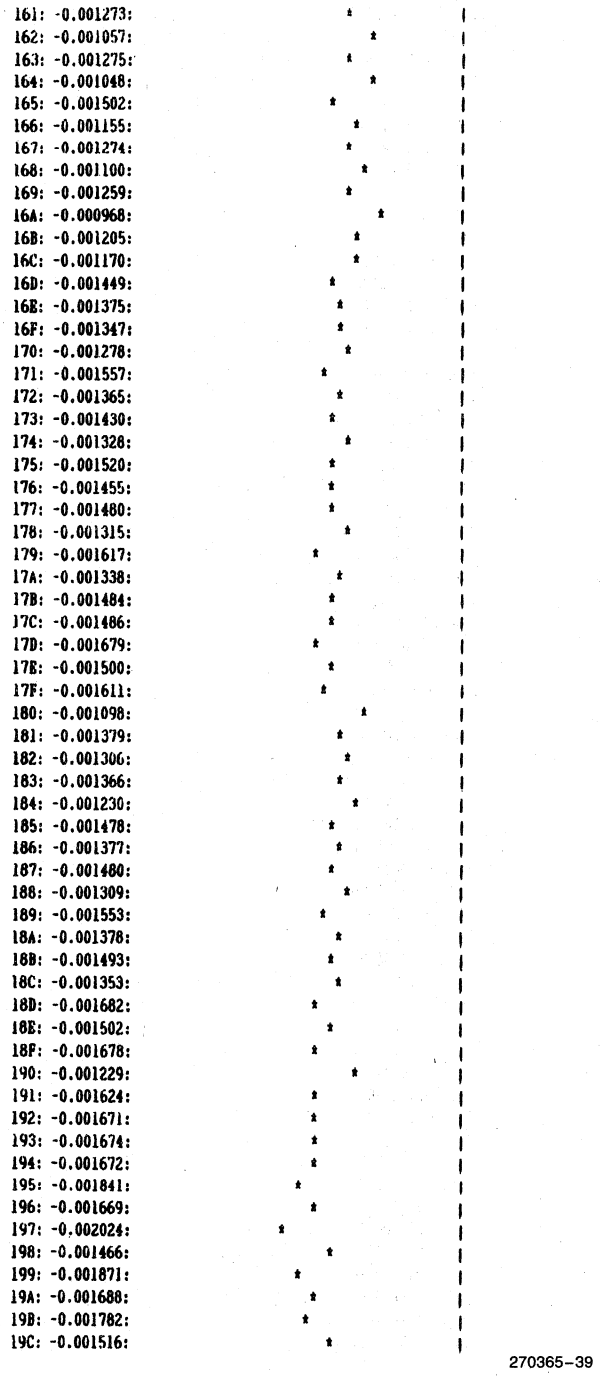
Non. Lin. Error, SN = 4130 (Continued)



270365-38

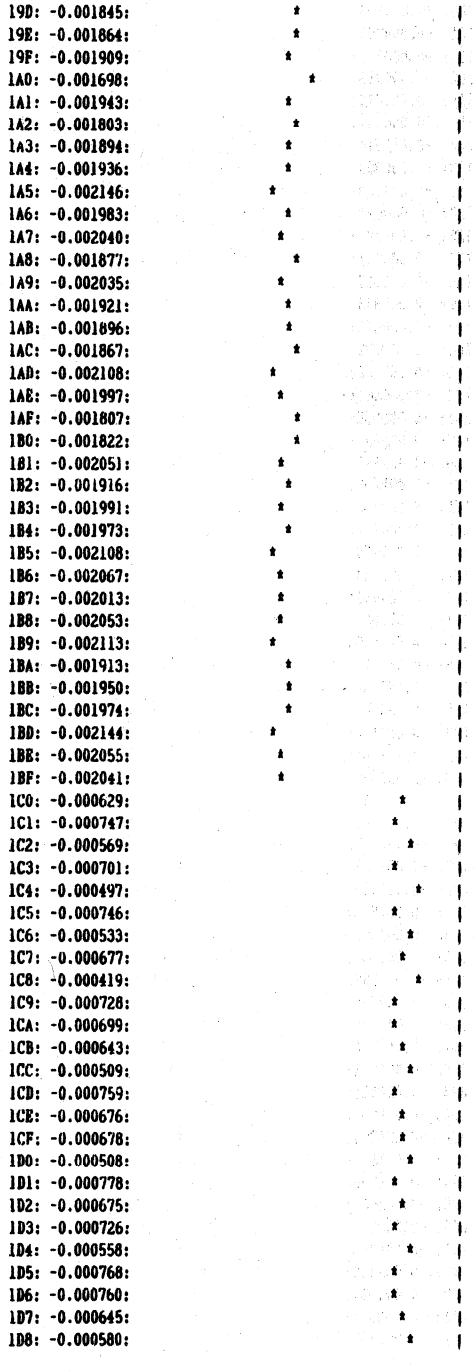
Non. Lin. Error, SN = 4130 (Continued)

6



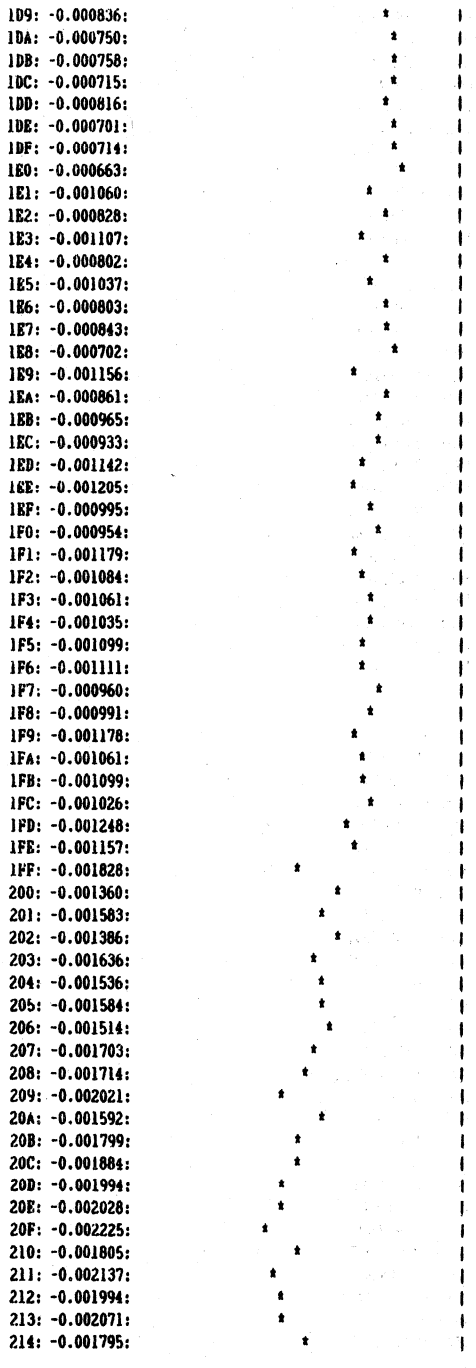
270365-39

Non. Lin. Error, SN = 4130 (Continued)



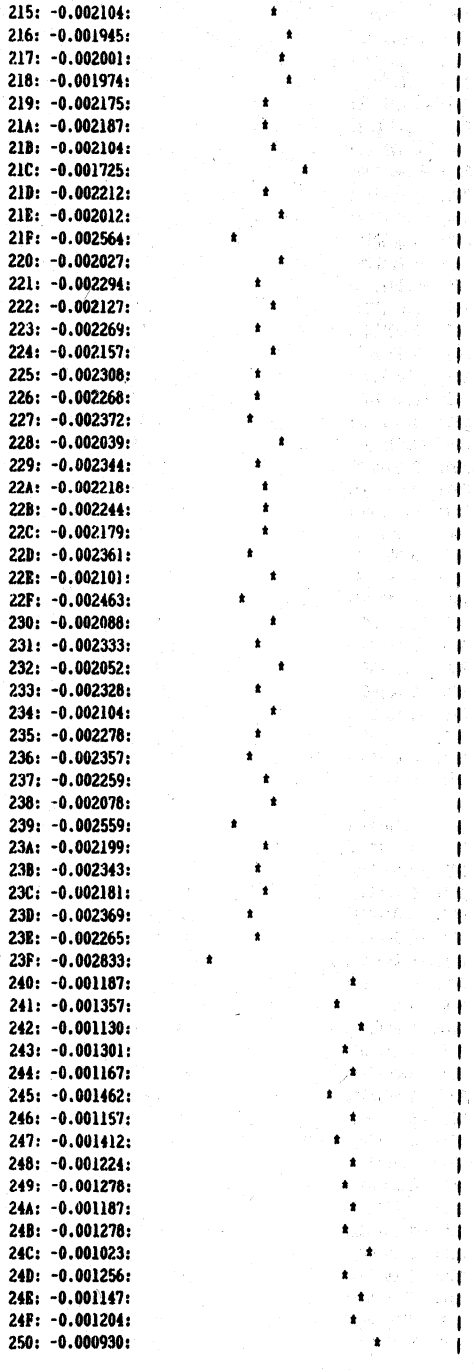
270365-40

Non. Lin. Error, SN = 4130 (Continued)



270365-41

Non. Lin. Error, SN = 4130 (Continued)



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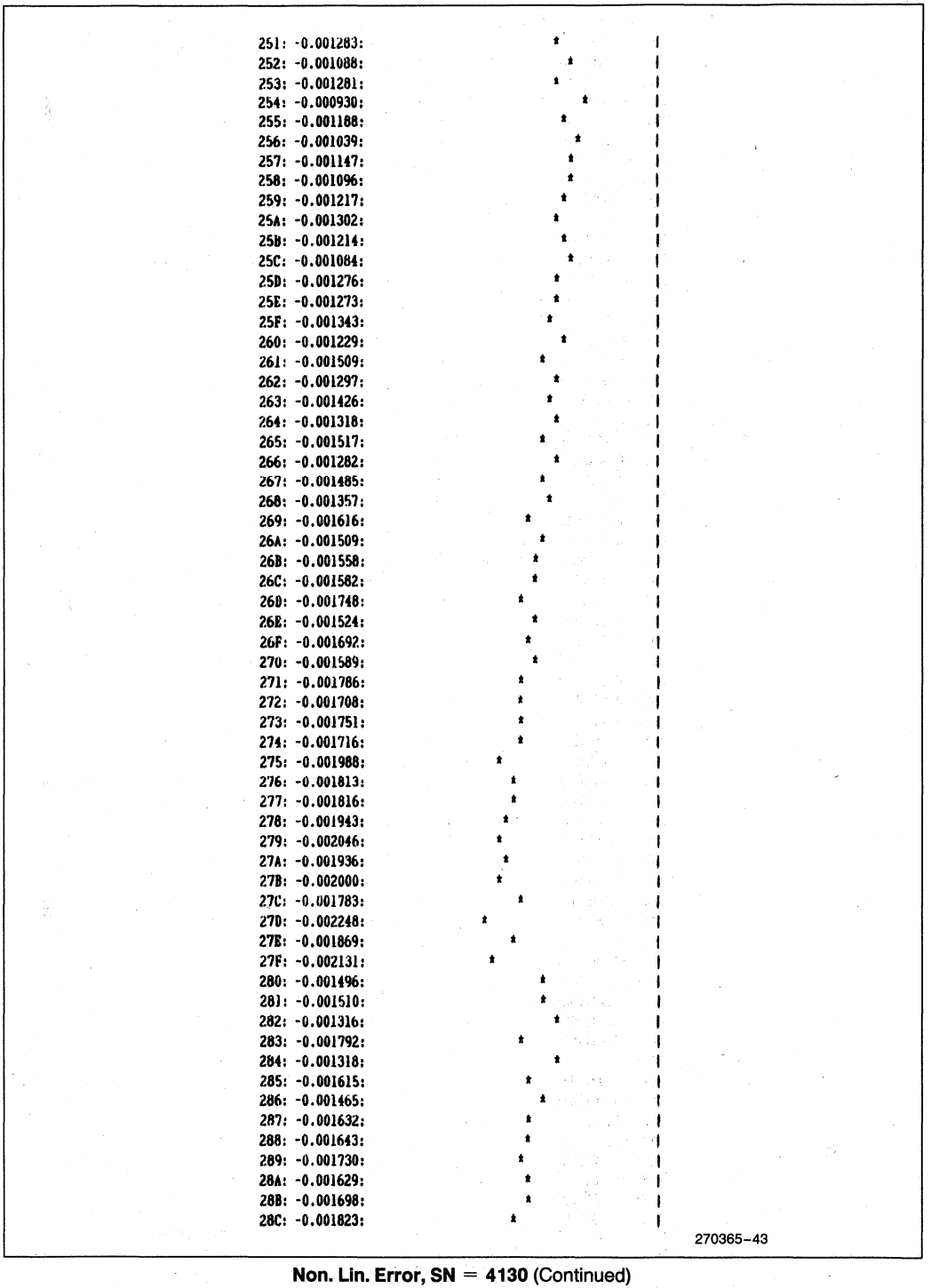

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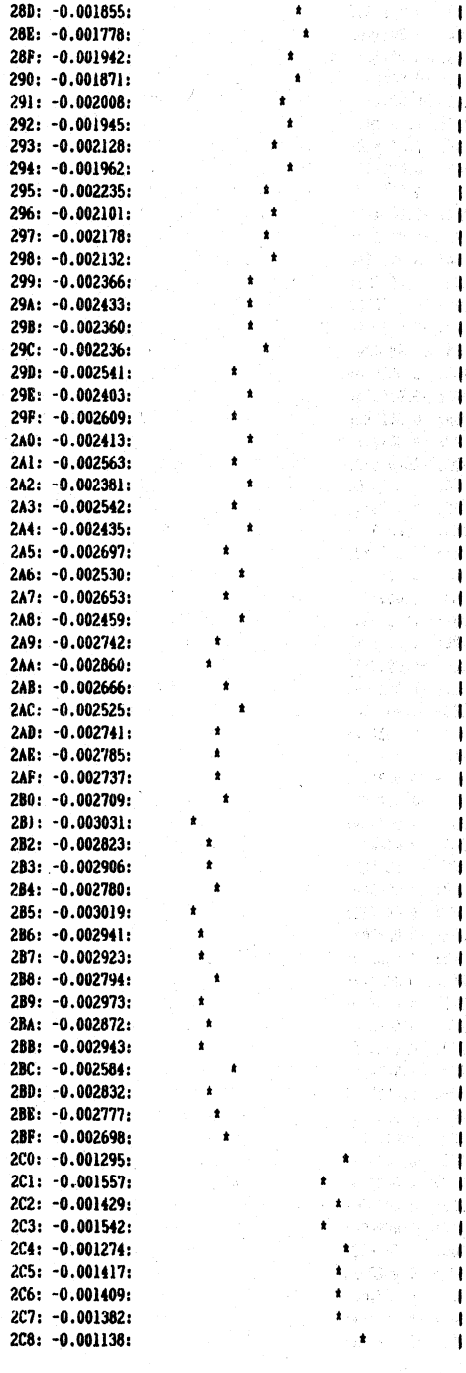

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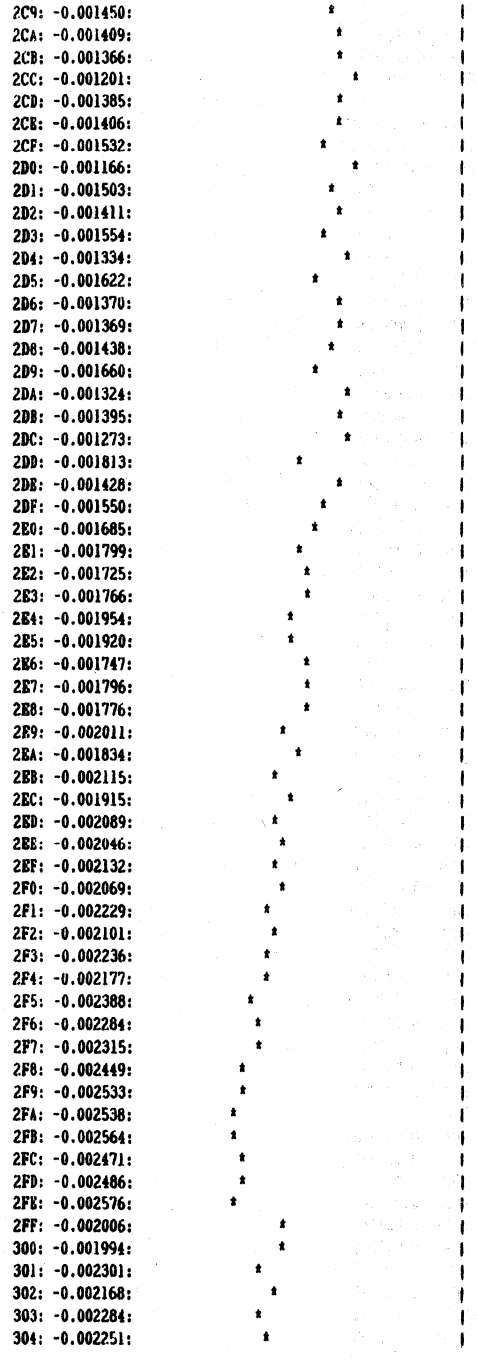

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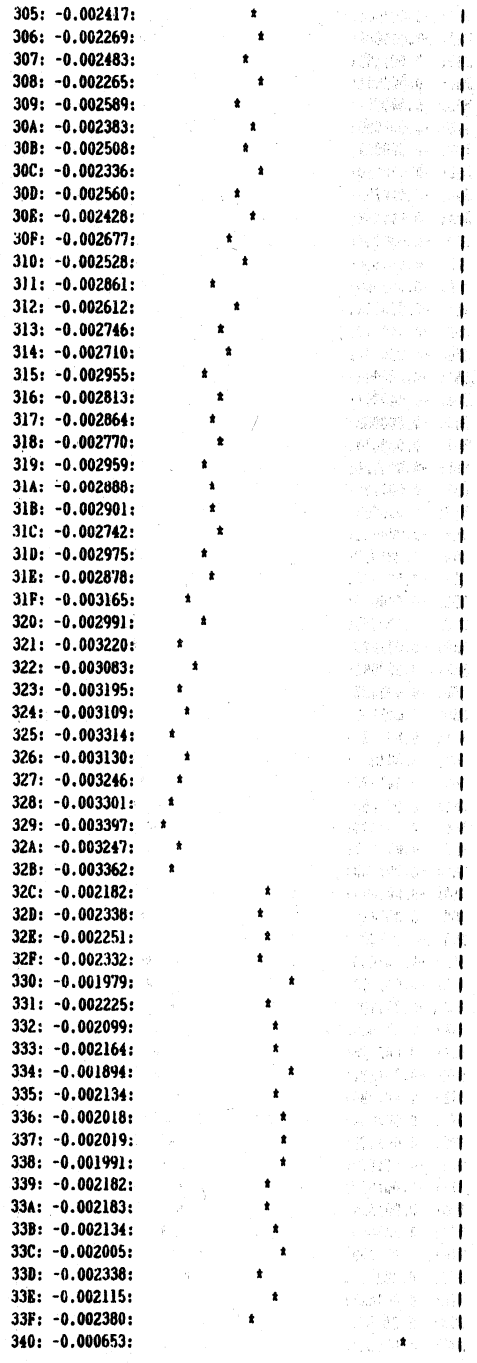

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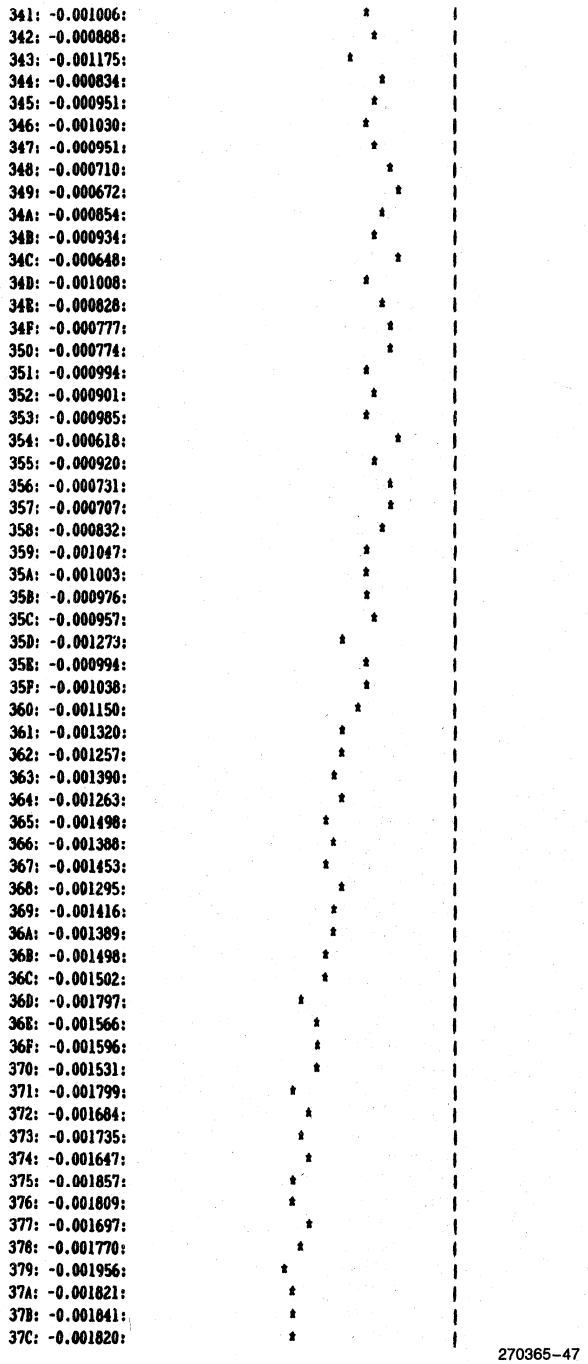

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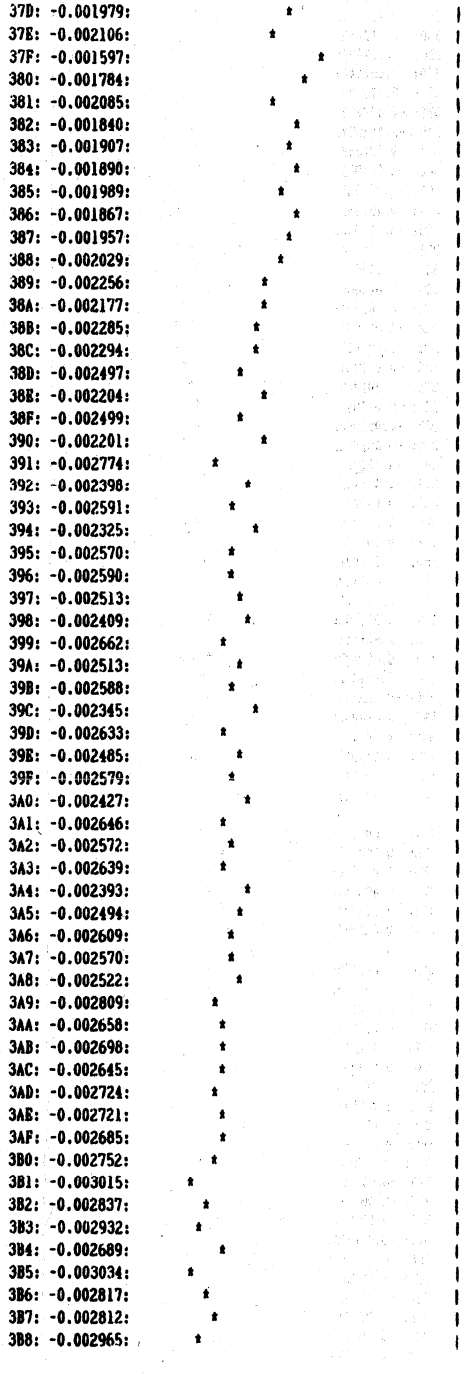

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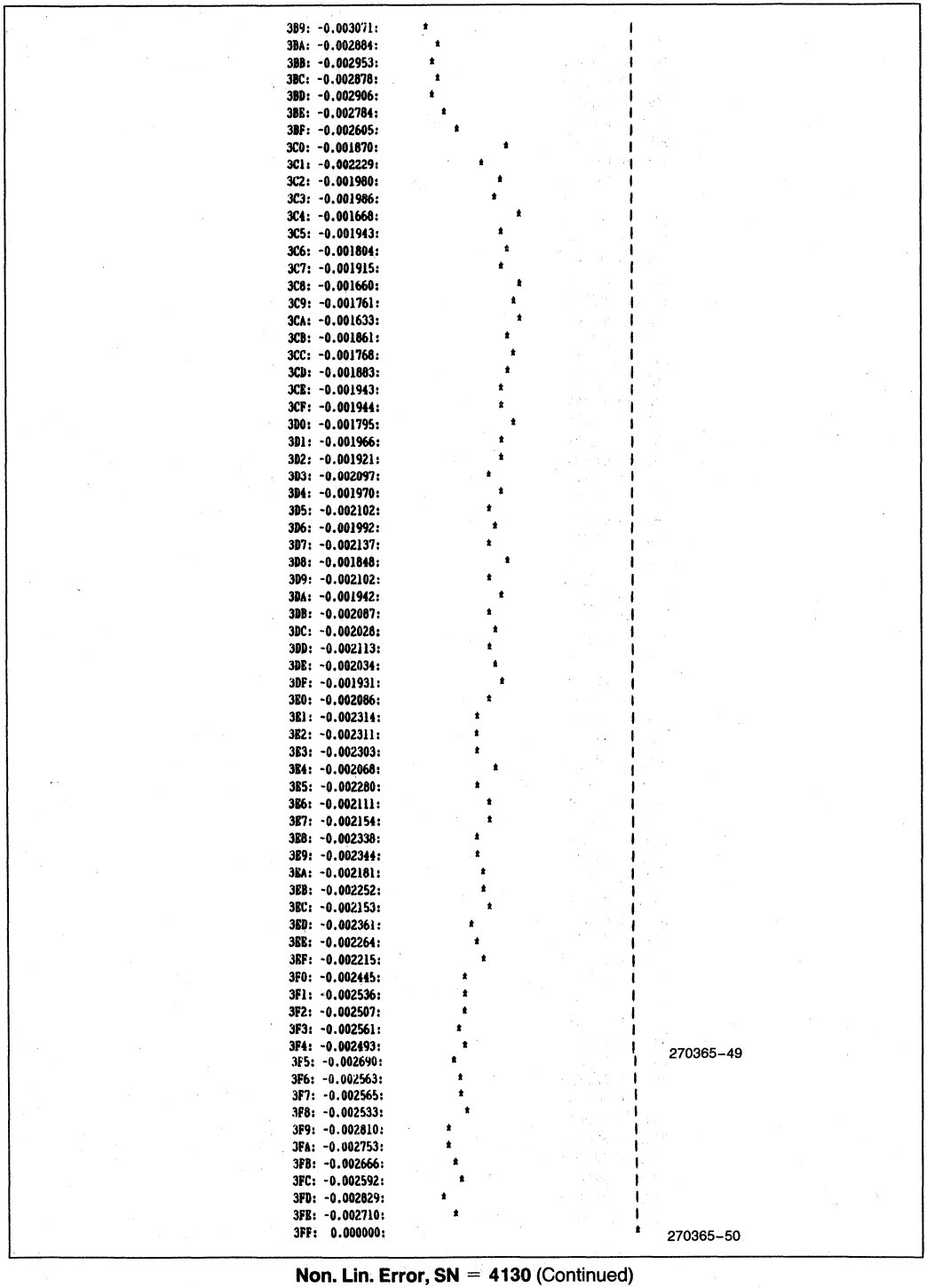

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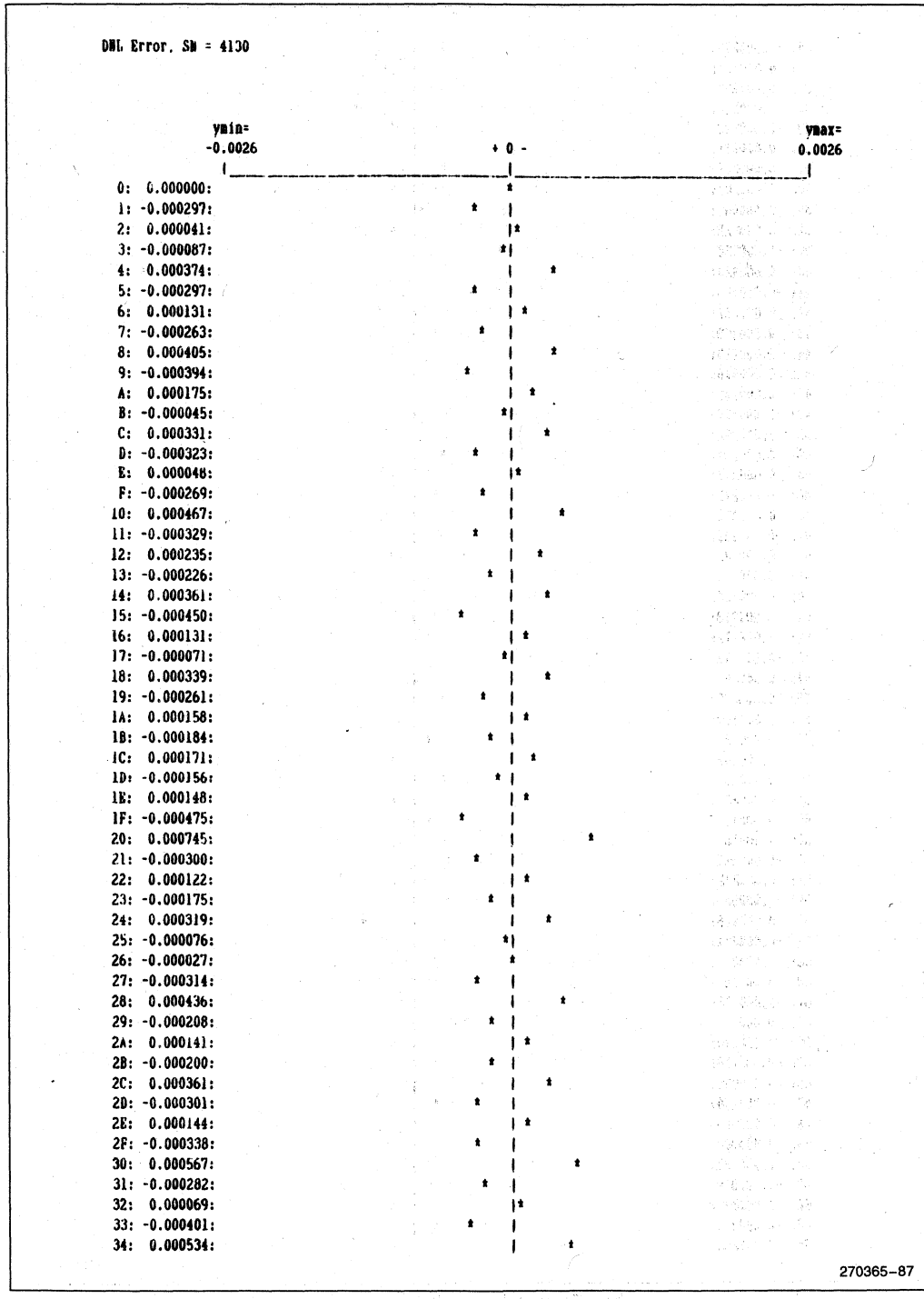

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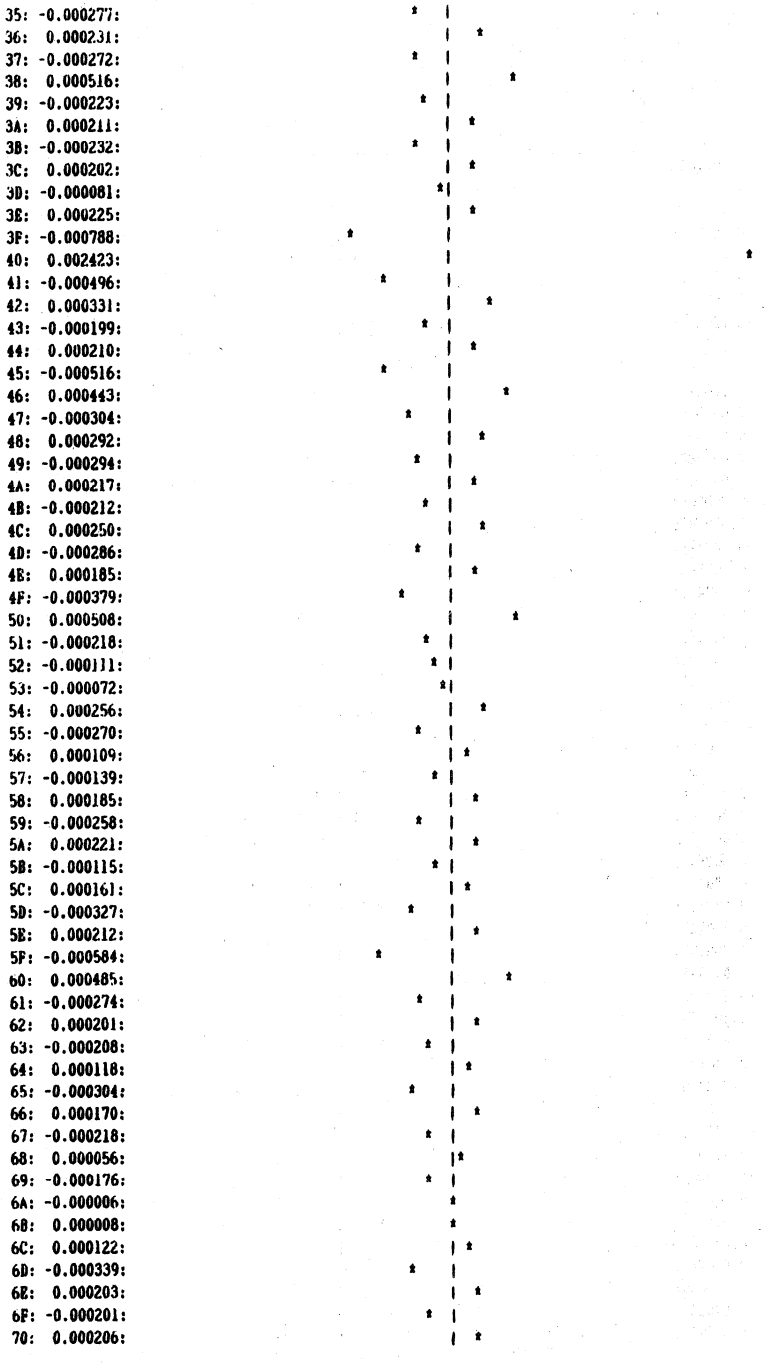

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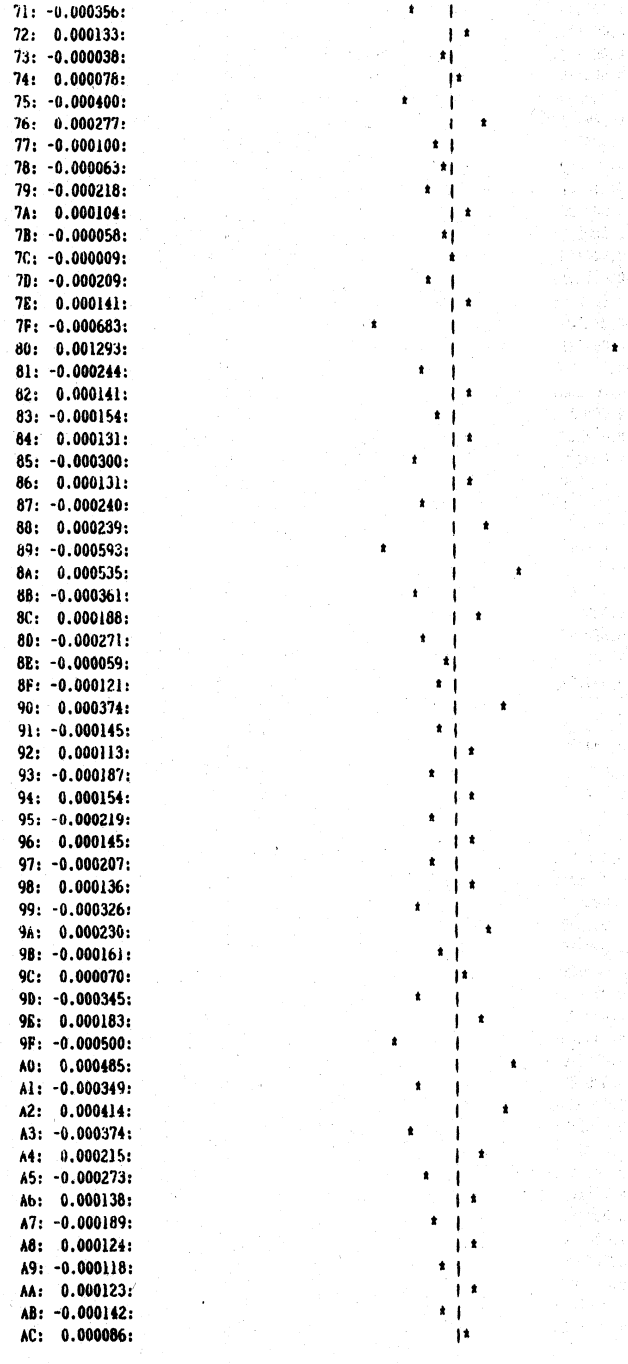

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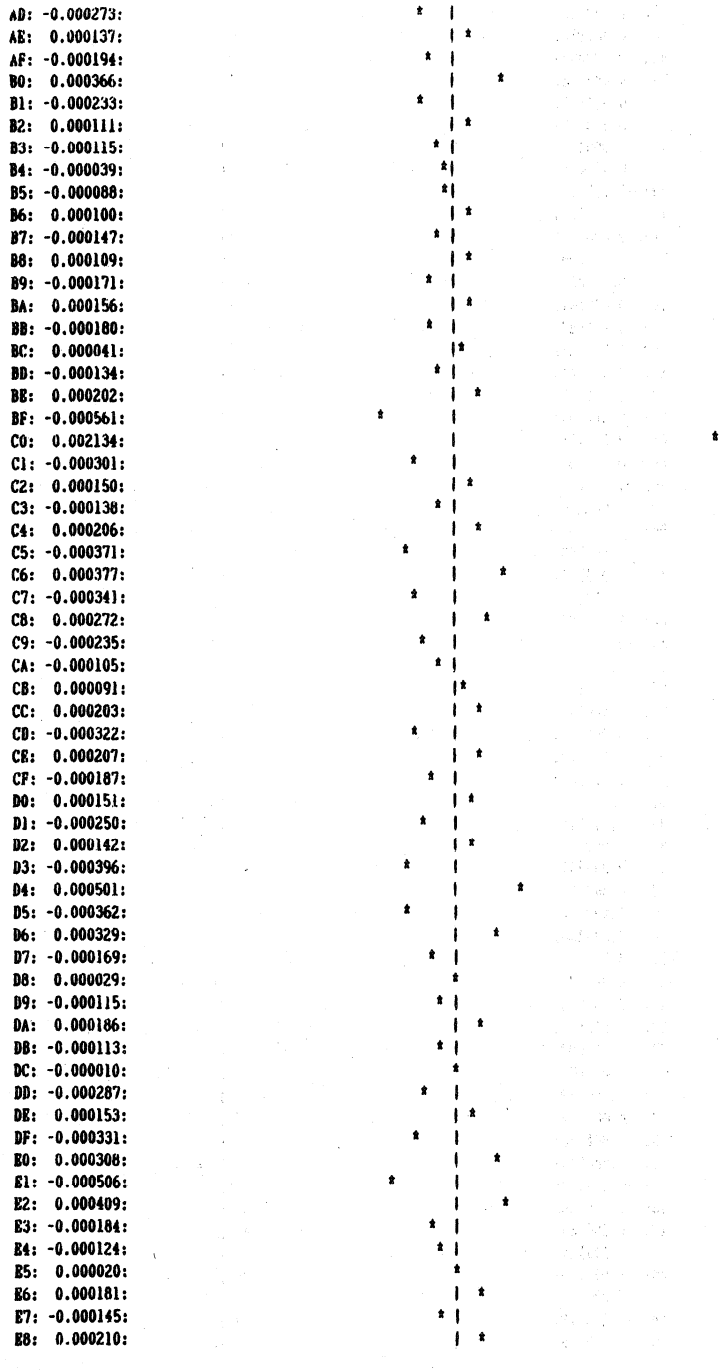

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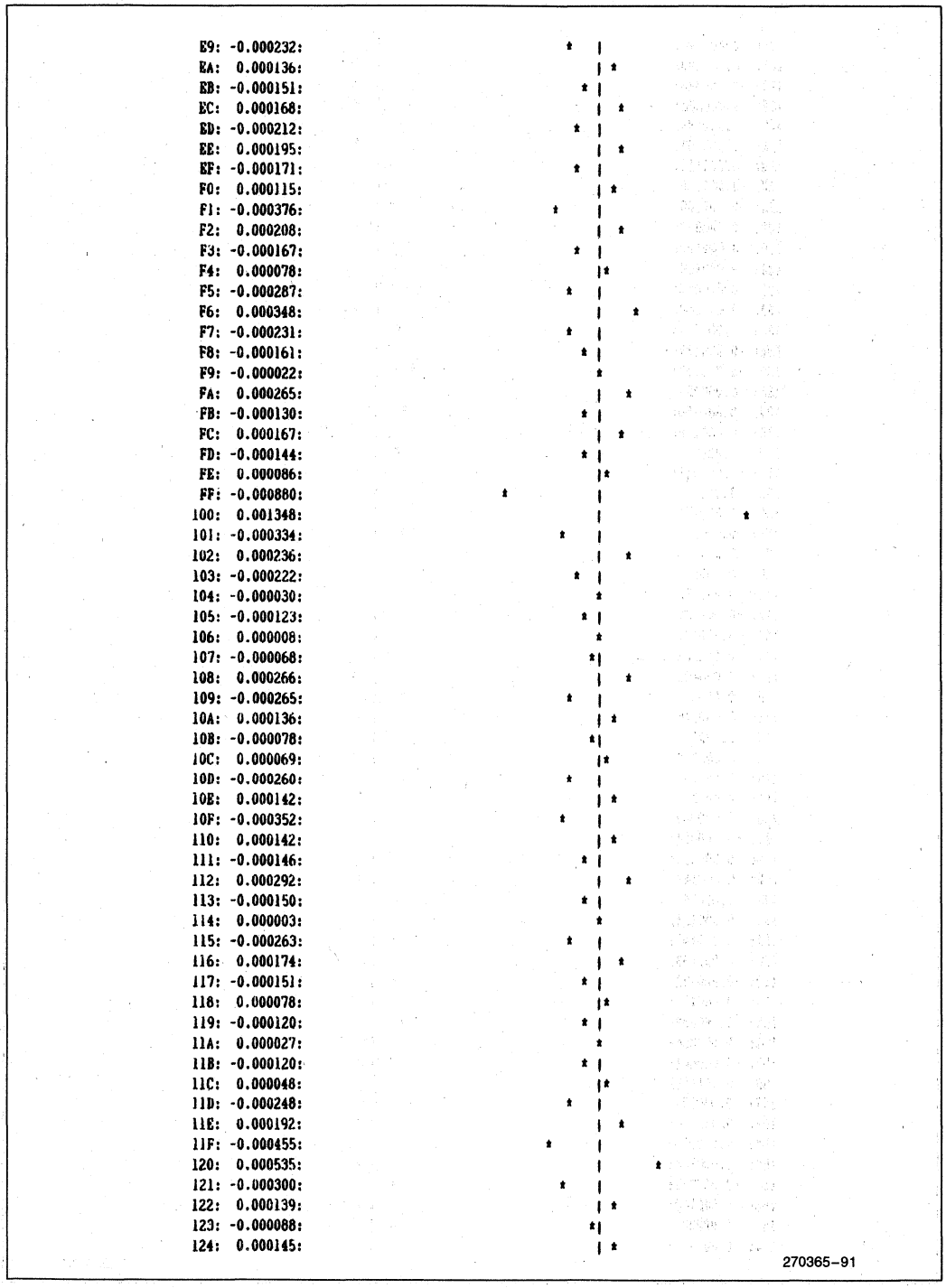

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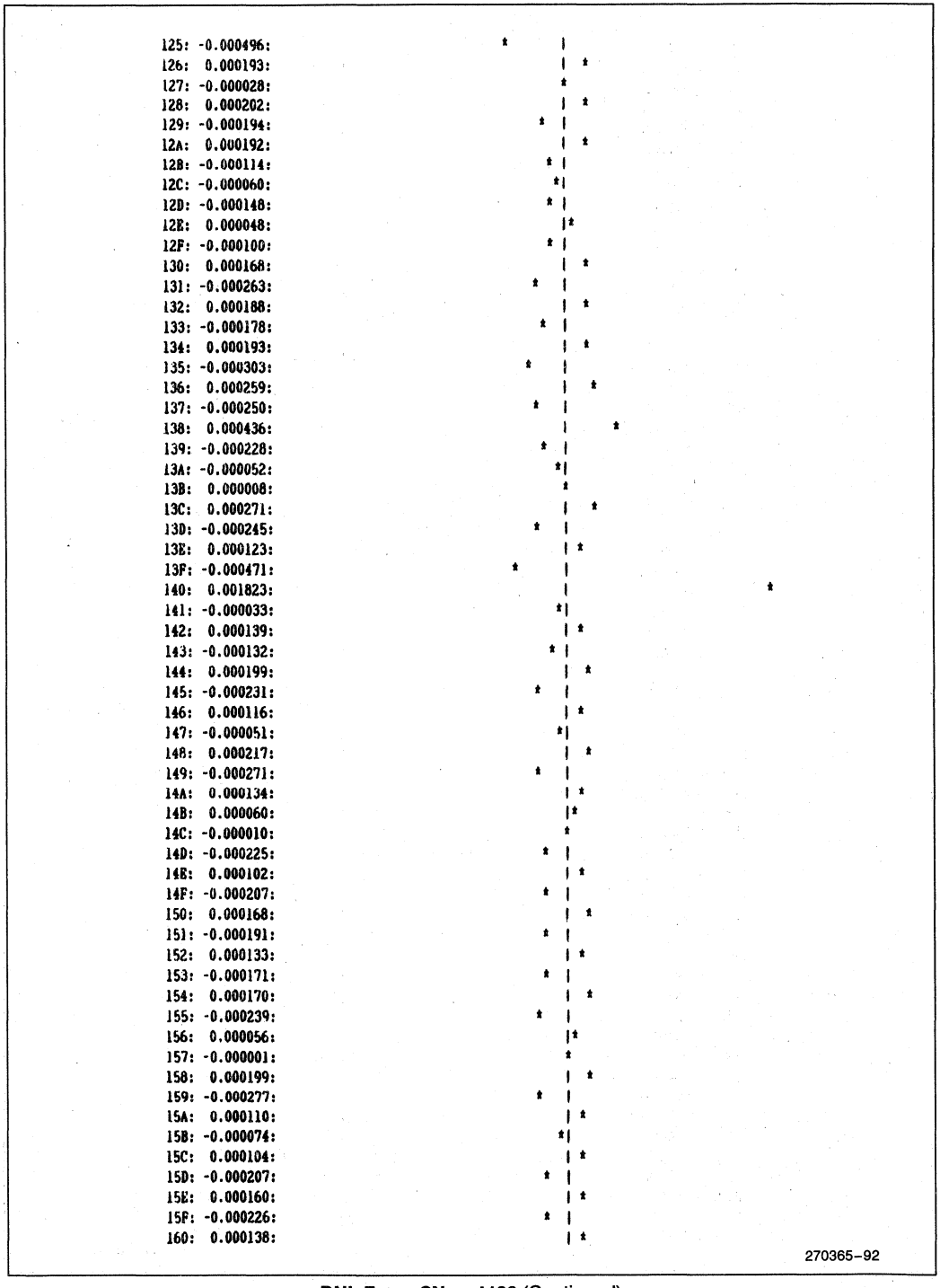

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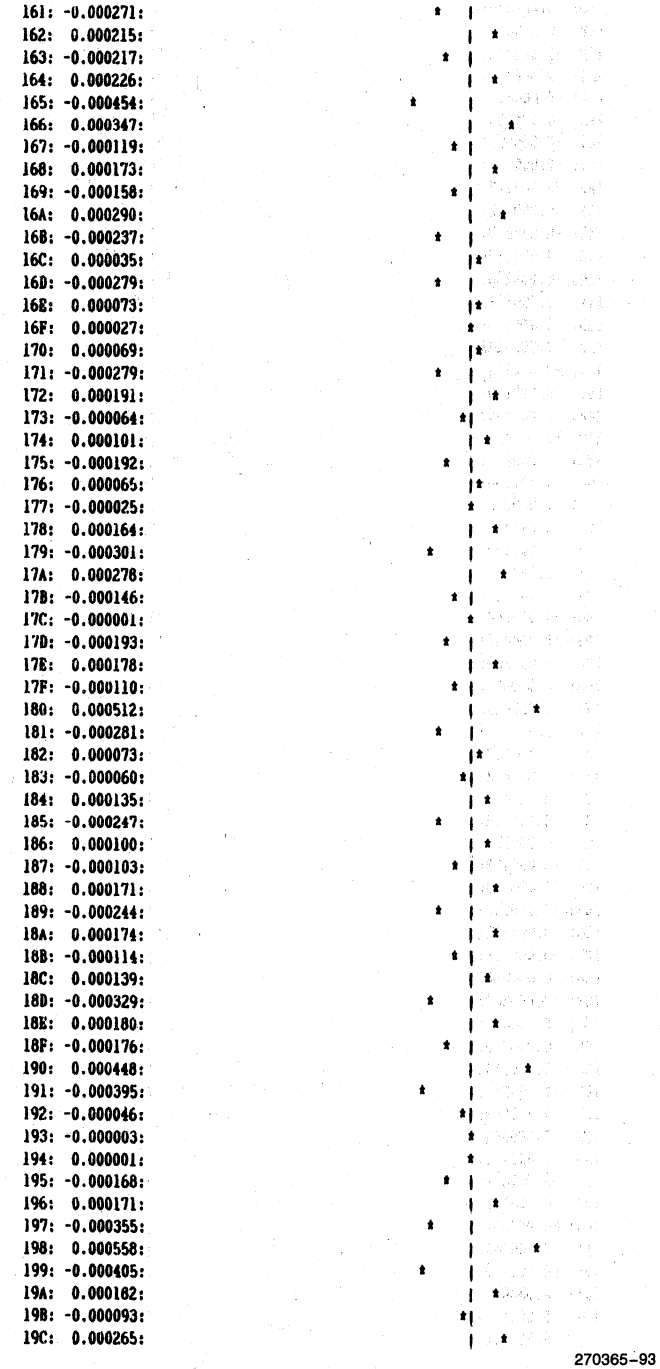

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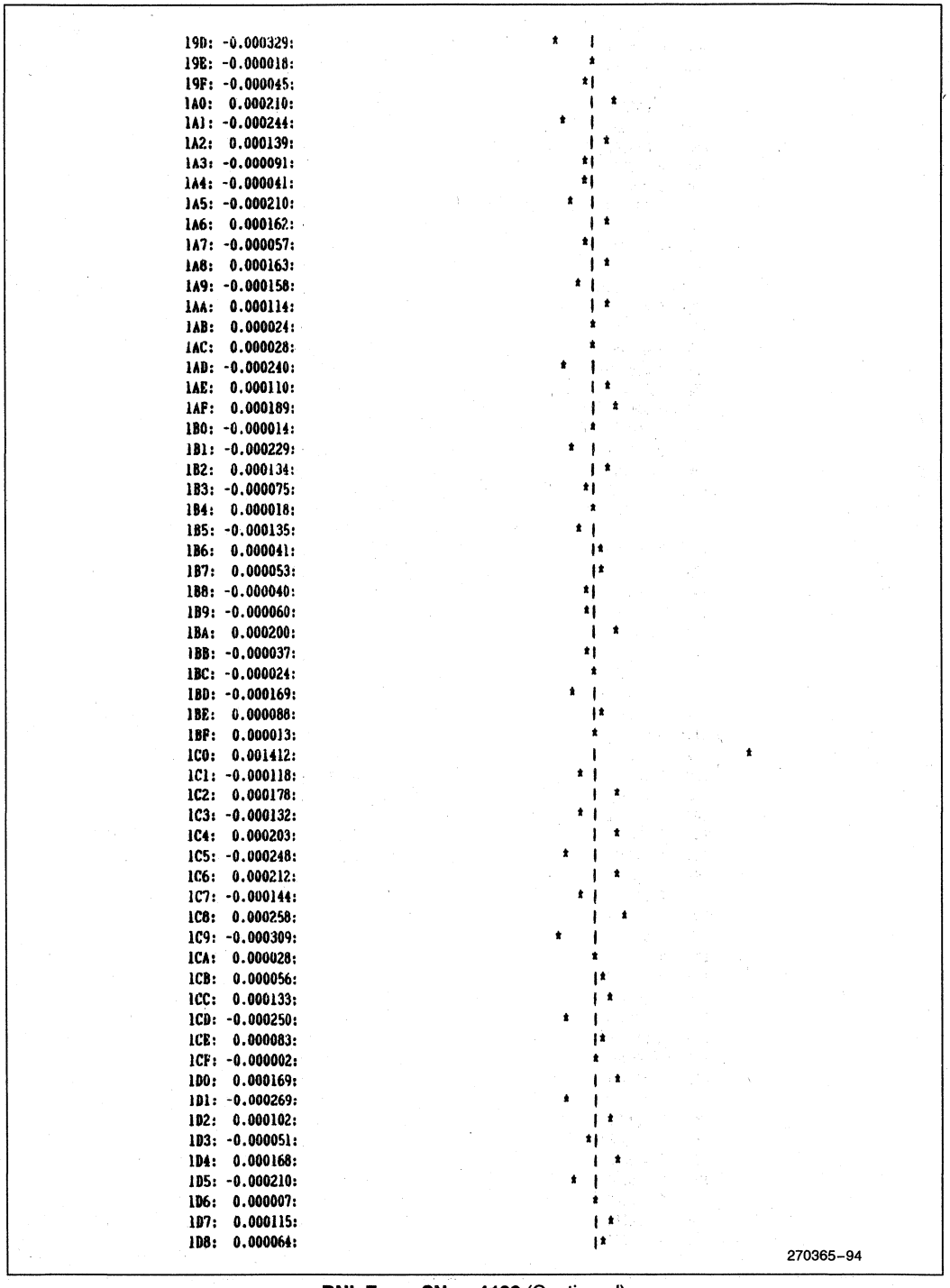

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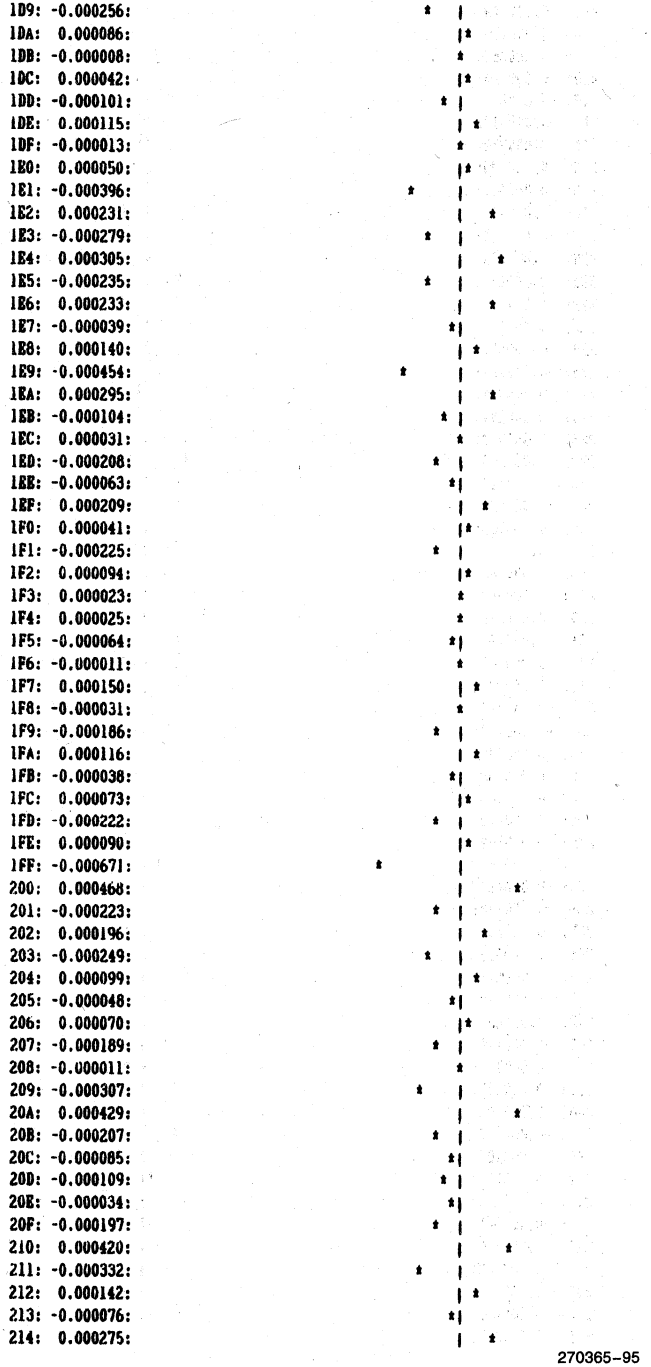

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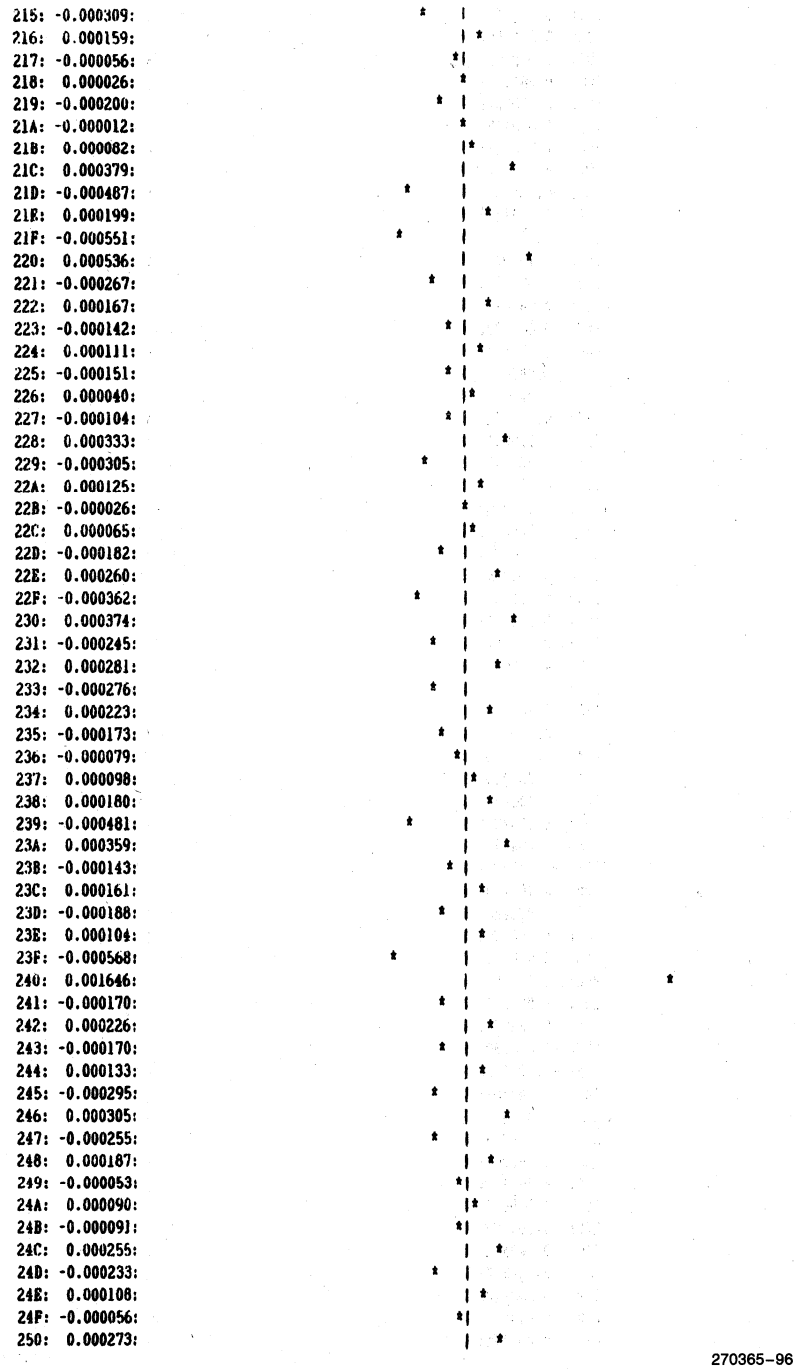

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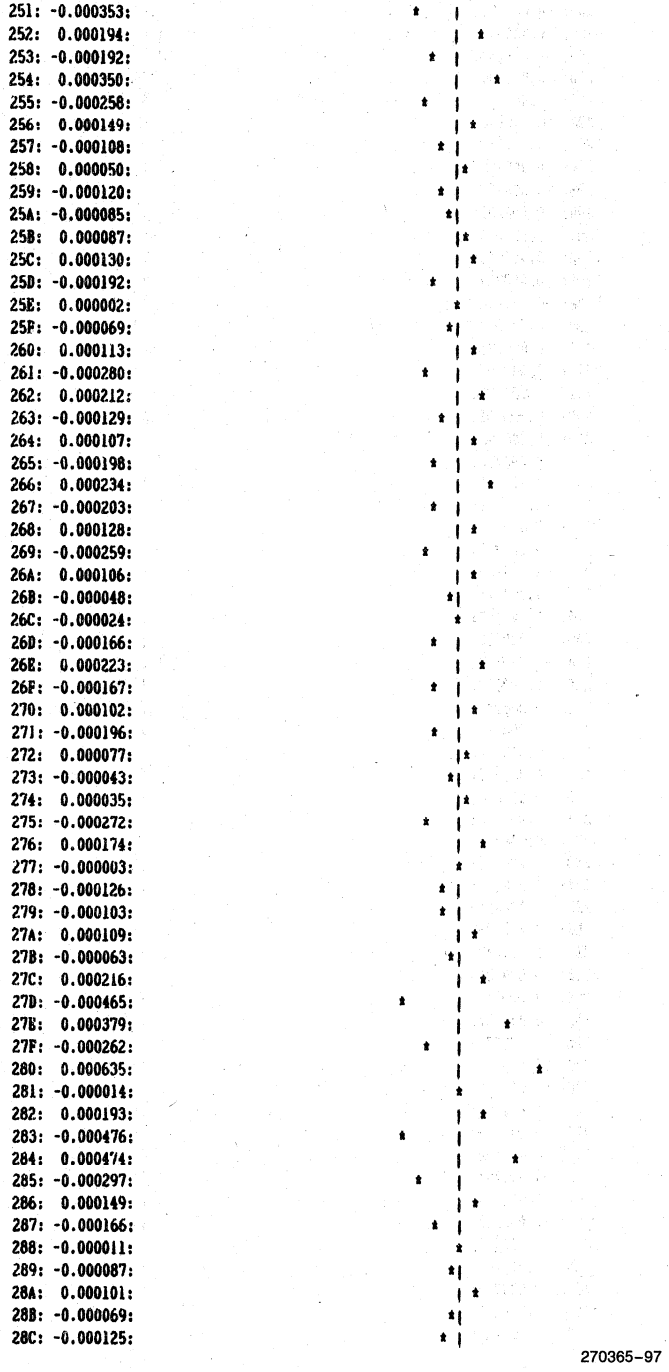

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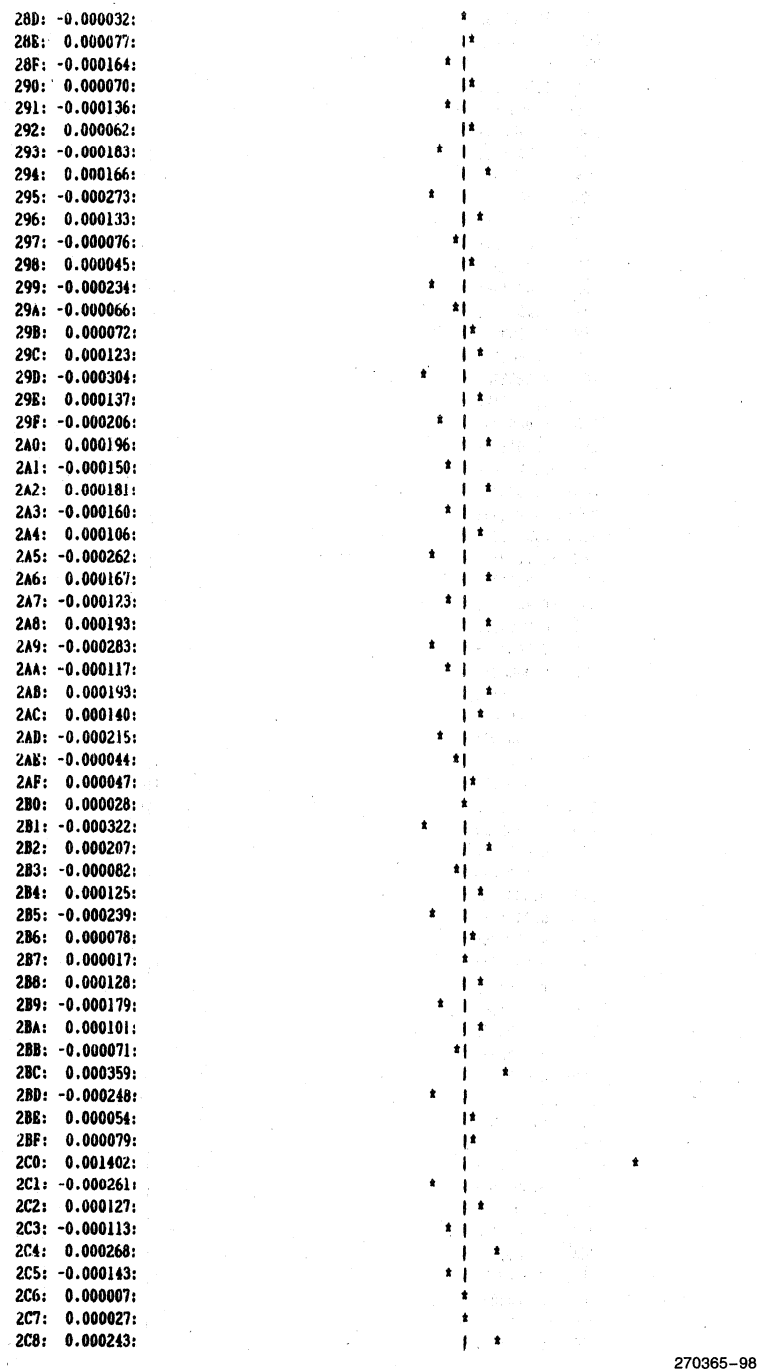

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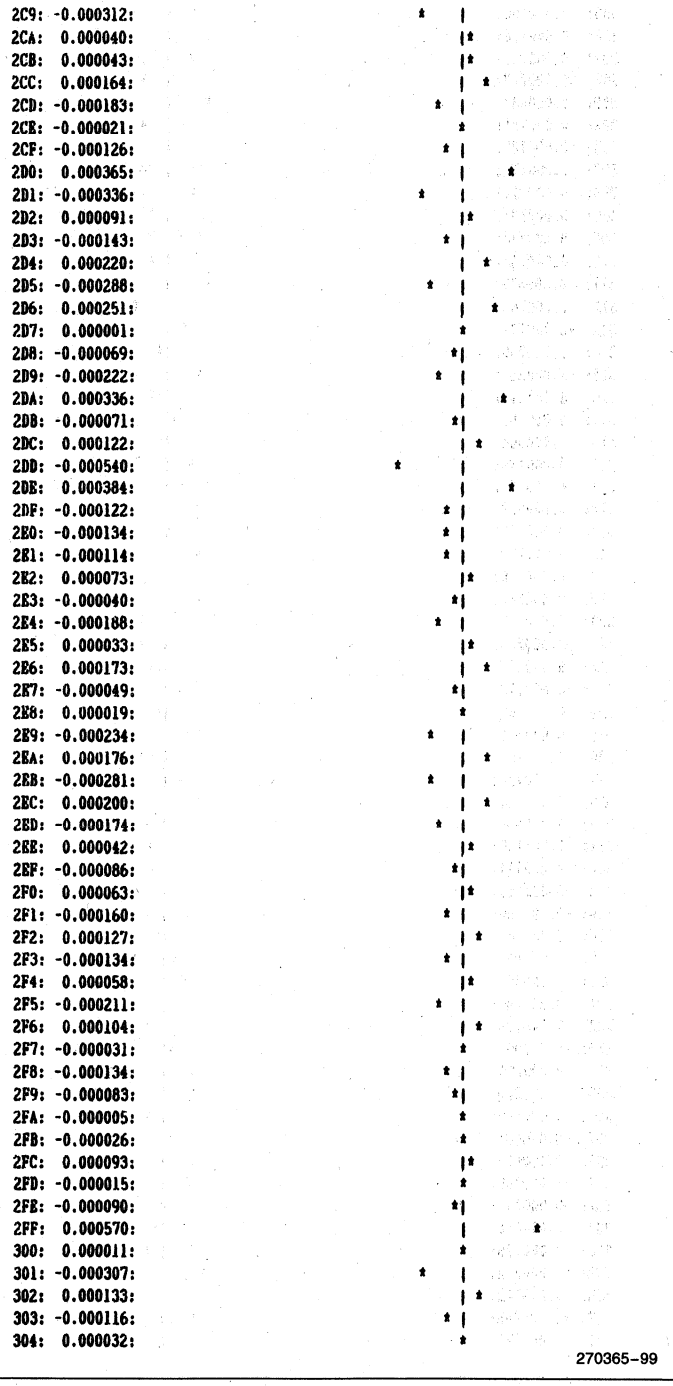

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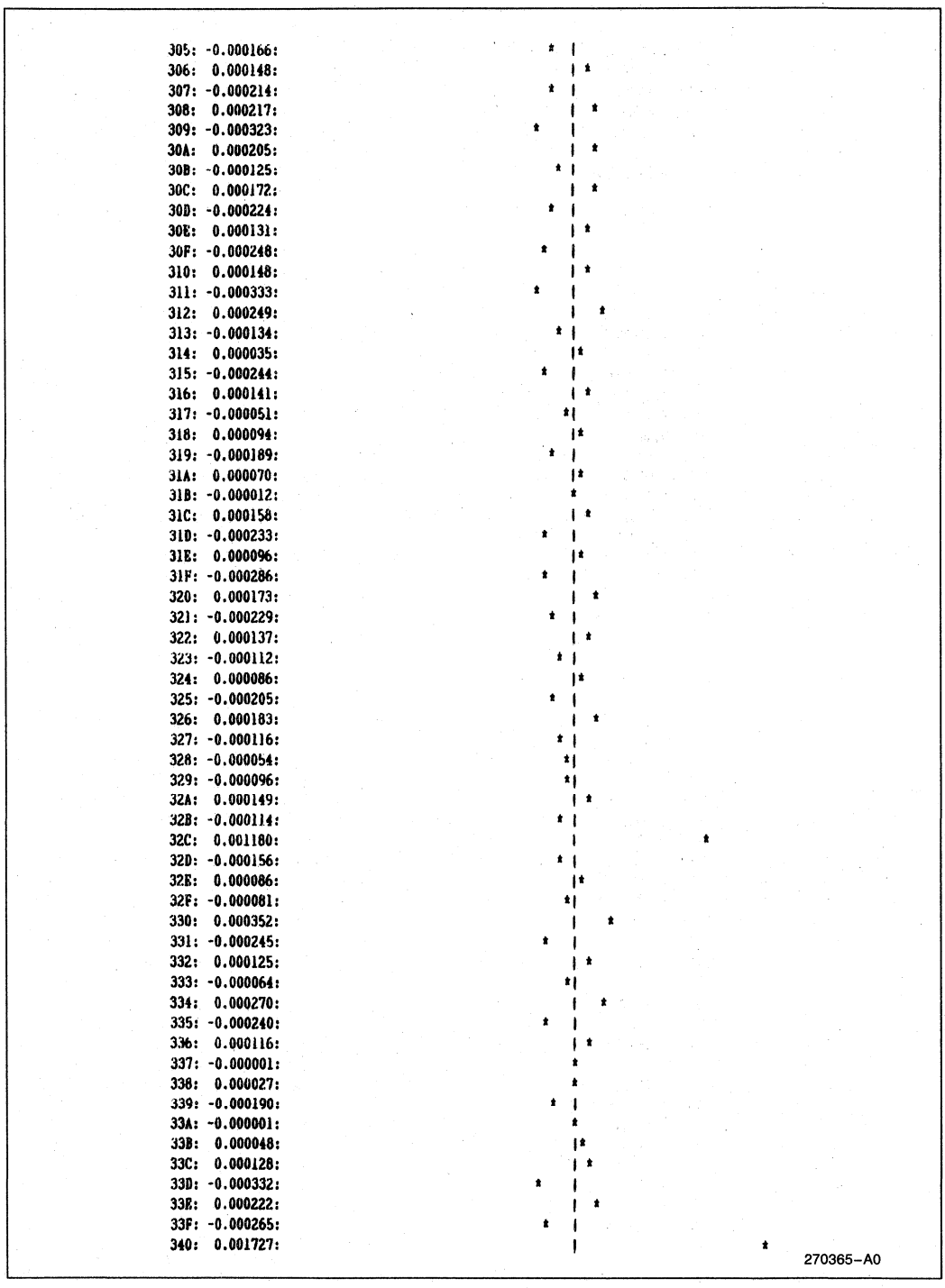

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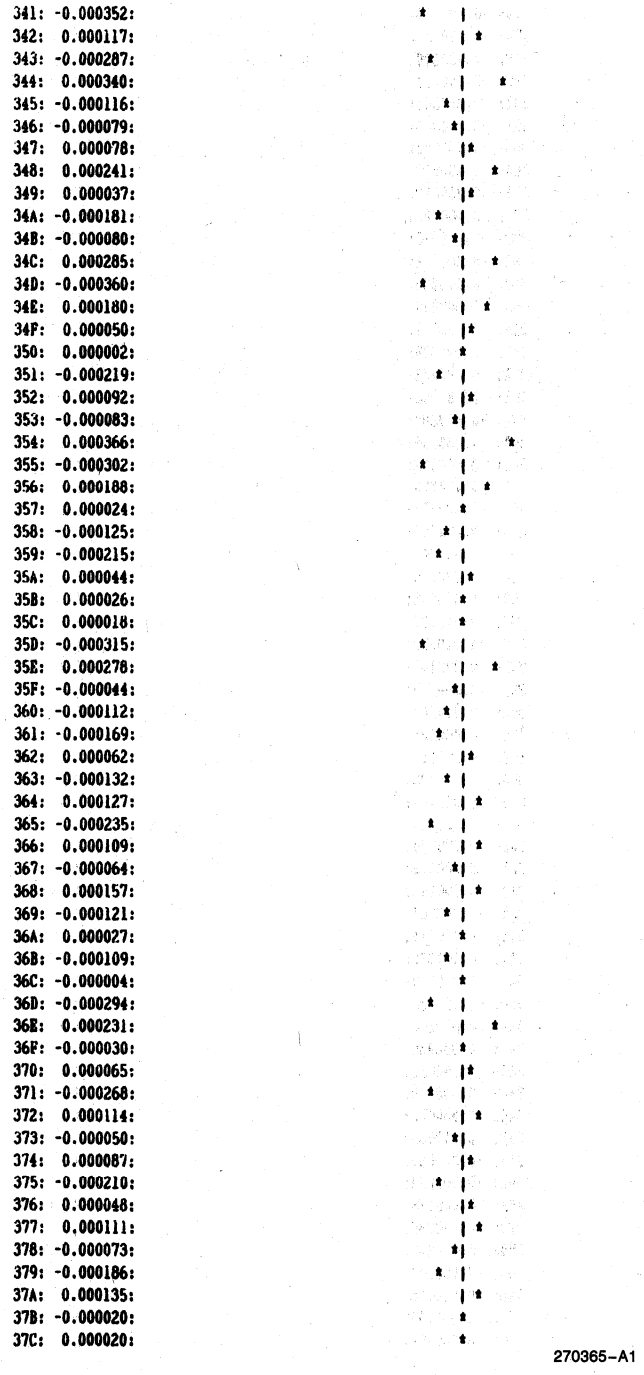

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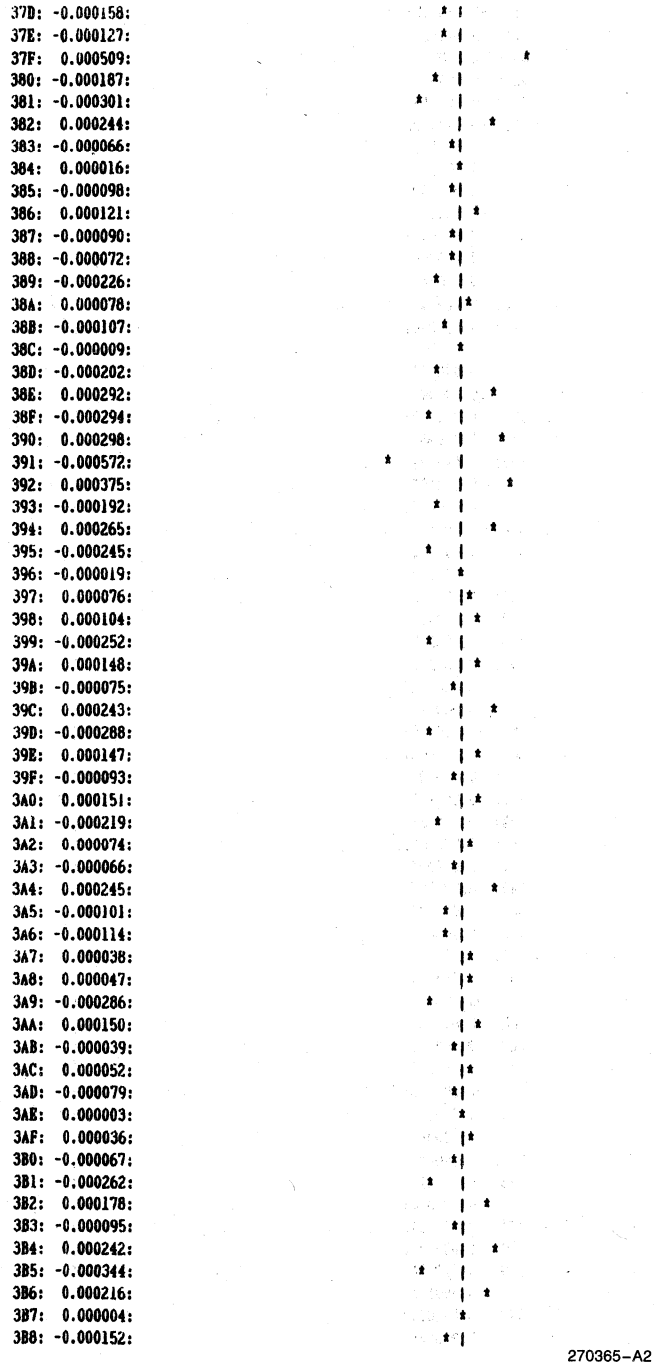

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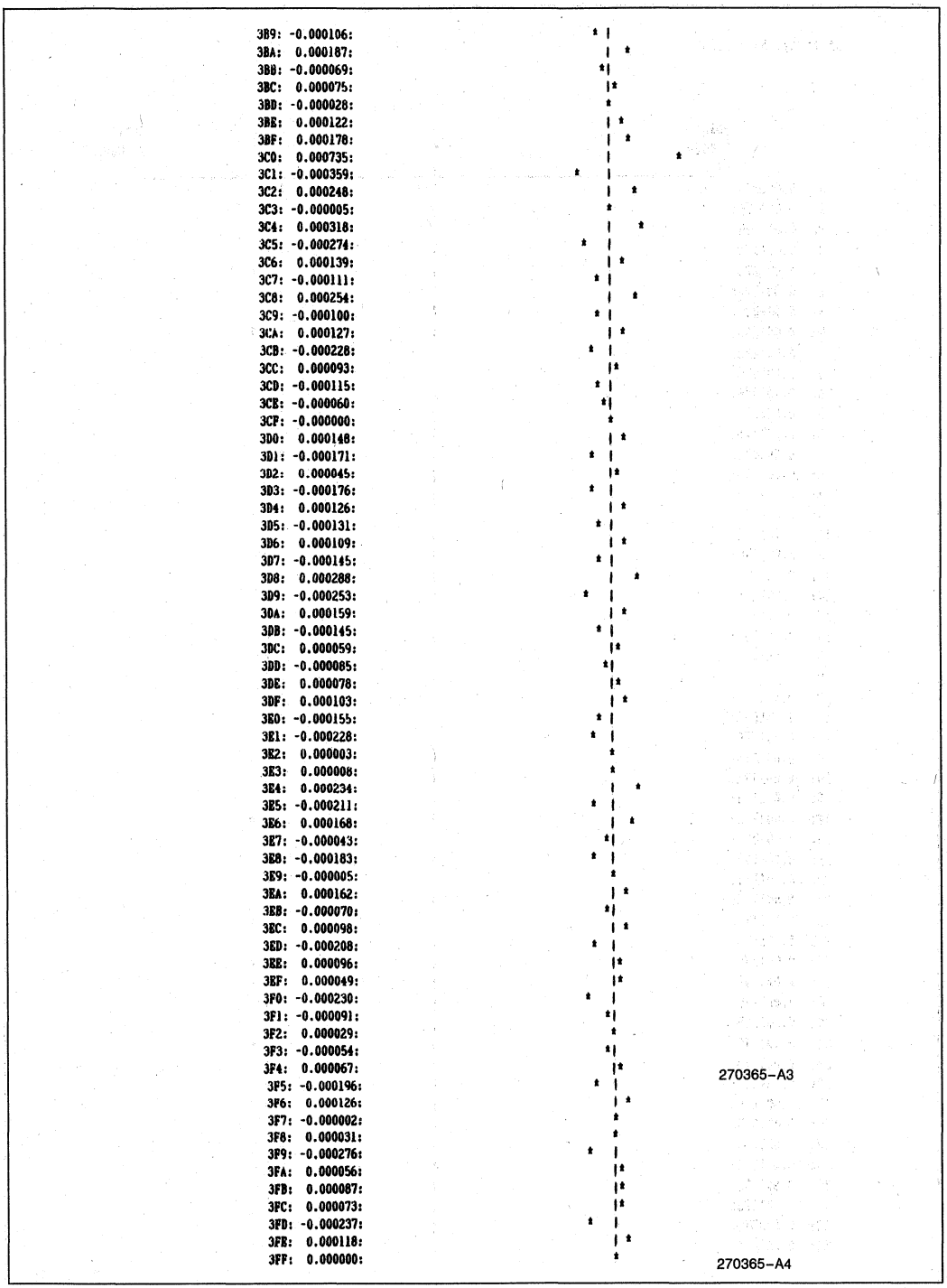

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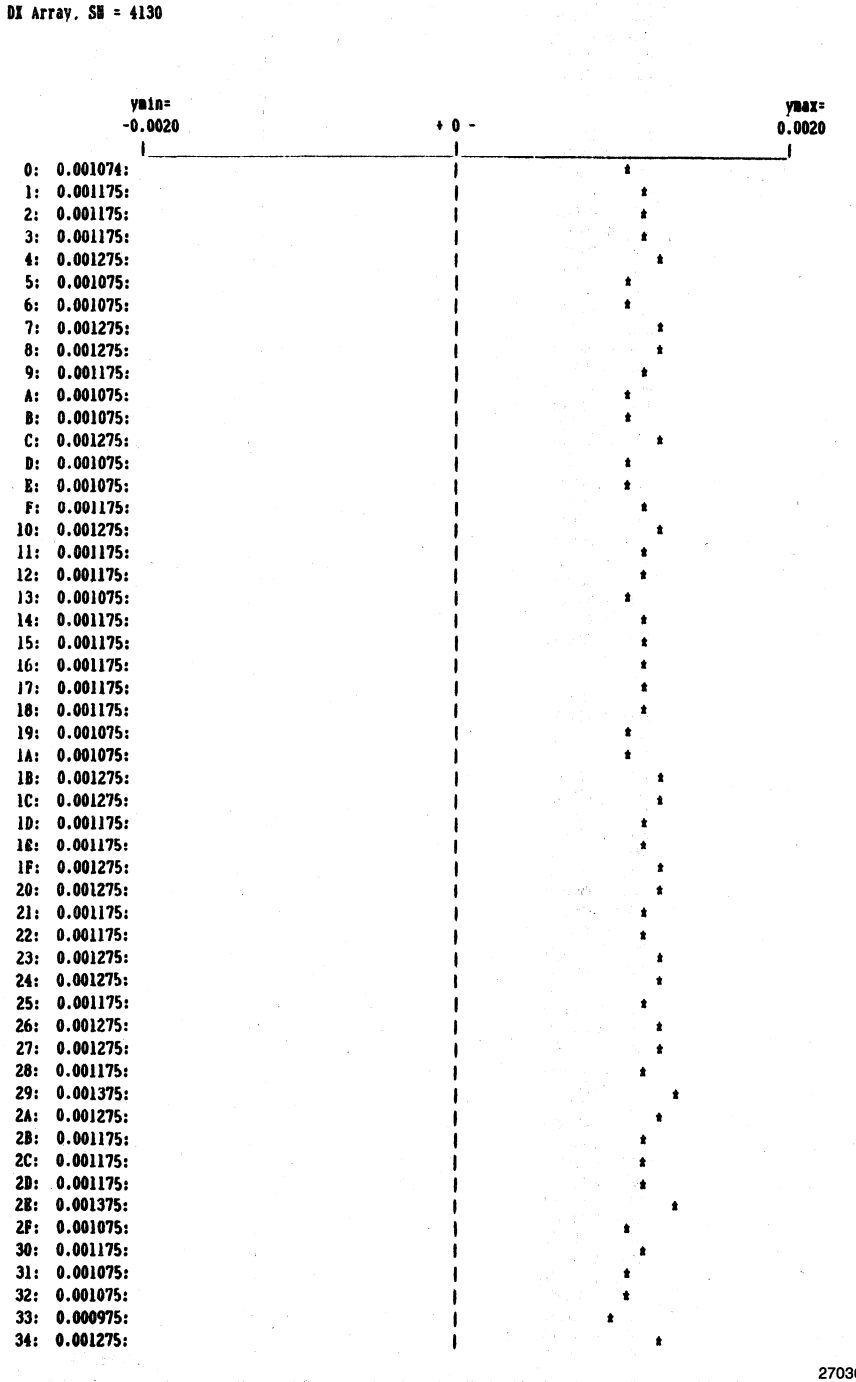

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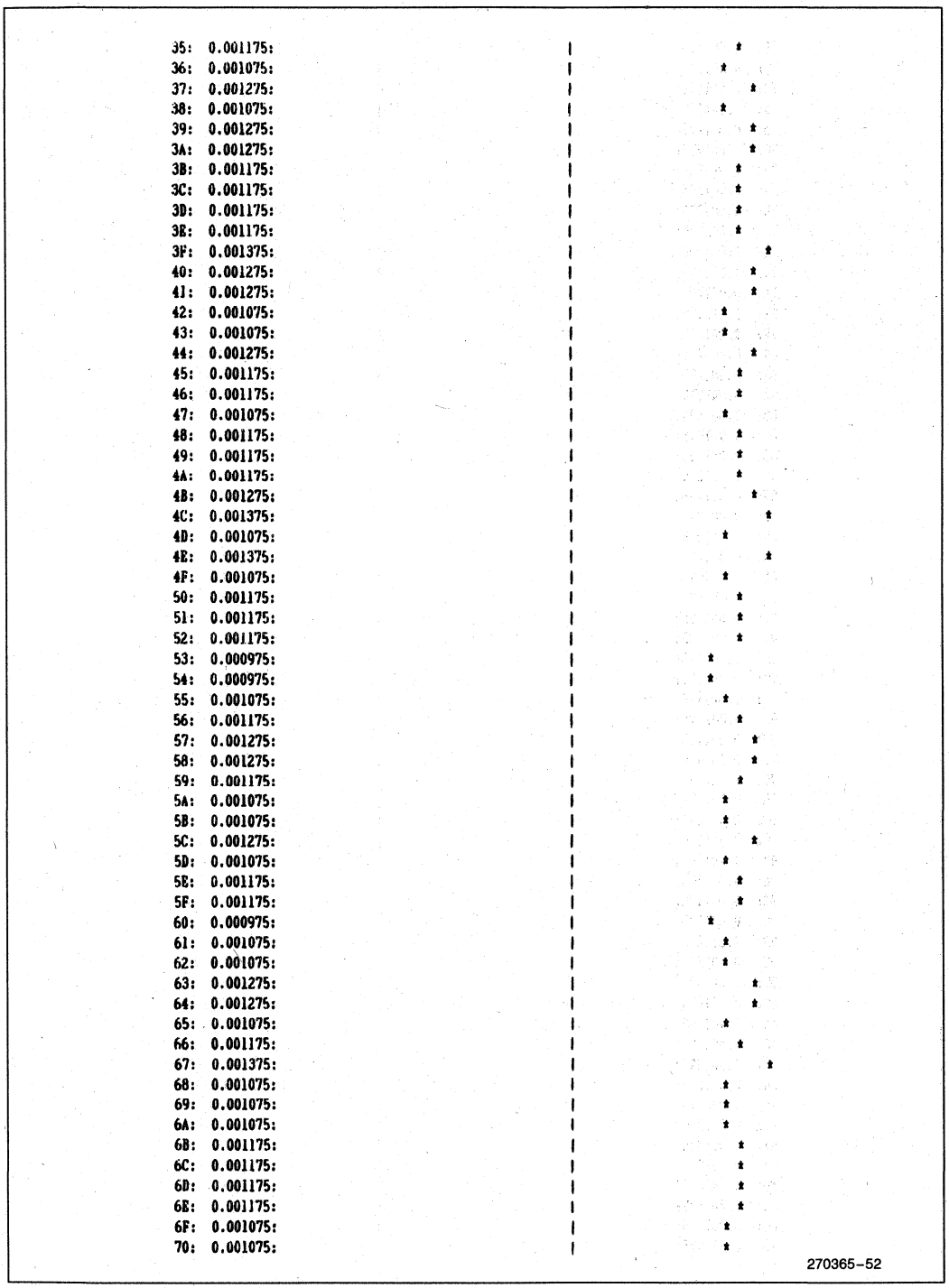

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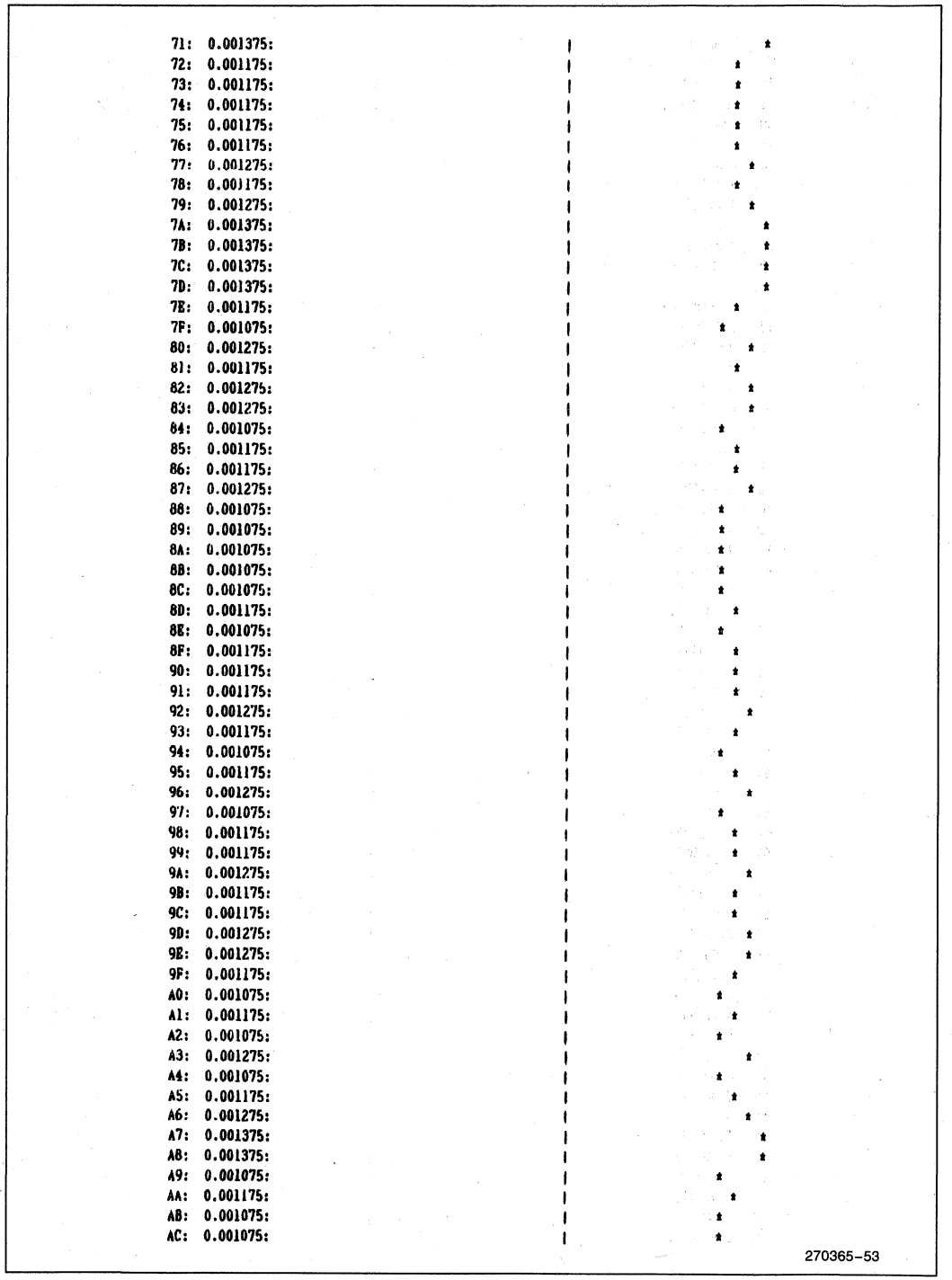

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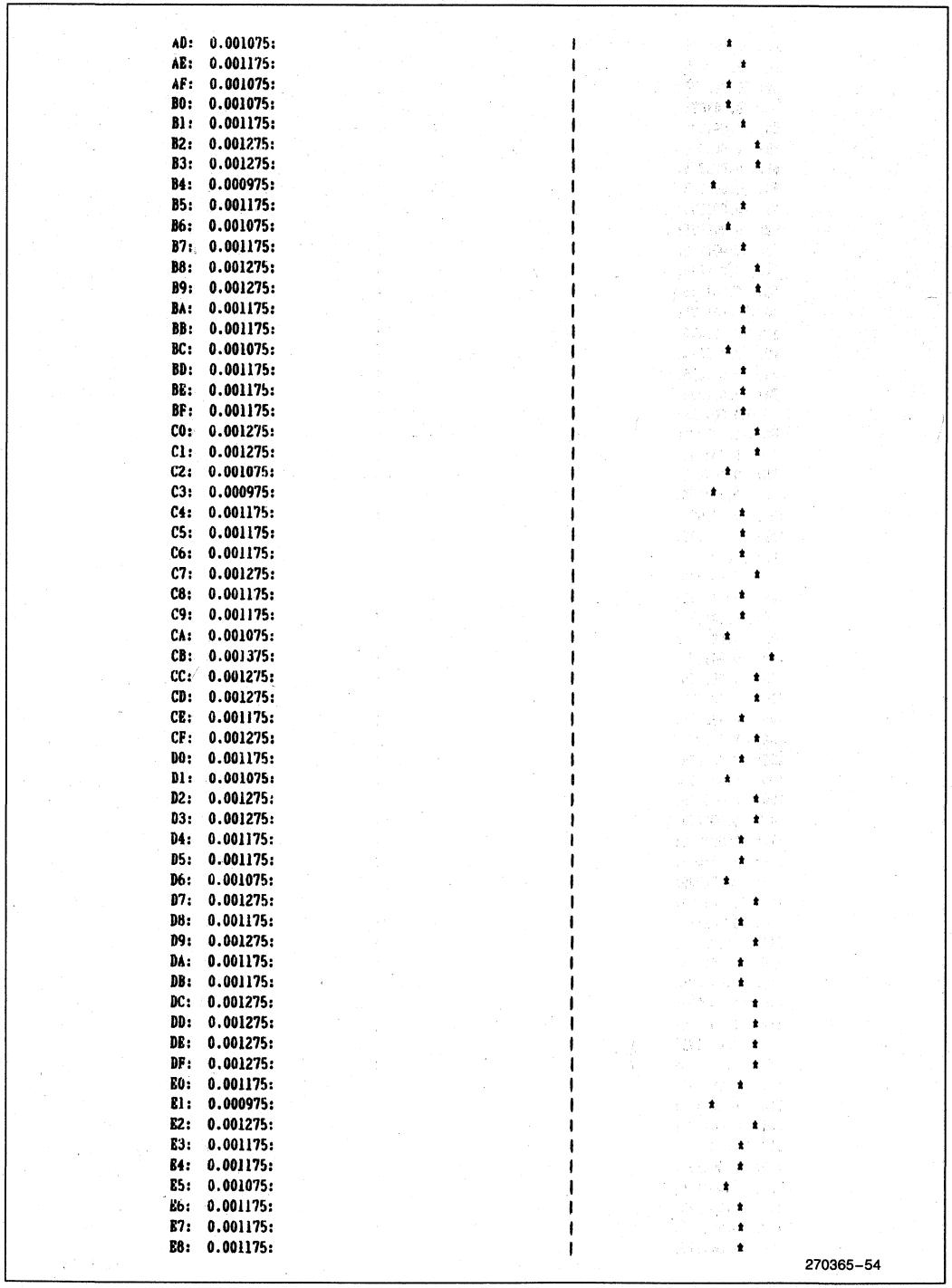

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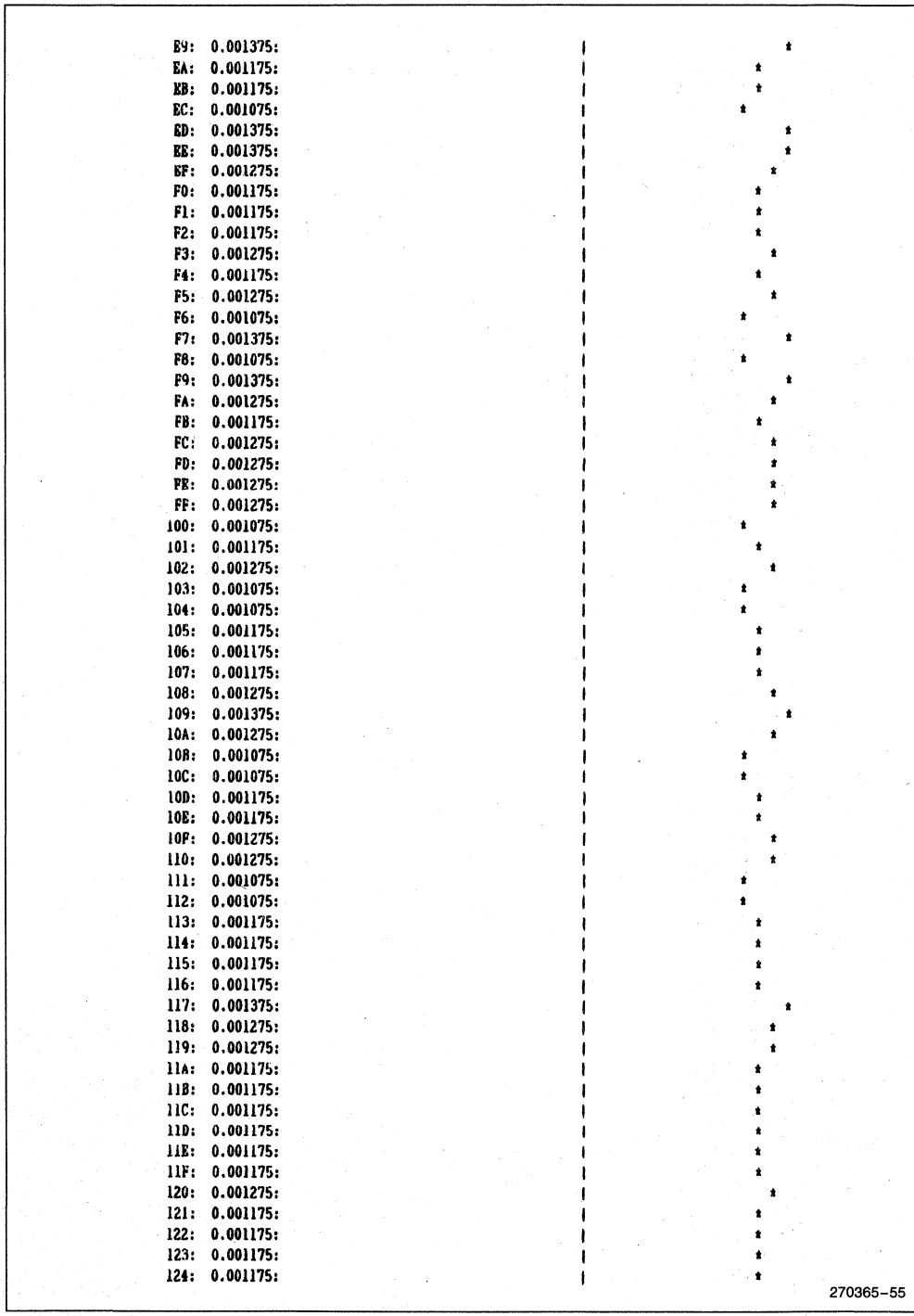

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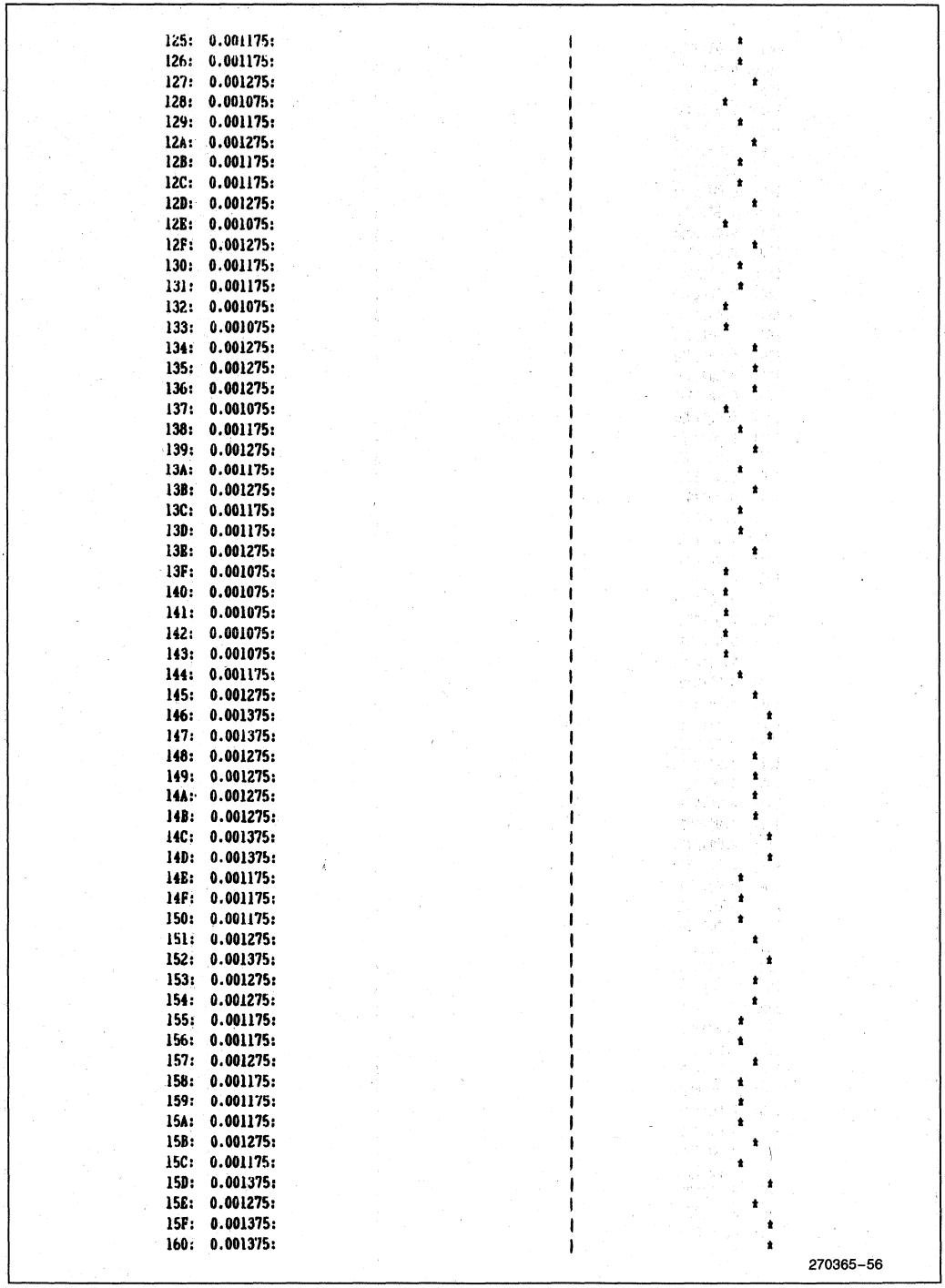

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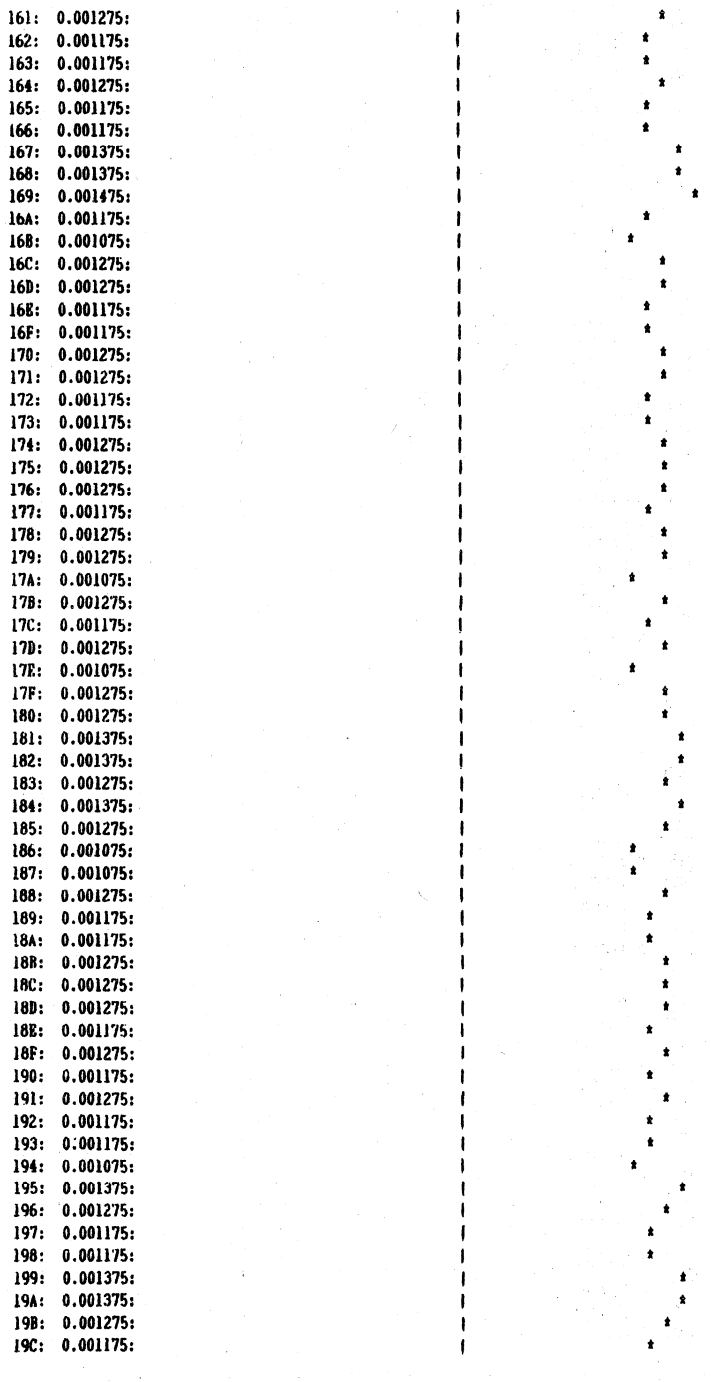

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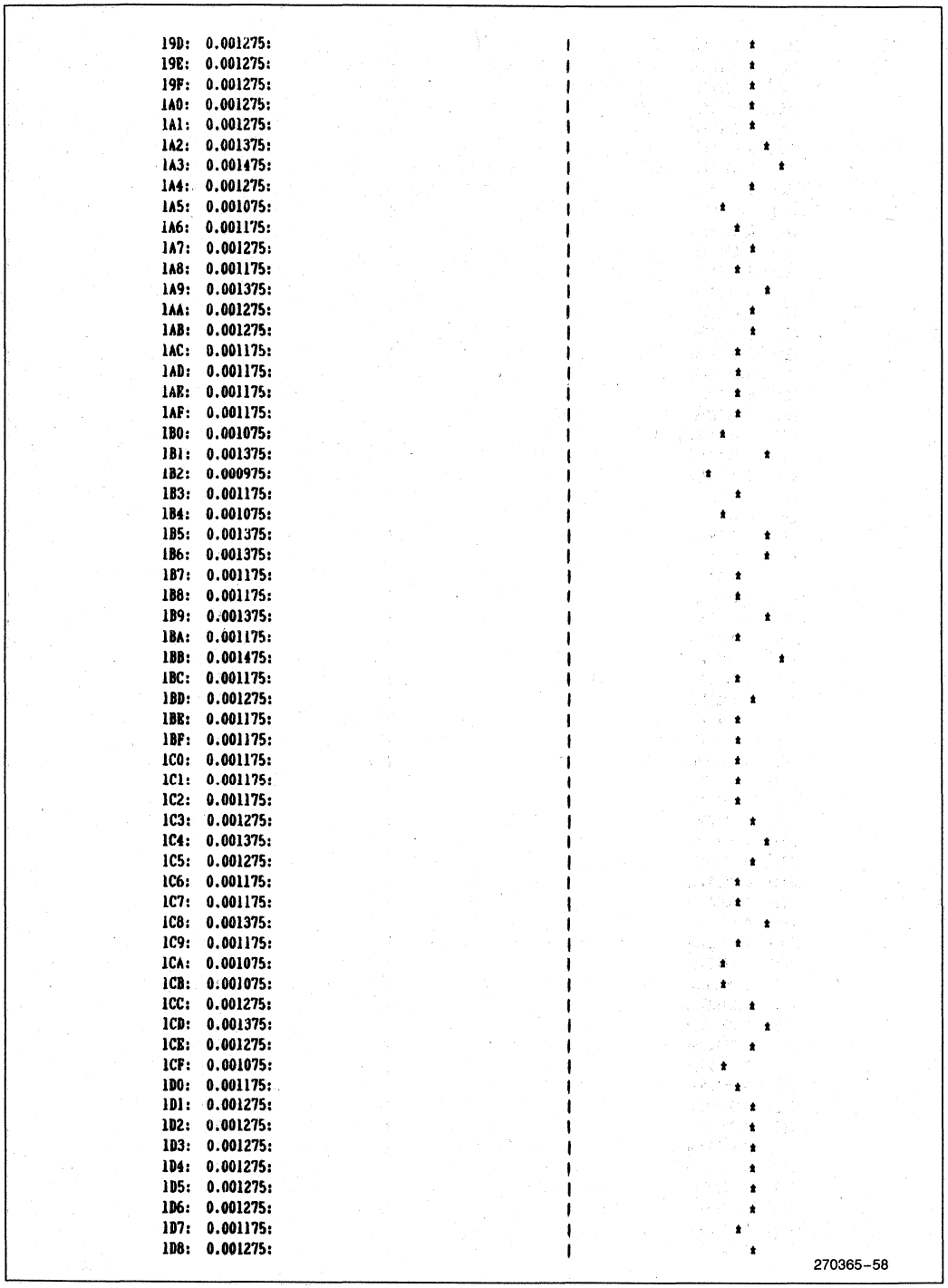

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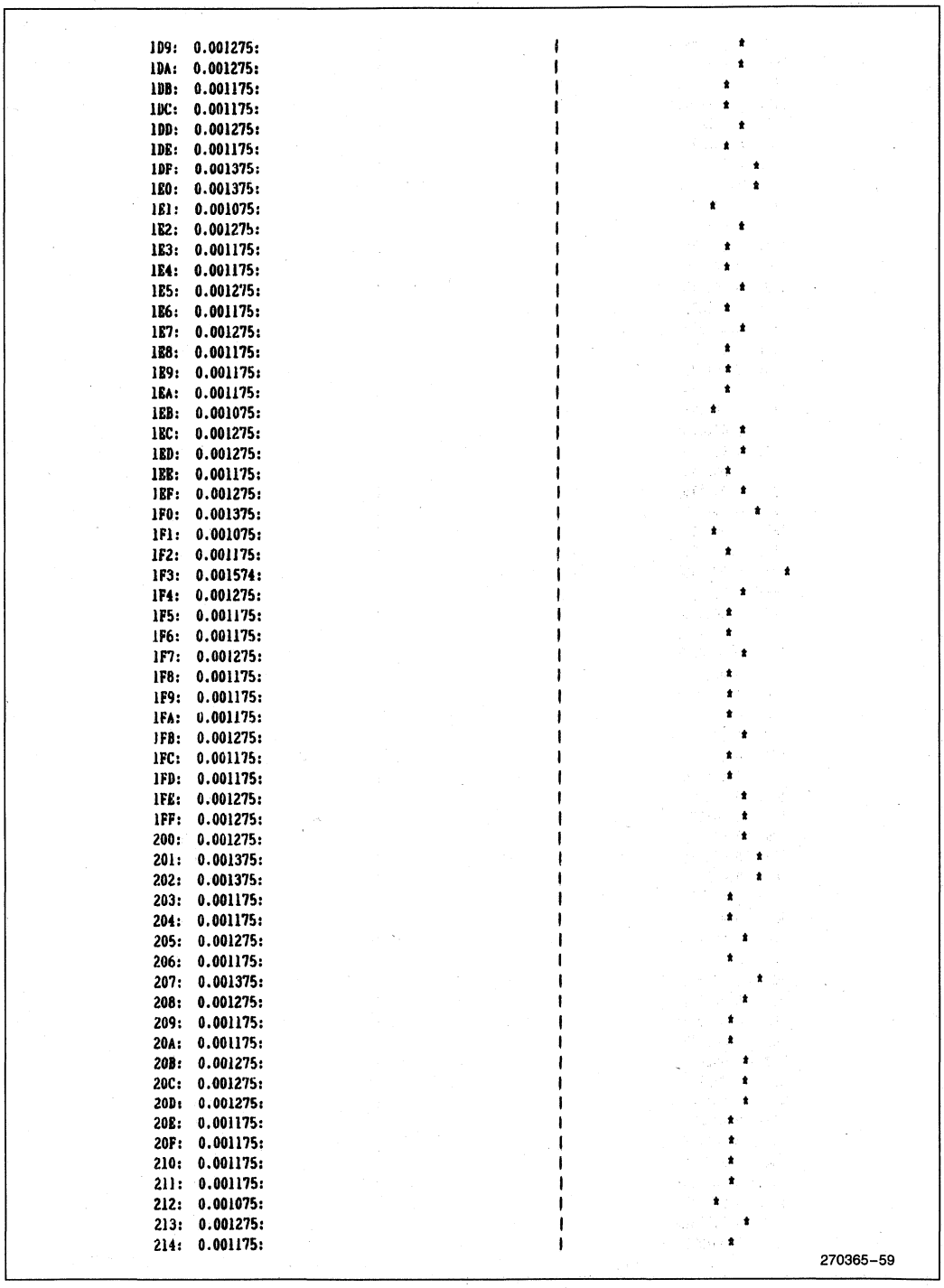

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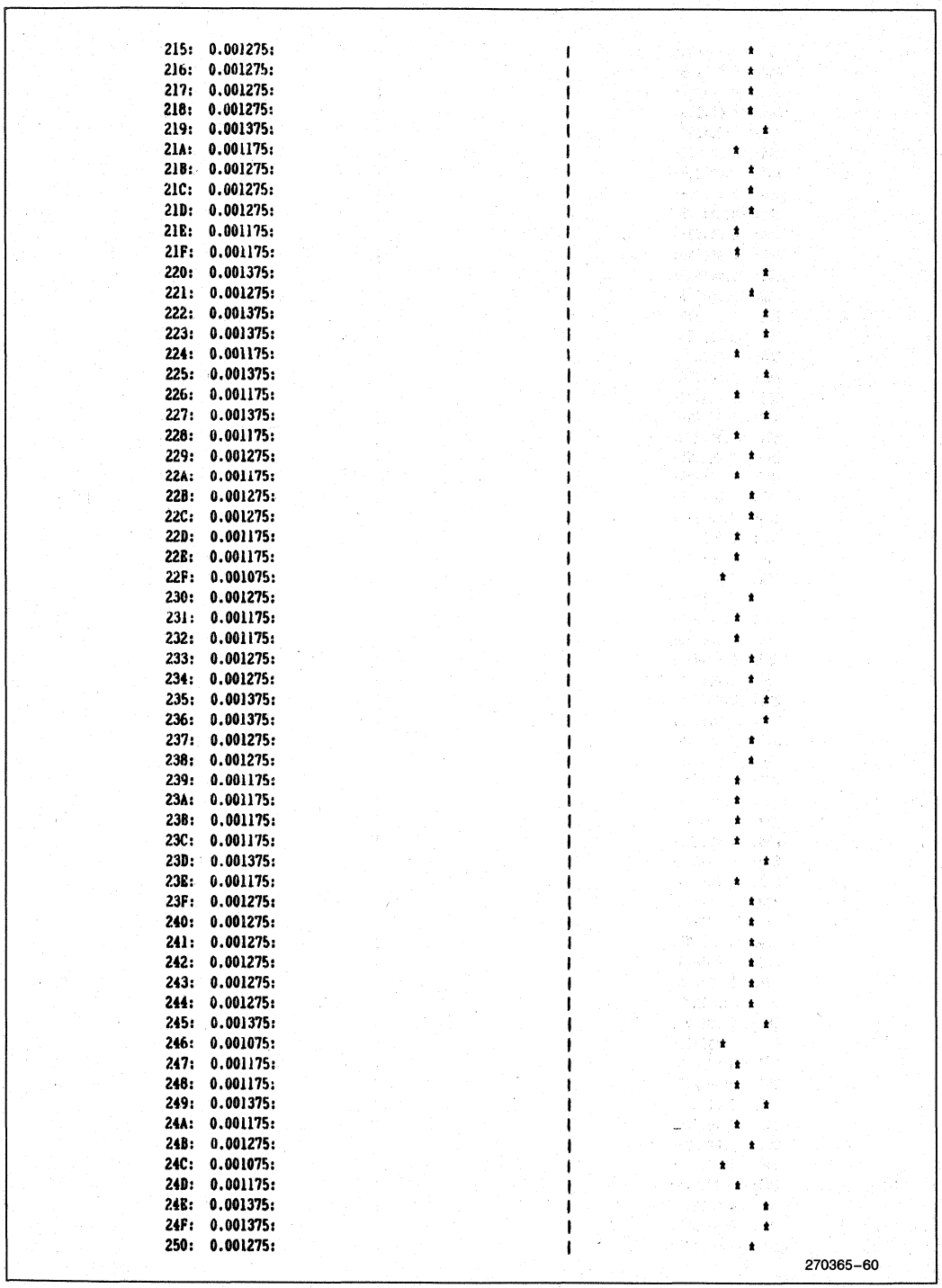

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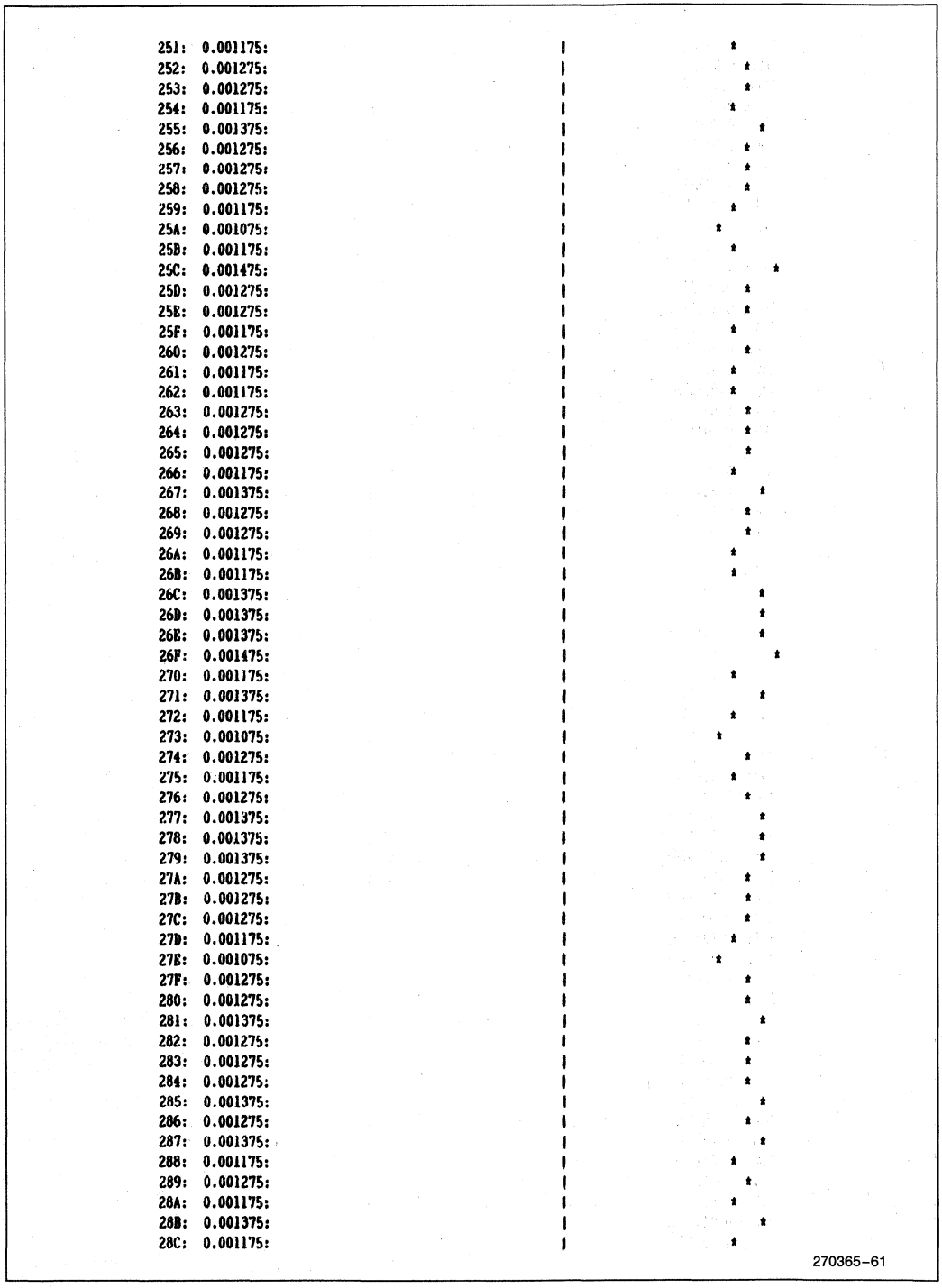

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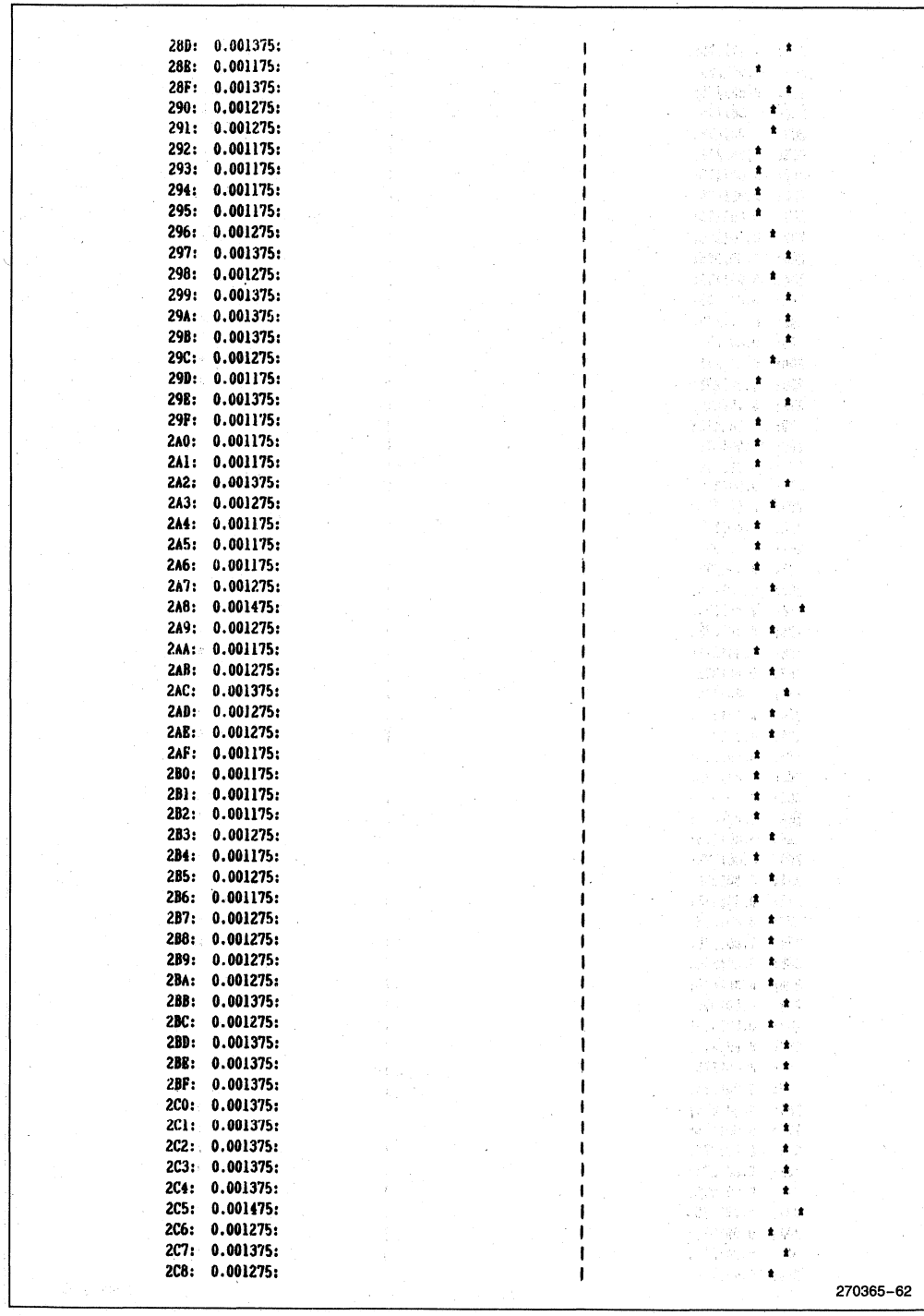

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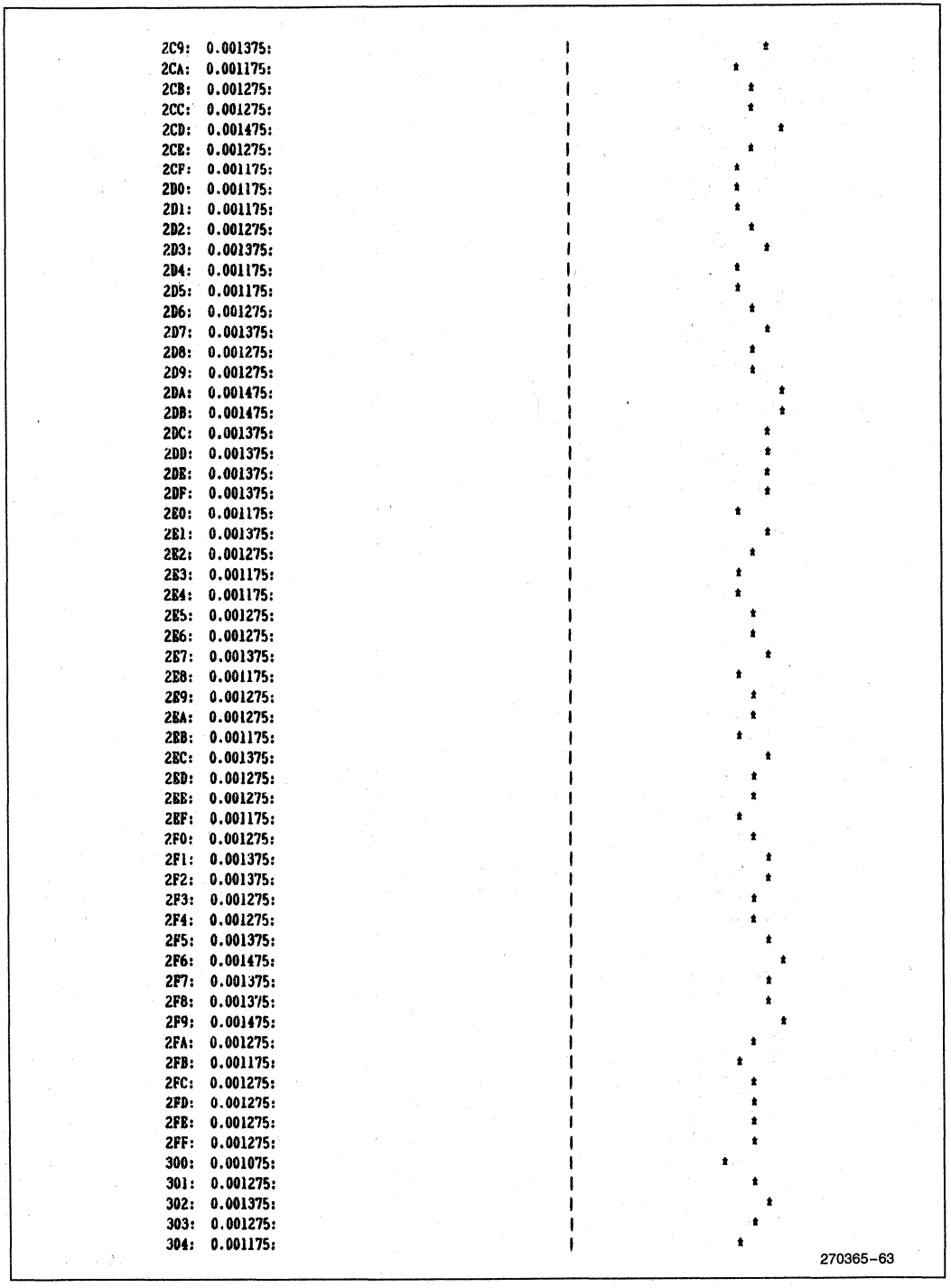

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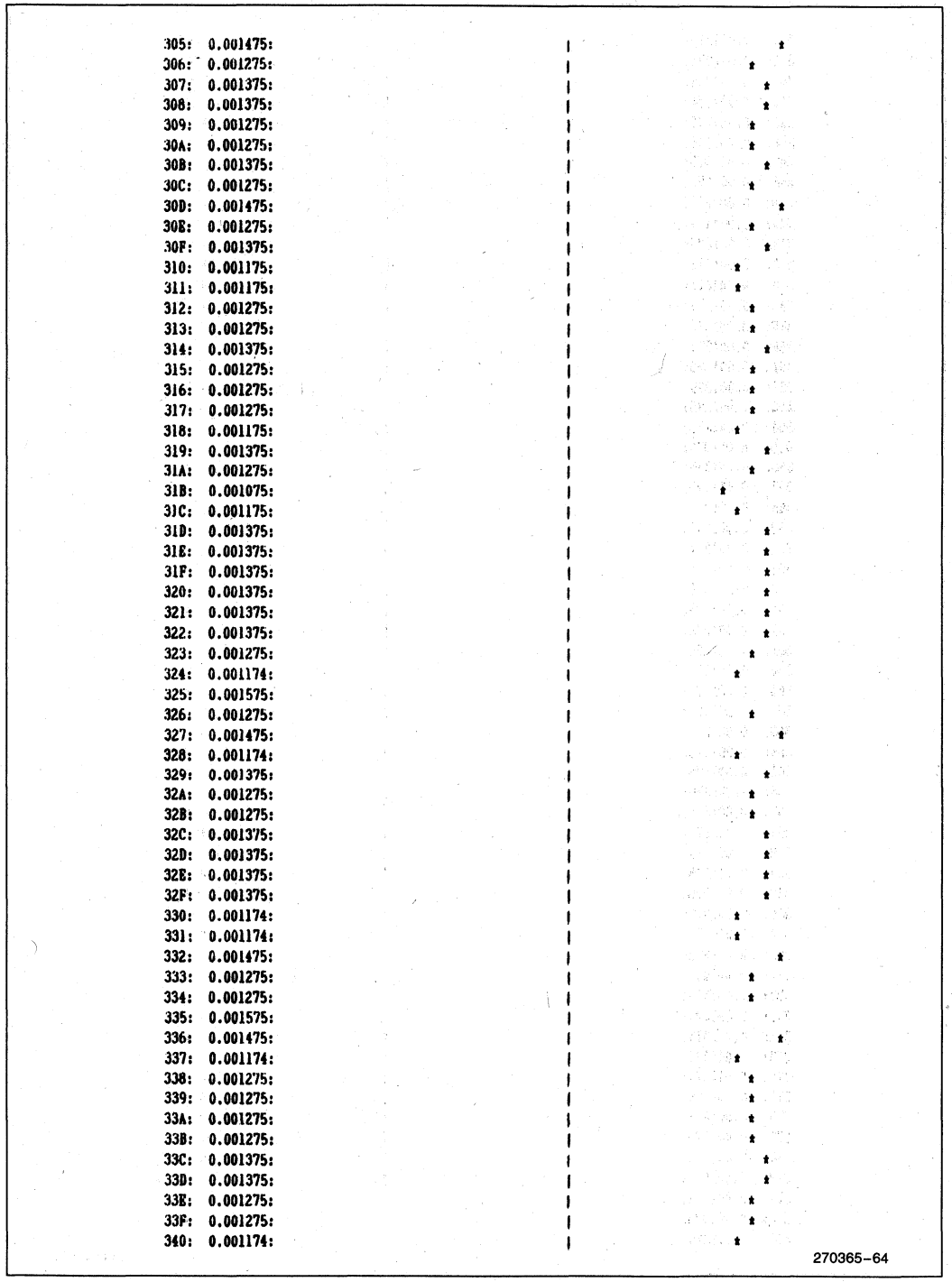

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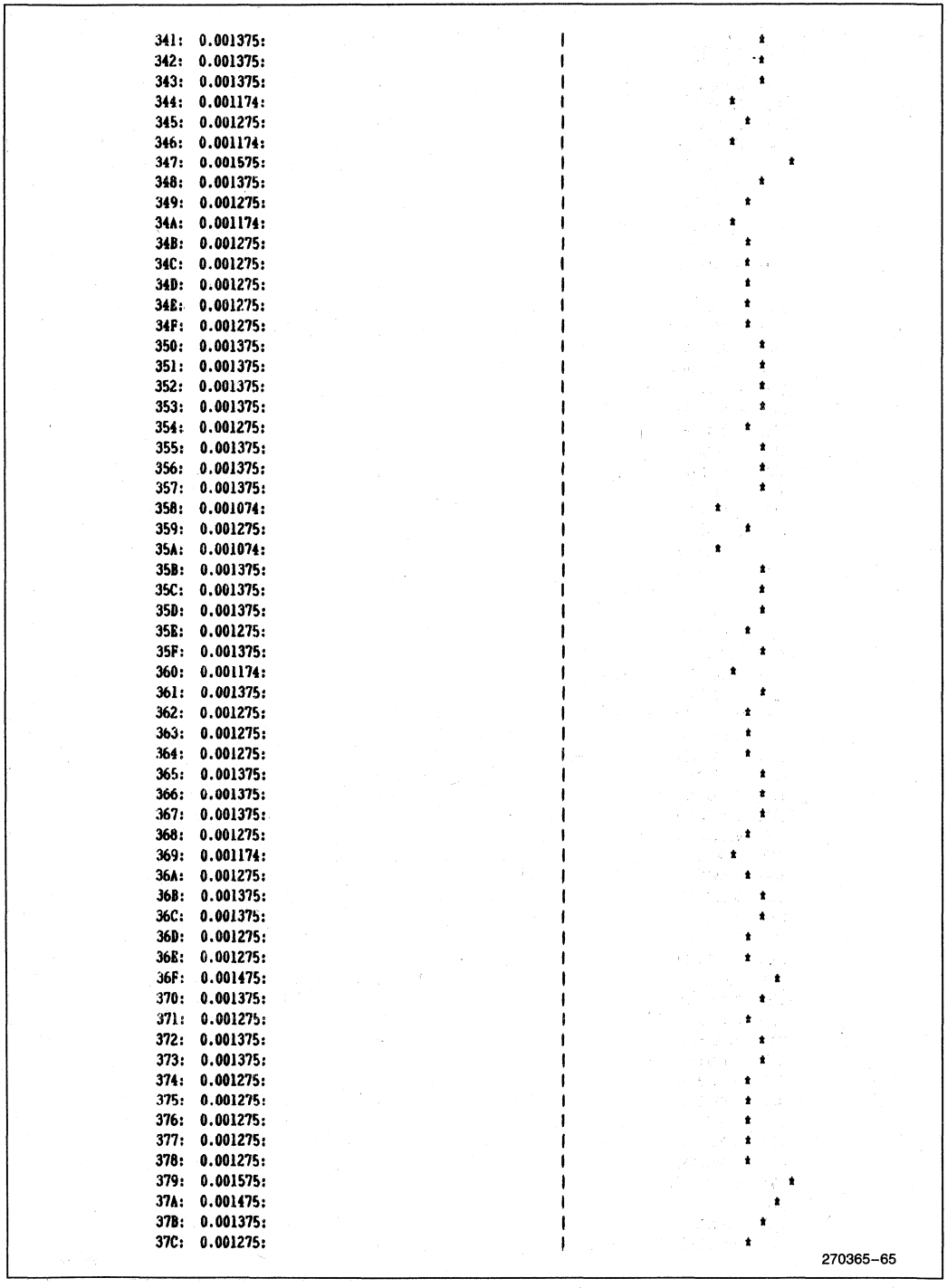

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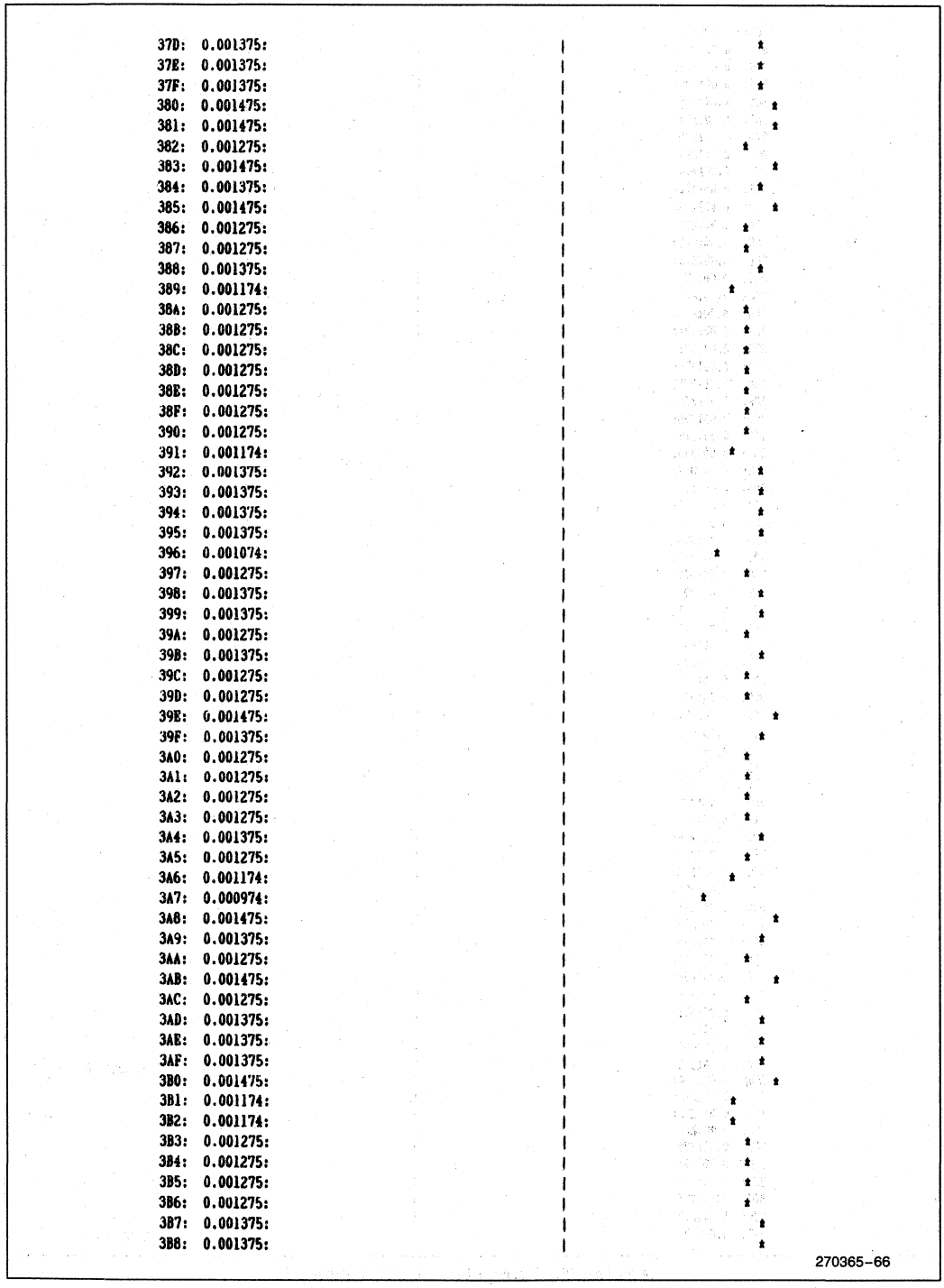

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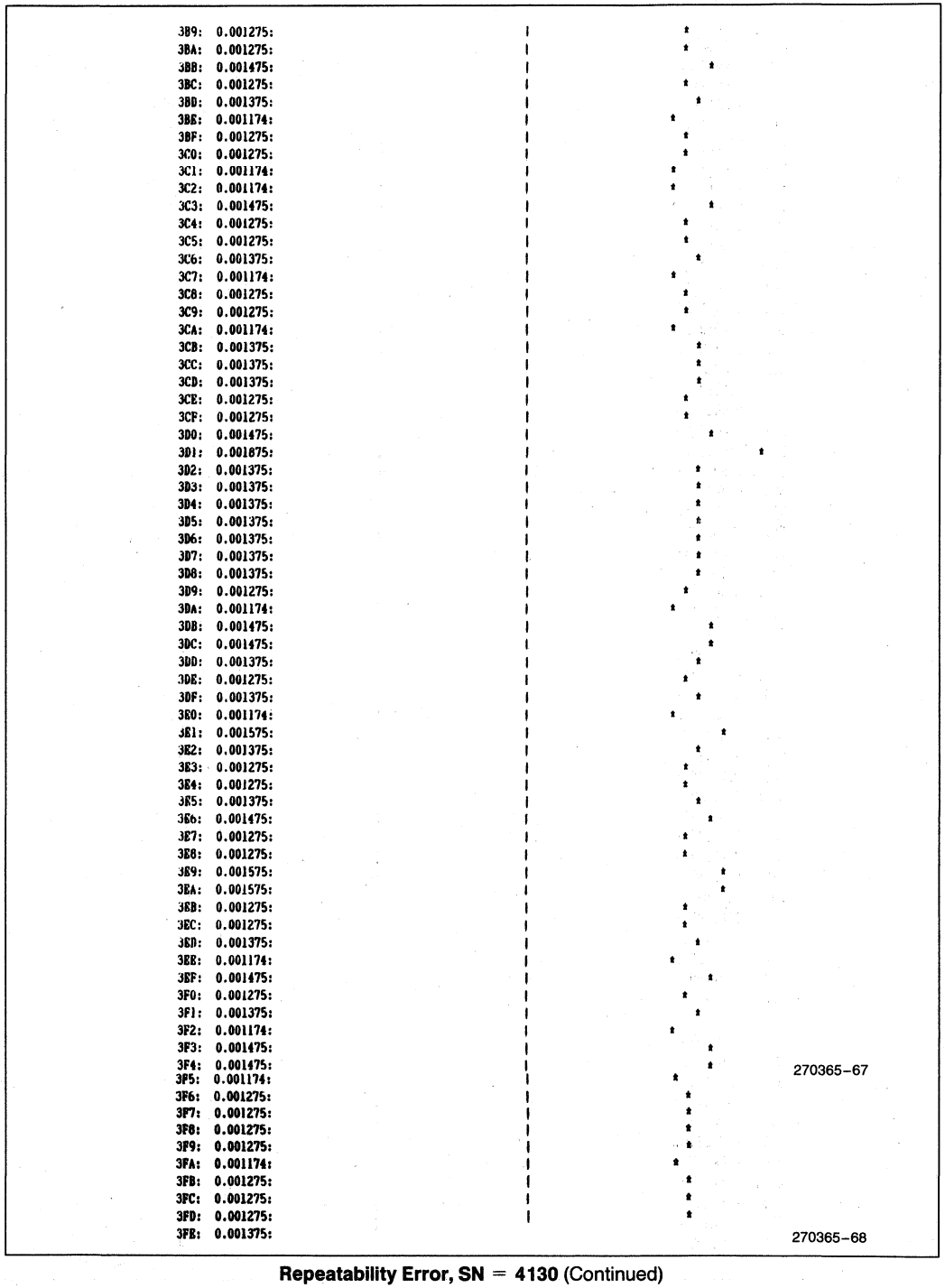

270365-67

270365-68

Repeatability Error, SN = 4130 (Continued)

APPENDIX E
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Many applications have throughput time requirements on the order of a few hundred milliseconds, and don't require real-time image analysis.

A Single-Chip Image Processor

A.L. Pai and S.H. Lin, Arizona State University, and David P. Ryan, Intel Corporation

Most of the research efforts on image processing focus on expanding the complexity and dimension of image analysis. Unfortunately, this emphasis results in algorithms that are so computationally intensive that expensive special-purpose vector and pipeline processors are required to evaluate an image fast enough to be considered "real-time." Not all applications, however, have the burdensome requirements of true real-life image analysis. Specifically, applications that have image throughput time requirements of greater than a few hundred milliseconds can use a lower cost, general-purpose microprocessor-based system. Applications that have even slower frame rates are candidates for not only the use of lower cost CPUs, but also allow for replacement of video-rate flash A/D converters with slower, less expensive converters.

Addressing the most cost-sensitive applications, the design described herein uses Intel's 16-bit microcontroller to implement a single-chip image processor. The on-chip 10-bit A/D converter of the controller digitizes the image of a charge injection device (CID) camera, while the chip's 16-bit CPU executes a library of standard vision algorithms and reports the results by passing a few tokens over an on-chip universal asynchronous receiver-transmitter (UART).

SYSTEM OVERVIEW

A block diagram of the single-chip image processor is shown in Figure 1. The image is acquired by the CID camera and input as an analog voltage to the 8096 where it is digitized and stored in one of two image buffers. The digital image is stored as an N x N matrix of 8-bit values corresponding to the gray level intensity at each picture element (pixel) as shown in Figure 2.

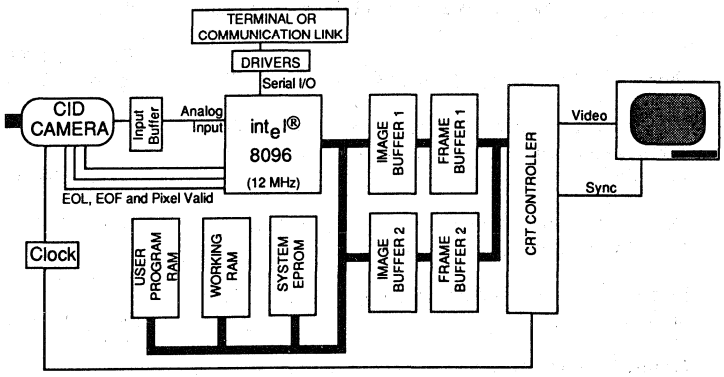


Figure 1. *System block diagram.*

After an image resides in an image buffer, the 8096 can execute a number of standard image processing algorithms available as system monitor commands. These programs perform thresholding and filtering functions on the digital image, and can analyze objects found within the image. If the 8096 were attached to a host system instead of a terminal, custom programs could be downloaded to the user program RAM and executed.

To view the raw and processed images, a CRT controller is used to keep a video monitor updated with the images stored in the two frame buffer memories of Figure 1. The 8096 updates the frame buffers with the data in its image buffers depending upon commands given to the system.

► **Hardware.** The system is composed of a 128 x 128 CID camera and Intel's 8096 (with on-chip A/D) for image acquisition and analysis. A standard CRT controller was added for displaying raw and processed images as directed by the 8096. Driving the decision to use a 128 by 128 digital

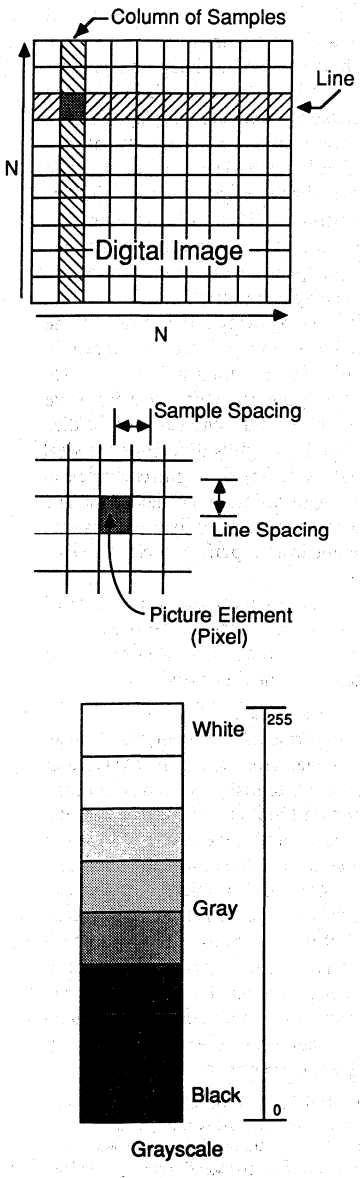


Figure 2. *Representation of an N x N digital image.*

image was the desire to store and operate upon two images simultaneously while minimizing memory requirements.

The image processing and communications software takes 5K of the 8K bytes allocated to the system monitor space, and would fit in the on-chip ROM space of an 8397 with 3K left. Two 32K x 8 SRAMs are used to provide space for two 16K byte image buffers, a 16K section of working RAM, and space for user-downloadable programs that are invoked by the monitor.

Two 16K byte frame-buffer memories are mapped to the same addresses as the corresponding image buffer used by the 8096. Normally, the frame buffers are mapped to the CRT controller to keep the video monitor updated. However, when the image stored in the image buffer is changed, the 8096 performs a frame-synchronized flyby block move to refresh the frame buffer (50 to 290 ms depending on whether frame synchronization is off or on).

To digitize an image, the 8096 monitors the end-of-line and end-of-frame signals from the CID camera and synchronizes the A/D conversion of the pixel data to a pixel valid signal from the camera. The analog output signal of the camera ranges from 0 to 1 V, corresponding to the gray level intensity at each pixel. This 1 V range is amplified to a 5 V range before being input to one of the eight A/D inputs of the 8096.

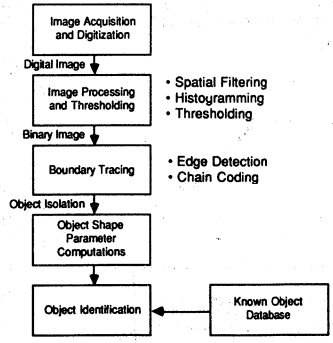


Figure 3. *Object identification.*

The 8096 converts the input voltage to a 10-bit digital representation in 22 μs. Another 18 μs are needed to store the pixel in the image buffer, update pointers, update a counter, and start another conversion. Therefore, the camera is clocked at a rate which results in a new pixel being output every 50 μs.

Although the 8096 converts its analog input to 10 bits, the externally generated analog errors (such as buffer error and noise) led to the decision to use only 8 bits of the result. This provides 256 gray levels, and greatly simplifies memory requirements.

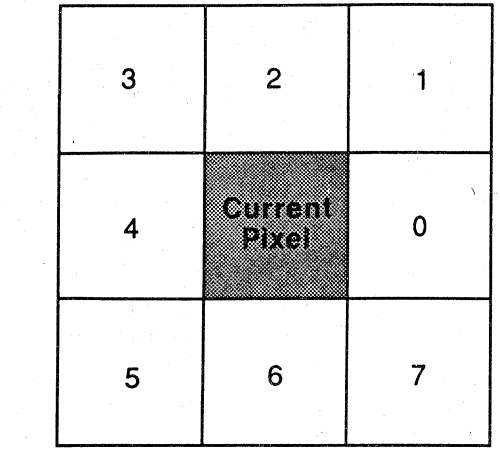
► **Software.** In addition to the code necessary to digitize images, the system EPROM contains an extensive set of algorithms for digital image acquisition and analysis. Video operations are used to acquire a digitized image. Point and arithmetic operations involve the pixel-by-pixel manipulation of a digital image. Neighborhood operations produce an output image that is the result of a combination of the gray level intensities around a specified neighborhood of each pixel. Measurement operations include the computation of desired parameters of objects located in an image for pattern recognition and other applications. Finally, utility operations are necessary for system operation.

The algorithms present in the system monitor can be used to identify desired objects in a digital image by following the approach shown in Figure 3. Once an image is digitized, it can be enhanced by the application of various image processing techniques including histogramming, thresholding, and spatial filtering to delineate the desired objects. The 8-directional chain code (Figure 4) can then be used to trace the boundaries of objects, and relevant object parameters can be determined and compared with those of a known object database to identify the unknown object.

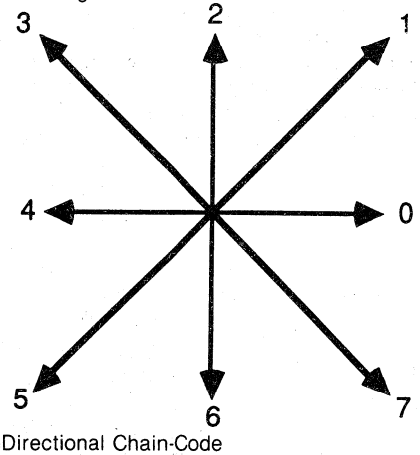
OBJECT CLASSIFICATION

In the following example, the 8096 performs a binary thresholding operation as described earlier to set the image background to pure white and the objects in the image to pure black. Then the 8096 searches the image for objects. When an object is found, the object boundary is traced and shape analysis is performed. Descriptive information about the object (or objects) is output over the on-chip UART of the 8096 to a terminal, or host computer. The controller, without consulting a host computer, can also be programmed to make the decision to accept or reject an object on a set of prescribed rules.

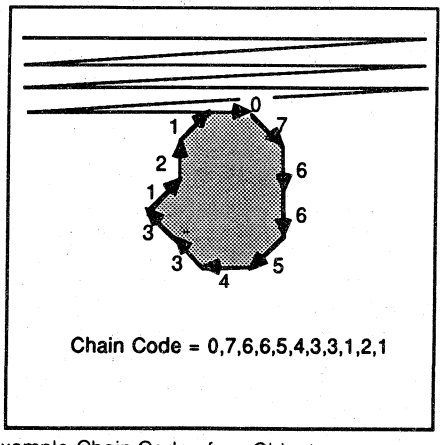
The sequence of processing for this example, from serial communication reception and interpretation to the reporting of the shape analysis results, takes approximately 1500 ms with an 8096 running at 12 MHz. The time will vary with the size and number of objects in the field of view.



(a) A 3x3 Neighborhood



(b) 8-Directional Chain-Code



(c) Example Chain-Code of an Object

Figure 4. *8-directional boundary chain code.*

Photos 1 through 4 show the original 256 gray level digitized image and resultant binary (two-level) image of a circular object and a square object. (The circle looks like an oval when displayed due to the aspect ratio of the video monitor).

Table 1 summarizes the output of the systems shape analysis program. The objects' perimeter (P), area (A), center of mass coordinates (cx, cy), and the coordinates of the endpoints of each minimum enclosing rectangle are listed.

The rectangularity and circularity of the objects were also calculated and appear in Table 1. The rectangularity of the circle and the square using the actual data were ideal. Although the circularity of the digitized circle is slightly different from ideal (12.416 vs. 12.56), the digitized circle can be distinguished from the digitized square since the circularity of the square is very different from a perfect circle (15.44 vs. 12.56).

From these typical results, it is clear that this image processor can be used to distinguish between and identify objects placed in its field of view.

CONCLUSIONS

If the stringent requirements of "real-time" image processing can be relaxed in favor of substantially reduced sytem cost, a standard 16-bit microcontroller can perform as a stand-alone image processor.

Not only does the design described here demonstrate that a microcontroller can undertake two-dimensional image processing, but the surprising speed with which it accomplishes the processing should lead to the reevaluation of current microprocessor applications for possible cost reduction via microcontrollers.

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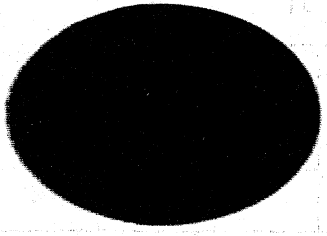


Photo 1. *A digitized image of a circle.*

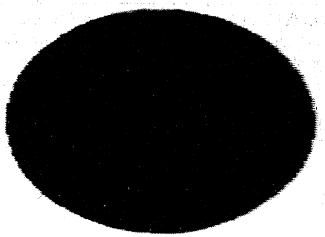


Photo 2. *A thresholded binary (two-level) image of the same circle. The circle appears oval because of the aspect ratio of the video monitor.*

Photo 3. *A digitized image of a square.*

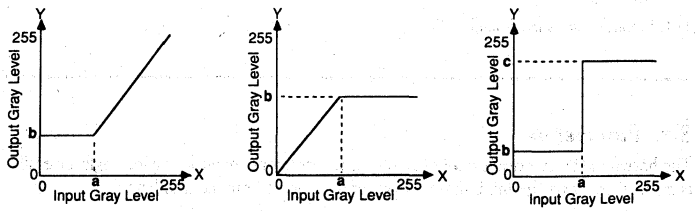
Photo 4. *A thresholded binary image of the same square.*

7. Castleman, K.R. *Digital Image Processing*, Prentice Hall International, Englewood Cliffs, NJ, 1985.
8. Baxes, G.A. *Digital Image Processing—A Practical Primer*, Prentice Hall International, Englewood Cliffs, NJ, 1984.

Image Processing Techniques

A **histogram** gives the distribution of all the gray levels in a digital image. The image histogram is used to select a desired threshold intensity level for separating an object from the background in the digital image.

A digital image can be **thresholded** using various threshold functions (three of which are shown in the figure) to yield an output image that contains a better definition of an object. For example, a binary (black and white) image is obtained by applying the two-level threshold function shown in (c).



(a) $Y = \begin{cases} b & 0<X\le a \\ X & \text{elsewhere} \end{cases}$ (b) $Y = \begin{cases} X & 0<X\le a \\ b & \text{elsewhere} \end{cases}$ (c) $Y = \begin{cases} b & 0<X\le a. \\ c & \text{elsewhere} \end{cases}$

In **spatial filtering**, the pixels adjacent to pixel (x,y) of image plane f are operated upon by the filter mask operation h. The resulting value of this spatial convolution is used to compute a replacement gray level intensity value at location (x,y) in the output image g. The following formula is used:

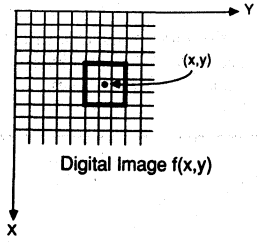
$$g(x,y) = h[f(x,y)] = [w_1\, f(x-1, y-1) + w_2\, f(x-1,y) + w_3\, f(x-1,y+1) + w_4\, f(x,y-1) + w_5\, f(x,y) + w_6\, f(x,y+1) + w_7\, f(x+1, y-1) + w_8\, f(x+1,y) + w_9\, f(x+1,y+1)]$$

Various types of **filter masks** can be used to perform different digital image enhancement operations. A low-pass filter uses neighborhood averaging to "smooth" the digital image to remove noisy pixels. A high-pass filter accentuates noisy pixels. A high-pass filter accentuates the higher frequencies present in an image, thus "sharpening" its edges. Operators such as the Sobel masks can be used to compute the gradient at each point in an image, thus producing a gradient edge-detected image.

Using such filtering methods, the boundaries of objects in an image can be isolated, thus permitting the computation of useful object parameters for object identification and classification.

W_1 (x-1,y-1)	W_2 (x-1,y)	W_3 (x-1,y+1)
W_4 (x,y-1)	W_5 (x,y)	W_6 (x,y+1)
W_7 (x+1,y-1)	W_8 (x+1,y)	W_9 (x+1,y+1)

(a) A 3 x 3 Pixel Window with Spatial Mask coefficients Wi and Corresponding Image Pixel Locations



(b) A 3 x 3 Neighborhood Around Pixel (x,y)

1/16	1/8	1/16
1/8	1/4	1/8
1/16	1/8	1/16

(c) A Low-Pass Filter Mask

-1	-1	-1
-1	9	-1
-1	-1	-1

(d) A High-Pass Filter Mask

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	2	1

(e) Sobel Gradient Masks

EXAMPLE SHAPE ANALYSIS OUTPUT

OBJECT	PERIMETER P	AREA A	C.O.M. COORDINATES CX,CY	ENCLOSING RECTANGLE				RECTANGULARITY $R=A_O/A_R$	CIRCULARITY $C=P^2/A$
				XMAX	XMIN	YMAX	YMIN		
CIRCLE	301	7297	(62,68)	111	15	116	21	0.785	12.416
SQUARE	328	6967	(55,73)	97	14	115	32	1.0	15.440

Table 1. *Example shape analysis output.*

Size Parameters

The **horizontal** and **vertical** extent of an object and its minimum enclosing rectangle are easily computed by using the minimum and maximum line and sample numbers.

The **perimeter** (circumferential distance) around an object boundary is obtainable from the boundary chain code by using the formula:

$$P = N_E + \sqrt{2}\, N_O$$

where N_E and N_O are the number of even and odd steps in the object boundary chain code.

The **area** of an object, which is a convenient measure of object size, is equal to the number of picture elements inside and including its boundary, multiplied by the area of a single pixel.

Shape Parameters

In addition to size parameters, shape parameters can be used to distinguish objects. Some shape parameters that are easily computed are described below.

The formula for computing the **rectangularity** R of an object is:

$$R = A_O / A_R$$

where A_O is the object area and A_R is the area of its minimum enclosing rectangle. R ranges from 0 to 1, with a value of 1.0 for rectangular objects, $\pi/4$ (0.785) for circular objects, and smaller values for slender, curved objects.

The **aspect ratio**, A, which is the ratio of width to length of the minimum enclosing rectangle of an object, is used to distinguish slender objects from roughly square or circular objects.

One of the commonly used **circularity** measures is:

$$C = P^2 / A$$

the ratio of the square of the object perimeter to its area, which reflects the complexity of the object boundary. C has a minimum value of 4π (12.56) for a circular object, while more complex shapes have higher values.

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MCS®-96 Diagnostic Library 7

THE MCS®-96 DIAGNOSTICS LIBRARY

Version X1.1

David Ryan
INTEL Corporation
October 1987

7

October 1987
Order Number: 270083-002

1.0 INTRODUCTION

In the real time world of microcontroller applications, system failures can be dangerous, and expensive. Preventing them, and understanding them when they occur, is very important to the reliability of any design.

The sources of a system upset are varied. But in general, the failure of a well designed application occurs as a result of either some form of noise, or a hardware failure. The 8096 hardware provides methods of detecting and recovering from the transient noise failures, while the MCS®-96 Diagnostics Library supplies software routines that can help diagnose or detect a failure in system hardware.

Graceful recovery from noise induced failures is possible using the WATCHDOG TIMER. While the 8096-based system is functioning as desired, the executing software periodically resets the WATCHDOG with a special two-byte code. If the WATCHDOG is not reset at least every 16 ms (12 MHz system), a system reset occurs. The two-byte code is a unique password which appears nowhere in the opcode map. This reduces the chance that an erroneous WATCHDOG reset would occur after a system upset.

The 8096 RESET instruction provides another form of protection. Since the opcode for a RESET is 0ffH, protection against the 8096 executing unimplemented external memory is obtained by placing pull-ups on the system bus. The RESET opcode is also the value in erased EPROMs. Therefore, any attempt to execute non-existent memory or an erased EPROM location causes the 8096 to execute the RESET instruction. RESET causes the 8096 to reinitialize itself and provide an external pulse on the RESET pin to reinitialize the system.

Even with the protection afforded by the 8096, a system is rarely complete without checks for hardware failures, both internal and external to the microcontroller. These checks are usually software routines that execute on power-up or periodically to verify that all parts of the system are present and function correctly. The tests generally execute standard check algorithms which are simply re-written in the host's assembly language.

To eliminate the need for every designer of an 8096-based system to write such tests, a collection of modular routines has been developed that any designer could easily use in his system (**General Diagnostics**). In addition, a set of 8096 interrupt service routines was developed for testing 8096 I/O units in a dedicated environment (**The Dynamic Stability Test**). Both sets of programs are contained in the **MCS-96 Diagnostics Library** (DIAG96.LIB).

This library is a collection of software modules that provide a number of ready-made **General Diagnostics** and a specialized MCS-96 diagnostic known as the **Dynamic Stability Test.** The **General Diagnostics** implement frequently used standard test algorithms, while the **Dynamic Stability Test** exercises hardware specific to the 8096.

The library can be considered a software "tool box" from which modules are selected for a variety of run-time diagnostics or laboratory tasks, for example:

- Include a few modules in other programs as a power-up test
- Use a memory module to create a map of external memory
- Use a few modules as a periodic system check
- Develop a simple stand-alone tester
- Build a custom test bed for burn-in, inspection or reliability tests
- Test new background code in an interrupt intensive environment

In addition to easing the development of a program that must perform standard diagnostics or system checks, the library can be a learning tool. Using the proven source code in the library, methods of interrupt management and on-chip peripheral handling can be reviewed to further understand how to use the 8096.

These tests were developed by the 8096 Applications group for experimental use with the 8096. With the programs in this library, the chip has been studied for its functional and asynchronous characteristics.

The General Diagnostics should be useful to almost anyone designing an 8096 application. The **Dynamic Stability Test** will be useful to those experimenting with the 8096 in a test environment. Figure 1 shows the modules in the **MCS-96 Diganostics Library.**

1.1 General Diagnostics

The General Purpose Diagnostics consist of 24 programs providing System, ALU and Memory tests. Each of the tests can be called independently, and none require special hardware or impose application limiting constraints.

Two Collected Test programs are also provided so that all tests may be called at once. A third Collected Test program executes a selection of **General Diagnostics** that might be reasonable to include in a typical system power-up.

Section 3 provides a detailed description of the **General Diagnostics.**

1.2 Dynamic Stability Test

The **Dynamic Stability Test** is an integrated set of 11 programs that provide the interrupt service routines necessary to run all forms of MCS-96 I/O concurrently while a user written main task is executing. Virtually all of the chip is made to run simultaneously, with the I/O units responding to asynchronous external events.

Unlike the **General Diagnostics,** the **Dynamic Stability Test** modules must all be linked together, and must run in a specific external environment.

Section 4 provides a detailed description of the **Dynamic Stability Test.**

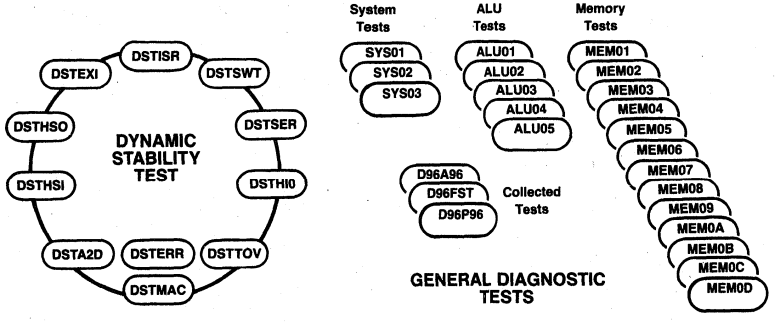

Figure 1. The MCS®-96 Diagnostic Library

1.3 How To Use This Manual

This publication is meant to be a guide for those using any of the programs in the **MCS-96 Diagnostics Library**. On a first pass the entire manual should be skimmed, with more attention paid to Section 2 and the overview sections of Sections 3 & 4. For the casual reader, the overview sections of each chapter should suffice.

Section 2 contains an overview of the general calling conventions to use any test in DIAG96.LIB. The section also describes DIAG96.LIB error reporting conventions and presents some warnings to heed when using this library.

Section 3 describes the classes of **General Diagnostics** and each test in detail.

Section 4 describes the concept of Dynamic Stability and its implementation on the 8096. The section also contains an overview of the tests performed, a description of the constraints placed upon the user-written background task, and detailed descriptions of each interrupt service routine.

The Appendices contain error code and command file descriptions, and of demonstration program listings. Source for the **MCS-96 Diagnostics Library** can be obtained from Insite User's Program Library at the address below. The Insite Catalog order number is AE-17.

Insite User's Program Library
INTEL Corporation DV2-24
2402 W. Beardsley Road
Phoenix, Arizona 85027

With the first-hand knowledge that many problems result from not being able to uncover information lodged in some dark corner of the user manual, information is repeated in the sections where it is pertinent.

2.0 USING THE LIBRARY

To simplify use of the diagnostics, the tests were developed in a modular fashion and collected in one linkable object file library (DIAG96.LIB). A modular program relies upon only the parameters sent at its invocation and employs standard parameter passing conventions to allow flexibility and uniformity of use. Collecting the modules into a library eliminates the tedium of listing twenty or thirty file names when performing a relocate/link on user developed code. When a program is linked to DIAG96.LIB, only those modules referenced in the user program are drawn from the library for inclusion in the output module.

Since PLM96 conventions were the ones chosen for this set of programs, the **General Diagnostics** are invoked by following the conventions for a PLM96 typed procedure. Parameters are placed on the STACK and the procedure activated via a function reference or explicit CALL. When the test is complete, test data is returned in the special register PLM$REG. The **Dynamic Stability Test** is not PLM96 compatible.

The next section describes the format of the test data that is returned by the diagnostics. Following sections give an overview of how to use a **General Diagnostics** test, how to use **The Dynamic Stability Test,** and what restrictions to keep in mind while using the library.

2.1 Reporting Convention

All DIAG96.LIB tests use the PLM$REG word locations 1CH and 1EH for returning condition codes to the calling program. Within DIAG96.LIB, these locations are the PUBLIC words EREG1 and EREG2. When a test concludes without finding an error, a zero is placed in the high byte of EREG1. If the high byte of EREG1 is non-zero, then some unexpected condition occurred. The low byte of EREG1 always contains the module number of the returning test, and EREG2 contains a detail code if an error was found. The complete listing of EREG1 code meanings and EREG2 meanings is in Appendices A & B.

All modules cease execution upon detection of the first error. The code describing which error was detected (EREG1) follows the format described in Table 1.

Table 1. Error Reporting Format

EREG1 =	nnmx Hex				
where;	nn = 00	if no error was found			
	= 01,. . .,08H	if an error was found, nn is the error code			
and;	mx = 0xH	for Test =	SYS0x;	1 ≤ x ≤ 03H	
	= 1xH		ALU0x;	1 ≤ x ≤ 05H	
	= 2xH		MEM0x;	1 ≤ x ≤ 0DH	
	= 3xH		D96A96;	x = 0	
	= 4xH		DSTISR;	x = 0	
	= 6xH		DSTHSI;	x = 1	
	= 7xH		DSTHSO;	x = 0	
	= 8xH		DSTHI0;	x = 0	
	= 9xH		DSTTOV;	0 ≤ x ≤ 1	
	= 0AxH		DSTEXI;	x = 0	
	= 0BxH		DSTSER;	x = 0	
	= 0CxH		DSTA2D;	x = 0	
	= 0DxH		DSTSWT;	0 ≤ x ≤ 1	
	= 0ExH		D96FST;	x = 0	
	= 0FxH		D96P96;	x = 0	

2.2 Using the General Diagnostics

The **General Diagnostics** provide a large set of system, ALU and memory tests that can be used in any combination, independent of system configuration or external circuitry. In addition to allowing for a wide flexibility in how a user's system is externally configured, the tests place minimal requirements on memory maps and interrupt environment.

Except where noted, all tests are interruptible, and maintain Program Status Word and Interrupt Mask integrity. The tests conform to PLM96 conventions, and require only run-time parameters to be passed for such specifics as memory test bounds and ALU test duration. To obtain access to the general diagnostics, the user should declare the needed module names EXTERNAL code segment symbols, and link to:

```
DIAG96.LIB
```

The tests are invoked in assembly language by placing the proper parameters on the STACK and CALLing the procedure. In PLM, the tests are run after a function reference is made with the appropriate parameters. The following is an example of an ASM96 call to a memory test:

```
PUSH    #4000h
PUSH    #5000h
CALL    MEM06
CMPB    EREG1+1,0
BNE     Error_Found
```

The diagnostic module called performs a complementary address test on the byte locations between 4000H and 5000H inclusive. If an error is found, the value returned in the word EREG1 will have a non-zero value as its high byte. Also in the case of an error, the MEM06 memory test will place the address of the error in location EREG2. The program D96A96, shown in Appendix D is a working ASM96 example that calls every **General Diagnostic** Test.

The same memory test could be called in a PLM96 program as follows:

```
Response = MEM06(4000h,5000h);
IF Error$Codes.Number > 255 THEN CALL Error$Found;
```

Since the diagnostics return two words in the PLM$REG locations 1CH and 1EH, the function MEM06 would be a PROCEDURE of type LONG. Error$Codes would have to be declared a STRUCTURE AT Response, with the word elements Number and Detail so that the error messages returned by the diagnostic can be stored. Number would contain the EREG1 value returned by the test, and Detail would contain EREG2. Response would have to be DECLARED a double word. The program D96P96, shown in Appendix D is a working PLM96 example that calls every **General Diagnostic.**

The action taken when an error is detected will depend upon the application. For example, the following Error_Found (or Error$Found) routine would output the error codes to a printer or terminal:

```
Error_Found:
  PUSHF
  PUSH    #Message_Ptr_A
  CALL    Send_String

  PUSH    EREG1
  CALL    Send_Hex_Word
  CALL    Send_CR_LF
  PUSH    #Message_Ptr_B
  CALL    Send_String
```

```
Error$Found:  PROCEDURE;
              DISABLE

              CALL output (.Message$Ptr$A,
                           Error$Codes.Number);

              CALL output (.Message$Ptr$B,
                           Error$Codes.Detail);
Self:         GOTO Self;
```

(Display continues on next page)

```
        PUSH    EREG2
        CALL    Send_Hex_Word
        CALL    Send_CR_LF
        BR $

Message_Ptr_A:
    DCB 27,'ERROR FOUND. Error Number = '
Message_Ptr_B:
    DCB 22,'Error Detail Code is = '
```

In the Error_Found routine, it is assumed that the subroutines Send_String, Send_Hex_Word, and Send_CR_LF transmit appropriate ASCII codes given the parameters passed to them. Send_String is sent a pointer to a byte string in memory, the first byte of which is the character count. Send_Hex_Word converts the word put on the STACK into the correct four ASCII code bytes and appends the ASCII code for H. Send_CR_LF outputs the ASCII codes to cause a carriage return, followed by a line feed. The PLM routine output would perform similar operations.

2.3 Using the Dynamic Stability Test

The **Dynamic Stability Test** consists of a set of 8096 interrupt service routines that are designed to run while a user-supplied background task executes. The routines are located in the object file library DST96.LIB, which is contained in the master library DIAG96.LIB. To obtain access to the test, the user should invoke the batch file DSTRL.BAT with the background task file name and directory parameters. For example type:

```
DSTRL \ SOURCE \ BACK
```

Since the interrupt service routines test 8096 on-chip I/O devices, the part under test must reside in a specified hardware environment. Two such environments are available for use with the **Dynamic Stability Test.** The test may run in either a single chip mode, or a cross-coupled two chip mode. Figures 2 and 3 show the connections required for each configuration. In the single chip mode, output pins are connected to input pins on the same 8096. In the dual chip mode, output pins of one 8096 are connected to the input pins of the other (and vice versa).

To run the test, the user must supply a background task that CALLs an initialization routine (DSTISR) with the specified parameters. After DSTISR returns, the interrupt service routines will begin running. The background task can then perform any function that conforms to the constraints discussed in Section 4. If the user does not wish to write a special background task, one is provided in the module DSTUSR.

The following is an example CALL and a description of the parameters that must be passed to the initialization module (DSTISR).

```
PUSH    <RAM segment1 starting address>
PUSH    <RAM segment1 ending address>
PUSH    <RAM segment2 starting address>
PUSH    <RAM segment2 ending address>
PUSH    <random seed>
PUSH    <random test length>
PUSH    <argument1 for Multiply/Divide Core test>
PUSH    <argument2 for Multiply/Divide Core test>
PUSH    <bit pattern for memory test>
CALL    DSTISR
```

The RAM starting and ending addresses form a memory map for the memory tests that DSTISR runs. The internal RAM is always tested. The random seed is the starting point for ALU tests that execute for as many number pairs as is specified in the random test length parameter. Argument1 and argument2 are the operands for a Multiply/Divide test. The bit pattern parameter is used during a memory test of the internal RAM and the memory segments specified.

Section 4 contains more detailed information on using the **Dynamic Stability Test**, while the next section lists some general restrictions and assumptions that need to be understood to properly use any **MCS-96 Diagnostic Library** module.

2.4 Restrictions and Assumptions

Some general restrictions and assumptions need to be understood before any DIAG96.LIB programs can be successfully used.

- Pay close attention to the warnings about STACK location in the test modules you use. If you use any of the specialized internal register tests, make sure that the STACK is located externally. Do not partition a region of memory that contains your STACK in any memory test, unless you first move the STACK to an area you already tested.
- All **General Diagnostics** assume that the WATCHDOG TIMER is either being RESET by an interrupt service routine created by the user, or that it was never enabled. Only SYS02 ever locks out interrupts for a significant period of time. The amount of time they are locked out depends upon the parameters passed.
- **The Dynamic Stability Test** takes care of the WATCHDOG TIMER within its interrupt service routines. But, do not write to the WATCHDOG before CALLing the initialization subroutine.
- In any Dynamic Stability application, the user's Main Task should not lock out interrupts for more than a few instructions, as the CPU can get quite loaded down with interrupt requests that are very time dependent.

3.0 GENERAL DIAGNOSTICS

The 24 **General Diagnostics** included in DIAG96.LIB provide a good set of basic memory and ALU confidence tests that can be easily linked to application programs.

The **General Diagnostics** allow for a wide flexibility in how a user's system is configured with respect to memory maps and interrupt environment. Except where noted, all tests are interruptible, and maintain Program Status Word and interrupt mask integrity. The tests conform to PLM96 conventions, and require only run-time parameters to be passed for such specifics as memory test bounds and ALU test duration.

The tests are independent to allow specialized diagnostics to be developed as desired. Use just the quick power-up test (SYS02) to verify operation, or use the module that calls all **General Diagnostics** (D96A96) and let it run continuously for months. A module that performs the most common set of tests is also provided (D96FST).

The tests provided are of four classes: System Tests (SYSnn), ALU Tests (ALUnn), Memory Tests (MEMnn), and Collected Tests (D96xxx). To use any of the modules, from zero to ten parameters are PUSHed onto the STACK and the test is CALLed. Results are returned in the two word registers beginning at #1CH. The symbolic names for these locations (EREG1 and EREG2) are made PUBLIC if any DIAG96.LIB module is linked. They also may be referenced in PLM$REG for PLM96 programs.

To obtain access to library modules, the user should declare the needed module names EXTERNAL code segment symbols, and link to:

```
DIAG96.LIB
```

The next few pages contain a brief overview of each of the four classes of tests. Then, the actions of each test are described in more detail.

System Tests

```
SYSnn
```

Common symbol definitions, storage reservations and two common routines are located in SYS01. A reference to any DIAG96.LIB module will cause SYS01 to be linked. SYS02 is meant to be called immediately after a RESET. It checks the special function register status and stack pointer, program status word and timer functionality. SYS03 is a simple program counter test. It does not test the complete range of the counter, and requires external RAM to execute.

```
SYS01: Common module
SYS02: RESET test
SYS03: Program counter exercise
```

ALU Tests

```
ALUnn
```

Five ALU modules are provided for checking ALU functionality. All report errors with a code in EREG1/EREG2.

Addition and subtraction are exercised in ALU01. A special eight-word add and subtract

is executed to test each adder bit with all possible combinations of a bit operation with and without carry-in.

Unsigned byte multiplication is verified by ALU02. This module simply executes all possible unsigned byte multiplications. Although not elegant, the test is effective. It takes six seconds.

A general test of the multiplication and division functions can be made with ALU03. The module executes all possible combinations of signed and unsigned, byte and word, two and three operand Multiplies and Divides using a specially selected table of numbers as operands.

ALU04 extends the ALU03 test by generating pseudo-random test pairs. The user program simply specifies a seed value for the random number generator, and the number of pairs to generate.

ALU05 is the core module for multiply/divide tests. Both ALU03 and ALU04 call ALU05. The user can also call ALU05 by passing a pair of test arguments. The module executes all possible combinations of signed and unsigned, byte and word, two and three operand Multiplies and Divides using the arguments passed as operands.

ALU01: Table-driven Addition/Subtraction
ALU02: MULUB (all possible arguments)
ALU03: Table-driven Multiply/Divide
ALU04: Pseudo-random Multiply/Divide
ALU05: Multiply/Divide core module

Memory Tests

MEMnn

The DIAG96.LIB MEMnn modules provide tests for register space, external RAM, and ROM. The algorithms used include: walking and galloping ones; walking and galloping zeros; checkerboard patterns; complementary addressing; and checksum verification.

The register tests are in MEM01-MEM05, and MEM0C. With the exception of MEM04, the register tests save the contents of all internal registers except PLM$REG on the STACK before testing, and restore the data when done. If a faulty location is found, its address is reported. MEM04 is a utility which returns the number of bits set in a specified operand.

The external RAM tests are located in MEM06-MEM0A, and MEM0D. They all return a two-word code upon completion. The calling program must partition the RAM to be tested before calling an external RAM test.

Table 2. Memory Tests

Algorithm	Internal Registers	External RAM	ROM
Complementary Address	MEM01	MEM06	
Walking Ones		MEM07	
Walking Ones/Zeros	MEM02	MEM09	
Galloping Ones		MEM08	
Galloping Ones/Zeros	MEM03	MEM0A	
Bit Counter	MEM04		
Checkerboard Pattern	MEM05		
User Specified Pattern	MEM0C	MEM0D	
Checksum	MEM0B	MEM0B	MEM0B

Collected Tests

D96xxx

The D96xxx set of modules collects together all, or several, of the General Diagnostics and performs them according to the parameters passed. D96A96 is an ASM96 module that calls all tests. D96P96 is a PLM96 module that calls all tests. D96FST is an ASM96 module that calls a logical selection of tests.

D96A96:	All tests	/ ASM96
D96P96:	All tests	/ PLM96
D96FST:	Selection of tests	/ ASM96

3.1 System Tests

Common Symbols (SYS01)

Brief Description:

This module contains the global symbol declarations and five utilities used by the **General Diagnostics.**

Assembly Language Calling Sequence:

```
CALL    Get_Psw
    or
CALL    Put_Psw
    or
CALL    Get_Parms
    or
CALL    Stack_Ram
    or
CALL    Restore_Ram
```

Get_Psw Action:

USER_PSW := **PSW**
EREG1 := 0
EREG2 := 0ffffh

Put_Psw Action:

PSW := **USER_PSW**

Get_Parms Action:

PARM2 := Last Parameter
put on the **STACK**
PARM1 := Next to last parameter
put on the STACK
USER_PSW := **PSW**
EREG1 := 0fffh
EREG2 := 0000h

Stack_Ram Action:

PUSH 1aH;
Ptr := 20H
Do While Ptr<100h;
PUSH [Ptr]+
End While;

Restore_Ram Action:

Ptr := 0feh;
Do While Ptr>1eh;
POP [Ptr];
Ptr: = Ptr-2;
End While;
POP 1aH;

Detailed Description:

A call to any **General Diagnostic** module will cause SYS01 to be linked. This module contains the definition of 4 words of memory used by every module to report errors and store temporary parameters. The STACK routines are used by the internal register tests to save and restore the data in the registers when called. It also INCLUDES an expanded 8096.INC file to provide the PUBLIC declarations of commonly used symbols for the special function registers and constants such as CR and LF.

Nearly all General Diagnostic modules use the routines in SYS01 to save the PSW when called, restore the PSW when returning control to the calling routine, save parameters from the STACK, and initialize the error registers.

System Power-up (SYS02)

Brief Description:

This test is a quick check of the Program Status Word, TIMER1, IOS0,IOS1 and the Interrupt Pending Register. It is meant to be called just after a RESET.

Assembly Language Calling Sequence:

```
CALL    SYS02
```

When Test Passes:

EREG1 := 0002h **EREG2** := 0000h

If Test Fails:

EREG1 := 0102h on unexpected IOS0 or IOS1	— **EREG2** :=	**IOS0** in low byte **IOS1** in high byte
EREG1 := 0202h if **TIMER1** does not change	— **EREG2** :=	**TIMER1**
EREG1 := 0302h if Zero register failed	— **EREG2** :=	**PSW** at Failure
EREG1 := 0402h if **PUSHF/POPF** failed	— **EREG2** :=	erroneous value found
EREG1 := 0502h if Sticky bit failed	— **EREG2** :=	3fffh if bit did not set
	:=	0000h if bit did not clear
EREG1 := 0602h if Carry Flag failed	— **EREG2** :=	xxxxh
EREG1 := 0702h on an overflow flag error	— **EREG2** :=	0002h if flags set wrong
	:=	xxxxh flags cleared wrong
EREG1 := 0802h if Int. Pending byte failed	— **EREG2** :=	offending Int. Pend. value

Detailed Description:

This module verifies that TIMER1 is changing, then attempts to change the value in the ZERO register. Then, a set of PUSHFs and POPFs is done with test values to verify correct action of these instructions. The carry, sticky and overflow bits in the program status word are then tested. Finally, the Interrupt Pending register bits are tested for their ability to be set and cleared. Any unexpected result is reported.

Any error found having to do with the PUSHF/POPF instructions or the PSW, including Interrupt Pending, will cause interrupts to be disabled before returning to the calling module.

Program Counter (SYS03)

Brief Description:

This test writes code into a user selected partition of RAM and executes the code. Elapsed time and special registers are checked for correctness.

Assembly Language Calling Sequence:

```
PUSH    <start address>
PUSH    <end address>
CALL    SYS03
```

When Test Passes:

EREG1 := 0003h
EREG2 := 0000h

If Test Fails:

EREG1 := 0103h if test code returned early
EREG2 := Early time

EREG1 := 0203h if test code returned late
EREG2 := Late time

EREG1 := 0303h if count register is incorrect
EREG2 := erroneous counter value

Detailed Description:

This module accepts starting and ending addresses for an external RAM partition, adjusts the boundaries to be double word aligned, and writes three lines of code repeatedly into the partition. The code that is written increments a counter then executes two NOPs every 12 state times. The last byte written into the RAM partition is a RET opcode.

After the RAM partition is adjusted and the code written into the RAM, the test puts a return address on the STACK, stores TIMER1 and CALLs the first byte of the RAM. When the last byte of RAM is executed, program control returns to SYS03. TIMER1 is again stored. The test then compares the elapsed time to the expected elapsed time. The value remaining in the counter is also checked for correctness. Any deviations from expected are reported.

Caution: Since interrupts are locked-out while the code in RAM is executing, partitioning more than 4000h bytes of RAM for this test could cause a WATCHDOG TIMER overflow if the watchdog was started before SYS03 is called.

3.2 ALU Tests

Add/Subtract (ALU01)

Brief Description:

This routine adds then subtracts two carefully selected eight-word variables and verifies the results.

Assembly Language Calling Sequence:

```
CALL    ALU01
```

When Test Passes:

EREG1 := 0011h
EREG2 := 0000h

If Test Fails:

EREG1 := 0111h on an addition error
:= 0211h on a subtraction error
:= 0311h on a flag error

EREG2 := offending argument on error

Detailed Description:

Two eight-word operands are added together and the results verified. Then, the operands are subtracted and verified. The operands were chosen to exercise every possible combination of two bits and a carry into each bit of the adder. Correctness of the result and the resultant flags is verified.

The operands are:

```
  05555AAAA5555AAAAFFFF0000AAAA5555H
+ 05555AAAAAAAA5555FFFF00005555AAAAH
  0AAAB555500000000FFFE0000FFFFFFFFH

  05555AAAAAAAA5555FFFF00005555AAAAH
- 0AAAA5555AAAA55550000FFFF5555AAAAH
  0AAAB555500000000FFFE0000FFFFFFFFH
```

Some versions of SIM96 do not pass this test.

MULUB (ALU02)

Brief Description:

This module simply tests the MULUB instruction for all possible combinations of byte multipliers and multiplicands.

Assembly Language Calling Sequence:

```
CALL    ALU02
```

When Test Passes:

EREG1 := 0012h
EREG2 := 0000h

If Test Fails:

EREG1 := 0112h on an error
EREG2 := multiplier/multiplicand

Detailed Description:

This test executes all possible combinations of operands into the MULUB instruction. Results are verified through a method of addition and subtraction as operands cycle. The status of PSW flags is not verified in this routine.

Multiply/Divide Table (ALU03)

Brief Description:

This module sends a specially constructed table of operands through the general Multiply/Divide Core test (ALU05).

Assembly Language Calling Sequence:

```
CALL    ALU03
```

When Test Passes:

EREG1 := 0013h
EREG2 := 0000h

If Test Fails:

EREG1 := 0115h on a signed error
:= 0215h on an unsigned error
:= 0315h on a flag error

EREG2 := offending argument on error

Detailed Description:

This test sends a table of operands through the Multiply/Divide Core test. The 18 operands were selected to exercise all of the hardware multiply and divide control signals.

The operands are:

Arg.1,Arg.2	Arg.1,Arg.2
1D99H, 0FFFFH	0FFFH, 9D99H
9D99H, 5555H	5555H, 0E266H
0E266H, 0AAAAH	0AAAAH, 1D99H
1D99H, 5555H	5555H, 9D99H
9D99H, 0AAAAH	0AAAAH, 0E266H
0E266H, 0FFFFH	0FFFFH, 0063H
0063H, 0055H	0055H, 0066H
0066H, 00AAH	00AAH, 0063H
0063H, 00FFH	

Some versions of SIM96 will not pass this test.

Multiply/Divide Random (ALU04)

Brief Description:

This module is a pseudo-random number generator that sends pairs of arguments to the Multiply/Divide Core test (ALU05).

Assembly Language Calling Sequence:

```
PUSH    <seed>
PUSH    <count>
CALL    ALU04
```

When Test Passes:

EREG1 := 0014h
EREG2 := 0000h

If Test Fails:

EREG1 := 0115h on a signed error
:= 0215h on an unsigned error
:= 0315h on a flag error

EREG2 := offending argument on error

Detailed Description:

This module first executes the table driven Multiply/Divide test (ALU03). Then, if passed, pseudo-random argument pairs are generated and fed into the generalized Multiply/Divide Test (ALU05). The parameters passed to ALU04 set the random number seed, and the duration of the test.

There is no restriction on the values passed to the test. However, it must be noted that all possible combinations of signed and unsigned, byte and word, two and three operand Multiply/Divides are done at least twice for each pair of arguments sent to ALU05. Each such test takes from 1 to 5 milliseconds depending upon the arguments. Therefore, if large values for the count parameter are selected, the test will be long. For example, 1000h as a count will take about 12 seconds, depending upon the seed. NOTE: Some versions of SIM96 will not pass this test.

The formula used to generate the number pairs is as follows:

$$X(n+1) = [(0101h + 0001h) * X(n) + 0001h] \text{ MOD } 0ffffh$$
where X(0) = seed

Multiply/Divide Core (ALU05)

Brief Description:

This test performs a Divide/re-Multiply sequence for all possible combinations of two or three operand, signed or unsigned, byte or word operations using the arguments passed to it as operands. The results are verified.

Assembly Language Calling Sequence:

```
PUSH    <argument1>
PUSH    <argument2>
CALL    ALU05
```

When Test Passes:

EREG1 := 0015h
EREG2 := 0000h

If Test Fails:

EREG1 := 0115h on a signed error
:= 0215h on an unsigned error
:= 0315h on a flag error

EREG2 := offending argument on error

Detailed Description:

This module takes arguments from a calling program and performs upon them all possible combinations of byte or word, two or three operand, signed or unsigned multiplication and division. Argument2 is used to create the high and low words for a word Divide, and the low byte of Argument1 is used as the divisor in a byte Divide.

The test checks multiplication and division by first dividing one operand by the other, then multiplying the quotient by the divisor and adding the remainder. If the result is the original dividend, the operations were correct. However, the possibility of legitimate division overflows must also be considered.

The test first performs a division and checks flag status for correct indication of overflow conditions. If there has been an overflow, the dividend is right shifted by one, the expected result is updated, and the division is performed over. If a division by zero occurred, just the expected result is corrected and the test is continued.

After a division and overflow check/fixup is complete, a re-multiplication occurs and the result verified. Flag status is also verified. If the results are correct, the original operands are reloaded into the test operand registers and the next Divide/re-Multiply combination is begun.

All Divide/Multiply combinations are performed twice. Once with flags set upon entry, and once with flags clear upon entry.

CALLing ALU03 will run a specially selected table of operands through this test. CALLing ALU04 will run a pseudo-random string of operands through this test.

3.3 Memory Tests

Complementary Address (MEM01) (for registers)

Brief Description:

This module performs a complementary address test on the registers locations 1ah to 0ffh.

Assembly Language Calling Sequence:

```
CALL    MEM01
```

When Test Passes:	If Test Fails:
EREG1 := 0021h	**EREG1** := 0121h
EREG2 := 0000h	**EREG2** := address of the error

Detailed Description:

This module performs a simple address and integrity test on register locations 1ah-0ffh. The algorithm stores the value NOT(ADDRESS) in the location pointed to by ADDRESS for the range, then loops through memory again to verify the contents.

Caution: If the STACK is partially internal, the STACK POINTER must be pointing at least 260 bytes into external RAM at the time MEM01 is called. The STACK cannot be entirely internal. The arithmetic flags in the PSW are undefined after execution of MEM01.

Walking Ones/Zeros (MEM02) (for registers)

Brief Description:

This module performs a Walking Ones and Zeros test on the internal registers 1ah-0ffh.

Assembly Language Calling Sequence:

```
CALL    MEM02
```

When Test Passes:	If Test Fails:
EREG1 := 0022h	**EREG1** := 0122h
EREG1 := 0000h	**EREG2** := address of the error

Detailed Description:

This module performs a Walking Ones and Zeros test on the internal registers.

The Walking Ones memory test first loads zero in all locations to be tested. Then, ones are placed in the first byte of memory, followed by a verification of all locations. Next, the first location is zeroed and ones are loaded into the second location. All memory is again verified. This process continues until all locations have been loaded with ones.

The Walking Zeros memory test works exactly like Walking Ones, except that a zero is "walked" through memory filled with ones, instead of ones being walked through a memory filled with zeros.

Caution: If the STACK is partially internal, the STACK POINTER must be pointing at lest 260 bytes into external RAM at the time MEM02 is called. The STACK cannot be entirely internal. The arithmetic flags in the PSW are undefined after execution of MEM02.

Galloping Ones/Zeros (MEM03) (for registers)

Brief Description:

This module performs a Galloping Ones and Zeros test on the internal registers 1ah-0ffh.

Assembly Language Calling Sequence:

```
CALL    MEM03
```

When Test Passes:	If Test Fails:
EREG1 := 0023h	**EREG1** := 0123h
EREG2 := 0000h	**EREG2** := address of the error

Detailed Description:

This module performs a Galloping Ones and Zeros test on internal registers.

The Galloping Ones algorithm tests memory by first loading zeros into all locations. Then ones are loaded into the first byte and all memory is verified. The verification is done by alternating reads to the first location and locations through all memory. Next, ones are placed in the second location without altering the first. Verification is again performed by alternating reads to the second location and the rest of memory. This process continues until all locations contain ones.

The Galloping Zeros test is similar to Galloping Ones, except that zeros slowly fill a memory filled with ones. In Galloping Ones, ones slowly fill a memory filled with zeros.

Caution: If the STACK is partially internal, the STACK POINTER must be pointing at least 260 bytes into external RAM at the time MEM03 is called. The STACK cannot be entirely internal. The arithmetic flags in the PSW are undefined after execution of MEM03.

Bits Set (MEM04)

Brief Description:

This module returns the number of bits set in the parameter passed to the routine.

Assembly Language Calling Sequence:

```
PUSH    test_value
CALL    MEM04
```

When All Bits Zero:	When One or More Bits Set:
EREG1 := 0024h	**EREG1** := 0124h
EREG2 := 0000h	**EREG2** := number of bits set

Detailed Description:

This module returns the number of bits that are set in the low byte of the parameter passed to the test. Any addressing mode may be used to put a value on the STACK, but the parameter on the STACK is treated as an immediate value.

Checkerboard Pattern (MEM05) (for registers)

Brief Description:

This module performs a Checkerboard Pattern test on the internal registers 1ah-0ffh.

Assembly Language Calling Sequence:

```
CALL    MEM05
```

When Test Passes:	If Test Fails:
EREG1 := 0025h	**EREG1** := 0125h
EREG2 := 0000h	**EREG2** := address of the error

Detailed Description:

This module performs a checkerboard test on the internal registers. A checkerboard pattern of ones and zeros is written into the physical rows and columns of the 8096 register space. As the pattern is being written, it is repeatedly verified. After the entire pattern is in place, the memory is verified again, complemented, and re-verified.

Caution: If the STACK is partially internal, the STACK POINTER must be pointing at least 260 bytes into external RAM at the time MEM05 is called. The STACK cannot be entirely internal. The arithmetic flags in the PSW are undefined after execution of MEM05.

Complementary Address (MEM06)

Brief Description:

This module performs a complementary address test on the memory partitioned by user supplied pointers.

Assembly Language Calling Sequence:

```
PUSH    <start address>
PUSH    <end address>
CALL    MEM06
```

When Test Passes:	If Test Fails:
EREG1 := 0026h	**EREG1** := 0126h
EREG2 := 0000h	**EREG2** := offending address

Detailed Description:

This module performs a simple address and integrity test on RAM locations partitioned by the parameters passed. The algorithm stores the value NOT(ADDRESS) in the location pointed to by ADDRESS for the range, then loops through memory again to verify the contents.

Caution: Do not partition RAM that contains valid STACK elements.

Walking Ones (MEM07)

Brief Description:

This module performs a Walking Ones Test on the memory partitioned by the user.

Assembly Language Calling Sequence:

```
PUSH    <start address>
PUSH    <end address>
CALL    MEM07
```

When Test Passes:	If Test Fails:
EREG1 := 0027h	**EREG1** := 0127h
EREG2 := 0000h	**EREG2** := offending address

Detailed Description:

This module performs a Walking Ones test on the memory partitioned by the calling program. The Walking Ones memory test first loads zero in all locations to be tested. Then, ones are placed in the first byte of memory, followed by a verification of all locations. Next, the first location is zeroed and ones are loaded into the second location. All memory is again verified. This process continues until all locations have been loaded with ones.

Caution: Do not partition RAM that holds valid elements of the STACK. And, execution time increases non-linearly with memory partition widths.

Galloping Ones (MEM08)

Brief Description:

This module performs a Galloping Ones test on memory partitioned by the calling program.

Assembly Language Calling Sequence:

```
PUSH    <start address>
PUSH    <end address>
CALL    MEM08
```

When Test Passes:	If Test Fails:
EREG1 := 0028h	**EREG1** := 0128h
EREG2 := 0000h	**EREG2** := offending address

Detailed Description:

This module performs a Galloping Ones test on memory locations partitioned by the calling program.

The Galloping Ones algorithm tests memory by first loading zeros into all locations. Then ones are loaded into the first byte and all memory is verified. The verification is done by alternating reads to the first location and locations through all memory. Next, ones are placed in the second location without altering the first. Verification is again performed by alternating reads to the second location and the rest of memory. This process continues until all locations contain ones.

Caution: Do not partition locations that contain valid elements of the STACK. And, execution time increases non-linearly with memory partition widths.

Walking Ones/Zeros (MEM09)

Brief Description:

This module performs a Walking Ones and Zeros test on the memory locations partitioned by the calling program.

Assembly Language Calling Sequence:

```
PUSH    <start address>
PUSH    <end address>
CALL    MEM09
```

When Test Passes:	If Test Fails:
EREG1 := 0029h	**EREG1** := 0129h
EREG2 := 0000h	**EREG2** := offending address

Detailed Description:

This module performs a Walking Ones and Zeros test on the memory partitioned by the calling program.

The Walking Ones memory test first loads zero in all locations to be tested. Then, ones are placed in the first byte of memory, followed by a verification of all locations. Next, the first location is zeroed and ones are loaded into the second location. All memory is again verified. This process continues until all locations have been loaded with ones.

The Walking Zeros memory test works exactly like Walking Ones, except that a zero is ''walked'' through memory filled with ones, instead of ones being walked through a memory filled with zeros.

Caution: Do not partition RAM that contains valid elements of the STACK. And, execution time increases non-linearly with memory partition widths.

Galloping Ones/Zeros (MEM0A)

Brief Description:

This module performs a Galloping Ones and Zeros test on the memory locations partitioned by the calling program.

Assembly Language Calling Sequence:

```
PUSH    <starting address>
PUSH    <ending address>
CALL    MEM0A
```

When Test Passes:

EREG1 := 002Ah
EREG2 := 0000h

If Test Fails:

EREG1 := 012Ah
EREG2 := offending address

Detailed Description:

This module performs a Galloping Ones and Zeros test on memory partitioned by the calling program.

The Galloping Ones algorithm tests memory by first loading zeros into all locations. Then ones are loaded into the first byte and all memory is verified. The verification is done by alternating reads to the first location and locations through all memory. Next, ones are placed in the second location without altering the first. Verification is again performed by alternating reads to the second location and the rest of memory. This process continues until all locations contain ones.

The Galloping Zeros test is similar to Galloping Ones, except that zeros slowly fill a memory filled with ones. In Galloping Ones, ones slowly fill a memory filled with zeros.

Caution: Do not partition RAM that contains valid elements of the STACK. And, execution time increases non-linearly with memory partition widths.

Checksum (MEM0B)

Brief Description:

This module calculates a 16 bit checksum for the memory partition specified by the calling program.

Assembly Language Calling Sequence:

```
PUSH    <starting address>
PUSH    <ending address>
CALL    MEM0B
```

Test Returns:

EREG1 := 012bh
EREG2 := 16-bit checksum

Detailed Description:

This module performs a 16-bit checksum on the region of memory partitioned by the calling program. RAM or ROM may be partitioned. The module is non-destructive to RAM.

User Pattern (MEM0C) (for registers)

Brief Description:

This module performs a Checkerboard Pattern test on the internal registers 1ah-0ffh with a user specified bit pattern.

Assembly Language Calling Sequence:

```
PUSH    <desired bit pattern>
CALL    MEM0C
```

When Test Passes:	If Test Fails:
EREG1 := 002Ch	**EREG1** := 012Ch
EREG2 := 0000h	**EREG2** := address of the error

Detailed Description:

This module performs a checkerboard test on the internal registers with the bit pattern specified by the calling program. The pattern is written into the physical rows and columns of the 8096 register space. As the pattern is being written, it is repeatedly verified. After the entire pattern is in place, the memory is verified again, complemented, and re-verified.

Caution: If the STACK is partially internal, the STACK POINTER must be pointing at least 260 bytes into external RAM at the time MEM0C is called. The STACK cannot be entirely internal. The arithmetic flags in the PSW are undefined after execution of MEM0C.

User Pattern (MEM0D)

Brief Description:

This module performs a Checkerboard Pattern test on a specified region of memory with a specified pattern of bits.

Assembly Language Calling Sequence:

```
PUSH    <starting address>
PUSH    <ending address>
PUSH    <bit pattern>
CALL    MEM0D
```

When Test Passes:	If Test Fails:
EREG1 := 002dh	**EREG1** := 012dh
EREG2 := 0000h	**EREG2** := offending address

Detailed Description:

This module performs a checkerboard test on a region of memory that is specified by the calling program using a bit pattern which is also specified. First, the pattern is written into memory. As the pattern is being written, it is repeatedly verified. After the entire pattern is in place, the memory is verified again, complemented, and re-verified.

Caution: Do not partition RAM that contains valid elements of the STACK.

3.4 Collected Tests Modules

ALL Tests in ASM96 (D96A96)

Brief Description:

This module causes every **General Diagnostics** test to execute.

Assembly Language Calling Sequence:

```
PUSH    <RAM segment1 starting address>
PUSH    <RAM segment1 ending address>
PUSH    <RAM segment2 starting address>
PUSH    <RAM segment2 ending address>
PUSH    <random seed>
PUSH    <random test length>
PUSH    <top of code address>
PUSH    <argument1 for Multiply/Divide Core test>
PUSH    <argument2 for Multiply/Divide Core test>
PUSH    <bit pattern for memory test>
CALL    D96A96
```

When Tests All Pass:

EREG1 := 0030h
EREG2 := code checksum

When a Test Fails:

EREG1 := test module error code
EREG2 := test module detail code

Detailed Description:

This module calls all **General Diagnostics** using the parameters passed by the calling program. The parameters needed by the test for proper execution specify two areas of external RAM for memory tests, the ending address of code to be checksummed, the seed and length of the random ALU test, two specific arguments to do the Multiply/ Divide Core test, and a bit pattern for memory tests.

Execution speed of this test is highly dependent upon the memory partitions and the length requested for the random ALU test. For example, partitioning 1k and 8k regions of memory, and calling for 1000h random ALU tests, the test takes 3 hours to complete. Testing smaller regions of memory (i.e. 1k and 1k) can reduce test time to a few minutes.

Caution: An external STACK must be used with this test, and it must be in a part of memory outside that partitioned during the CALL.

ALL Tests in PLM96 (D96P96)

Brief Description:

This module causes every **General Diagnostics** test module to execute.

PLM96 Calling Sequence:

```
D96P96(RAM segment1 starting address,
       RAM segment1 ending address,
       RAM segment2 starting address,
       RAM segment2 ending address,
       random seed, random test length,
       top of code address,
       argument1 for Multiply/Divide Core test,
       argument2 for Multiply/Divide Core test,
       bit pattern for memory tests);
```

When All Tests Pass:

PLMREG := 00F0h
PLMREG+2 := 16-bit checksum

When a Test Fails:

PLMREG := module error code
PLMREG+2 := module detail code

Detailed Description:

This module calls all **General Diagnostics** using the parameters passed during invocation. The parameters needed by the test for proper execution specify two areas of external RAM for memory tests, the ending address of code to be checksummed, the seed and length of the random ALU test, two specific arguments to do the Multiply/Divide Core test, and a bit pattern for memory tests.

Execution speed of this test is highly dependent upon the memory partitions and the length requested for the random ALU test. For example, partitioning 1k and 8k regions of memory, and calling for 1000h random ALU tests, the test takes 3 hours to complete. Testing smaller regions of memory (i.e. 1k and 1k) can reduce test time to a few minutes.

In his program, the user will have to DECLARE D96P96 an external procedure of the LONG type, with its parameters declared SLOW. The EREG1 and EREG2 values reported by library modules are placed in the long-word location at PLM$REG.

The DECLARations in D96P96 show how any one General Diagnostic Module could be called from a PLM96 program. Each needed module needs to be DECLAREd an external procedure of the LONG type.

Caution: An external STACK must be used with this test, and it must be in a part of memory outside that partitioned during the CALL.

Selected Tests in ASM (D96FST)

Brief Description:

This is an ASM module that invokes a selected set of **General Diagnostic** tests.

Assembly Language Calling Sequence:

```
PUSH    <RAM segment1 starting address>
PUSH    <RAM segment1 ending address>
PUSH    <RAM segment2 starting address>
PUSH    <RAM segment2 ending address>
PUSH    <random seed>
PUSH    <random test length>
PUSH    <top of code address>
PUSH    <argument1 for Multiply/Divide Core test>
PUSH    <argument2 for Multiply/Divide Core test>
PUSH    <bit pattern for memory test>
CALL    D96FST
```

When Tests All Pass:

EREG1 := 00E0h
EREG2 := code checksum

When a Test Fails:

EREG1 := test module error code
EREG2 := test module detail code

Detailed Description:

This module calls the Power-up and Program Counter tests then all ALU tests. Then, Complementary Address, Galloping Ones/Zeros and Checkerboard tests are run on the internal registers. Finally, Complementary Address and specified pattern tests are done on external memory and the program is checksummed.

The parameters needed by the test for proper execution specify two areas of external RAM for memory tests, the ending address of code to be checksummed, the seed and length of the random ALU test, two specific arguments to do the Multiply/Divide Core test, and a bit pattern for memory tests.

Execution speed of this test is highly dependent upon the memory partitions and the length requested for the random ALU test. For example, partitioning 1k and 8k regions of memory, and calling for 1000h random ALU tests, the test takes about 20 seconds to complete. Testing smaller regions of memory (i.e. 1k and 1k) can reduce test time further.

Caution: An external STACK must be used with this test, and it must be in a part of memory outside that partitioned during the CALL.

4.0 THE DYNAMIC STABILITY TEST

The **Dynamic Stability Test** is a set of interrupt service routines designed to run over a user's background task in either one stand alone 8097, or two 8097s that are cross-coupled. In the stand alone mode, the chip's output pins are hooked to its input pins. In the dual chip mode, each controller's output pins are tied to the input pins of the other. The minimum configuration for each mode are shown in Figures 2 and 3. See Figure 11 for the circuit diagram of a board that can be jumpered for either configuration.

What is Dynamic Stability?

A "Dynamic Stability" test was developed to enable testing of the 8097 in an asynchronous environment. In the one chip mode, HSO events are synchronized with the HSI

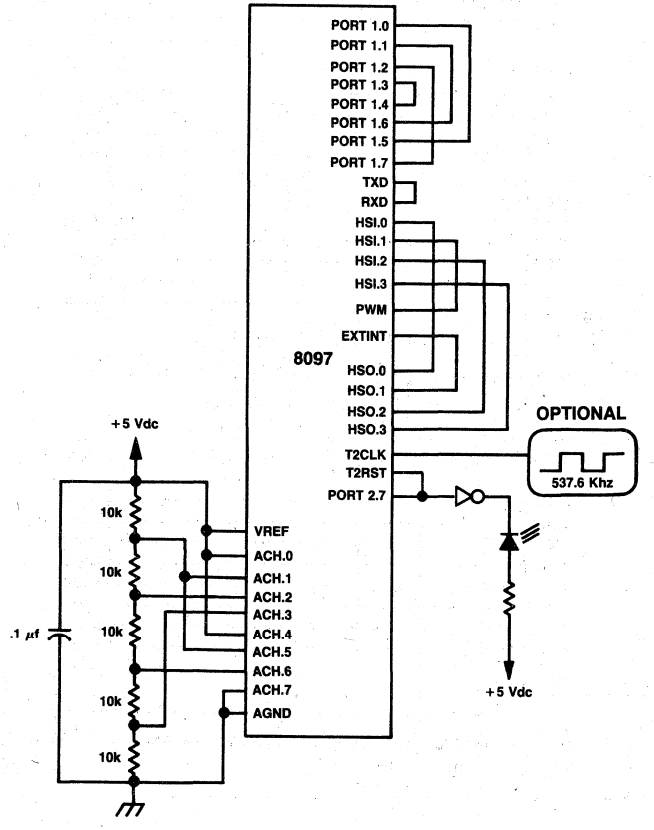

Figure 2. 8097 Strapback Configuration Single Chip Mode

event capture logic. However, in the cross-coupled mode, HSO events generated by one chip are captured in the HSI unit of another. As long as separate, non-syncronized clock sources are used for each chip, the HSI line events will occur asynchronously to the chip.

To implement a test that could be either stand alone or co-resident without modification, the creation and verification of I/O events needed to be decoupled. Thus the basic structure of the **Dynamic Stability Test** takes the form of a set of I/O Producers causing events that I/O Consumers verify. Figure 4 gives a macro view of the Producer/ Consumer relationship.

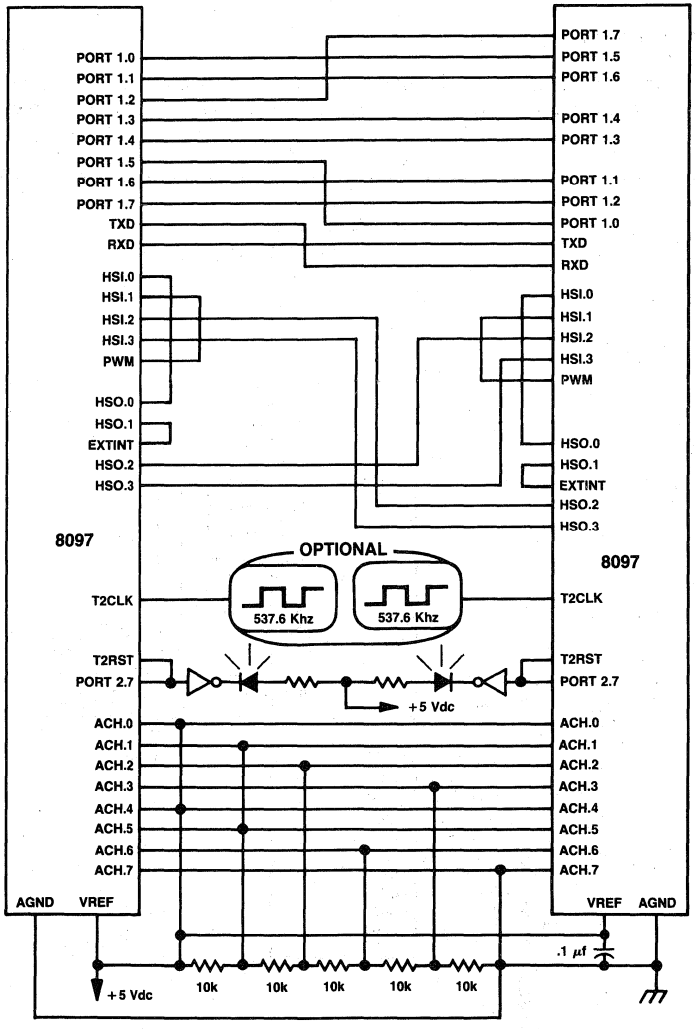

Figure 3. 8097 Strapback Configuration Dual Chip Mode

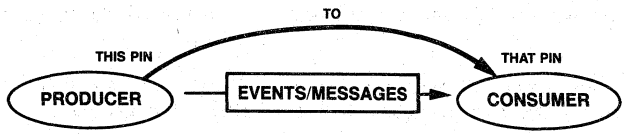

Figure 4. Producer/Consumer Relationship

What Does the Test Do?

Producer/Consumer exchanges were defined to test nearly all of the 8097 I/O capabilities concurrently. Following initialization, the transactions described are carried out by the set of interrupt service routines that make up the **Dynamic Stability Test.** The following section describes the test initialization. Then the tests performed are briefly described in the Producer/Consumer framework.

Initialization

To get the ball rolling, the background task must first CALL an initialization routine (DSTISR). This routine clears memory, executes the Selected Tests program (D96FST) from the **General Diagnostics,** and checks for the presence of an external clock on T2CLK. The serial port is then initialized for internal or external baud rate generation based on the presence of an external clock, and sign on messages are sent over the serial channel.

After initial tests are complete, and just prior to initiation of the interrupt service routines, a pulse is sent out on PORT1.3 that is used to synchronize controllers in the two chip mode. (See Figure 5.) Remember that the objective of the **Dynamic Stability Test** is to test the controllers asynchronously. Therefore, the synchronization is only done to insure that neither controller starts testing before both are ready to begin.

When a controller is ready to synchronize, it places a 0 on the PORT1.3 pin and looks for a 0 on its PORT1.4 pin. When a 0 is seen, the chip delays 600 microseconds, and then PORT1.3 is set high. The chip then loops until PORT1.4 also goes high. Another delay is inserted, and the tests begin. The worst skew between two controllers that can

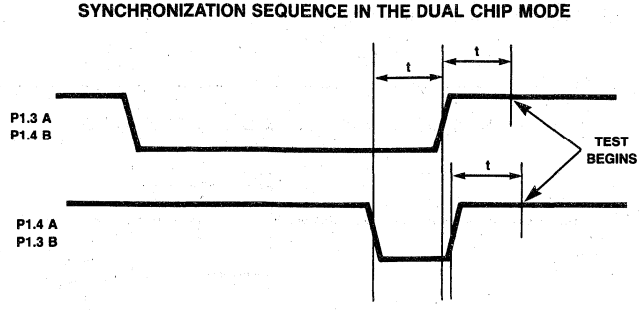

Figure 5. Dual Chip Synchronization

occur using this method is 9 state times (2.25 μs in a 12 Mhz system). However, the skew should average between four and five state times. In any case, the parts will be far from synchronized shortly after the tests begin. This is fine, as long as the tests begin together.

In a one chip system, this process appears as a 600 microsecond pulse on PORT1.3. (See Figure 6.) The tests begin 600 microseconds after the rising edge.

When synchronization is complete, the interrupt service routines are initialized, interrupts are enabled, and control is returned to the background task. At this point, the testing really begins.

Producers and Consumers

The Producer/Consumer exchanges on the 8097 are executed by the interrupt service routines of the **Dynamimc Stability Test.** While some interrupt routines contain an entire Producer or Consumer, some are spread through many routines. Figure 7 shows on a broad level the transactions that occur during test execution. Short descriptions of each Producer and Consumer follow, along with an indication of which interrupt routines contain them.

Serial Producer •DSTSER• The Serial Producer constantly transmits a table of alphabetic and special characters, and test data which includes the current status of the test and the REAL TIME since reset.

Serial Consumer •DSTSER• The Serial Consumer monitors the data coming over the serial link to see if all the expected characters are transmitted correctly and in the correct order. Transmission of the test data and the REAL TIME is checked by counting characters between carriage returns.

Port1 Producer •DSTSWT• The Port1 Producer outputs a series of values on Port1 that are contained in a table constructed to test all possible combinations of input and output of ones and zeros. The test producer executes every 5000h TIMER1 counts via the expiration of Software Timer 1.

Port1 Consumer •DSTSWT• The Port1 Consumer verifies the patterns appearing on Port1 using a table which contains the expected values. The check executes every 1000h TIMER1 counts via the expiration of Software Timer 2.

A/D Producer •DSTSWT• The A/D Producer continually starts A/D conversions by loading an HSO command to initiate an A/D. The A/D Producer executes every time Software Timer 0 expires.

A/D Consumer •DSTA2D• The A/D Consumer verifies the result of conversions initiated by the A/D Producer. It then changes the channel set for conversion and loads an HSO command to cause a Software Timer 0 expiration.

SYNCHRONIZATION PULSE IN THE SINGLE CHIP MODE

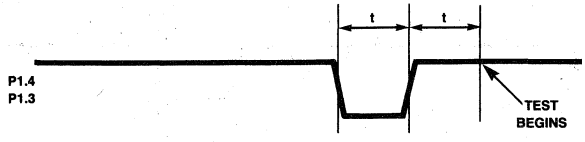

Figure 6. Single Chip Sync Pulse

External Interrupt Producer •DSTHSO• The External Interrupt Producer causes rising edges on HSO.1, which is tied to EXTINT. This Producer executes every time there has been a falling edge on HSO.1.

External Interrupt Consumer •DSTEXI• The External Interrupt Consumer responds to rising edges on EXTINT. It resets the WATCHDOG TIMER every execution and tests the Test Status Words every 30h executions to see that all tests are running. This Consumer also loads an HSO command to cause a falling edge on HSO.1

PWM Producer •DSTTOV• The PWM Producer executes every time there is a timer overflow. In addition to changing the PWM period, it toggles an LED and checks for unexpected T2CLK overflows. There is no PWM Consumer per se, but the PWM output is tied to HSI.1 which is configured to clock T2CLK. In this way T2CLK counts at a known average rate, and is used by the test in a modulo count fashion to generate a real

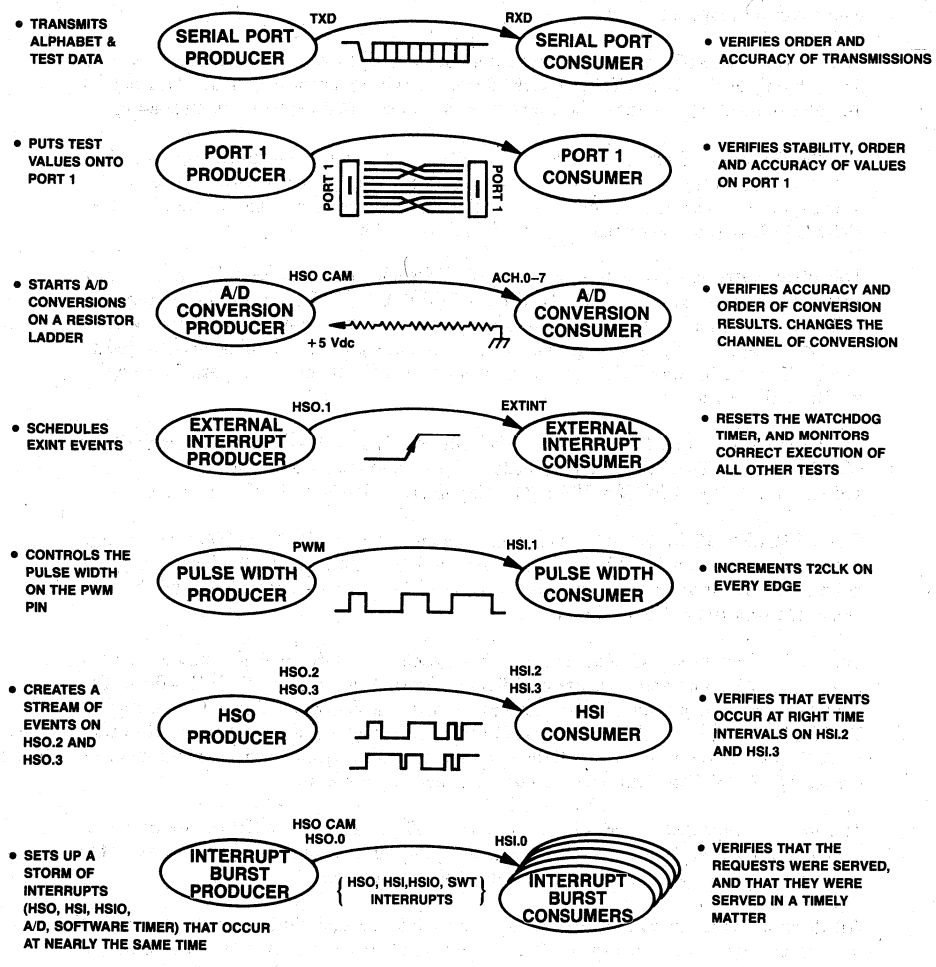

Figure 7. Producer/Consumer Overview

time clock. This module is also expandable to include tests that a user might want to execute only periodically.

HSO Producer •DSTHSO• The High Speed Output Producer executes every time an HSO event on HSO.2 or HSO.3 occurs. Varying pulse widths are created on the pins using predetermined tables of values. The minimum pulse width is 1000H; the maximum is 0C000H TIMER1 counts.

HSI Consumer •DSTHSI• The high speed inputs are monitored by the High Speed Input Consumer. The check executes every time an event occurs on HSI.2 or HSI.3. The HSI Consumer verifies that the proper pulse widths appear on the pins, and that the series of pulse widths is in the right order.

Interrupt BURST Producer •DSTSWT,DSTHI0,DSTHSO,DSTHSO• The previous Producer/Consumer transactions either go between controllers in the dual-chip mode, or stay within the same controller in the single-chip mode. However, there is one **Dynamic Stability Test** that executes invisibly to a co-controller in the dual-chip mode. This test, the Interrupt BURST Test, causes a flood of interrupts that almost fully load the 8097 with interrupt response requests.

The Interrupt BURST Producer causes a complex chain of events that eventually lead to the updating of the REAL TIME Clock. Since the succession of events involves half of the interrupt service routines, the whole process is described here for understanding.

The Big Picture — Each time the REAL TIME Clock is ready to be updated, a BURST of interrupts is setup to occur as close together as possible. Figure 8 shows the sequence of events that occur, their dependency on T2CLK and the commands written into the HSO CAM. If you don't need any more detail, skip "The nitty-gritty".

The nitty-gritty — Every time an the A/D Consumer finishes executing it sets up a Software Timer 0 expiration for TIMER1 = TIMER1 + 2. While T2CLK is between 100h and 600h, the A/D Producer (Software Timer 0) causes a new conversion with an HSO command. If T2CLK is greater than 600h, then an HSO command is loaded to cause a falling edge on HSO.0 instead of causing an A/D conversion to start. This begins the BURST sequence.

The falling edge on HSO.0 causes an HSO interrupt and an HSI interrupt, since HSO.0 is tied to HSI.0. The HSO interrupt loads commands to raise HSO.0 at T2CLK = 1900h and start an A/D at T2CLK = 18ffh. The HSI interrupt loads no HSO commands.

When T2CLK = 18ffh an A/D conversion is begun. When T2CLK = 1900h a rising edge occurs on HSO.0 causing T2CLK to be reset and HSO,HSI and HSI.0 interrupt requests to be made. At approximately the same time an A/D conversion completes and the A/D Done interrupt request is made.

The HSO interrupt service causes no further events. The HSI interrupt service routing loads an HSO command to cause a Software Timer 3 interrupt at T2CLK = 0ffh. The A/D Consumer loads an HSO command to cause a Software Timer 0 interrupt at TIMER1 = TIMER1 + 2. When the A/D Producer executes it loads a command to start an A/D conversion at T2CLK = 100h. And the HSI.0 interrupt service routine updates the REAL TIME Clock (the real output from this whole mess).

The last interrupt that is serviced from this BURST is a Software Timer 3 expiration. This is the BURST Checker. It verifies that all interrupts occurred within a reasonable time window, but causes no further events if all tests passed.

All these activities keep the HSO CAM almost fully loaded. So, to ensure that CAM overwrites never occur, two precautions were taken. First, one CAM slot was allocated to four of the tests that use the HSO unit, and two slots were allocated for shared use by the Interrupt BURST process and the A/D conversion process.

The second precaution was to confirm that either the CAM was not full or the HOLDING REGISTER was empty (depending upon the test) before allowing any write to the CAM.

Figure 9 shows the HSO CAM loading over time, with T2CLK as the timebase. External Interrupt, Port1, HSO.2 and HSO.3 events each are allocated the use of one CAM slot all the time. While T2CLK is below 600h, but above 100h, another CAM slot is used by the A/D Done — Start A/D sequence. When T2CLK goes above 600h, two slots are used by the Interrupt BURST process. The BURST events conclude when T2CLK is reset and climbs to 100h. At 100h, the A/D Done — Start A/D sequence being again.

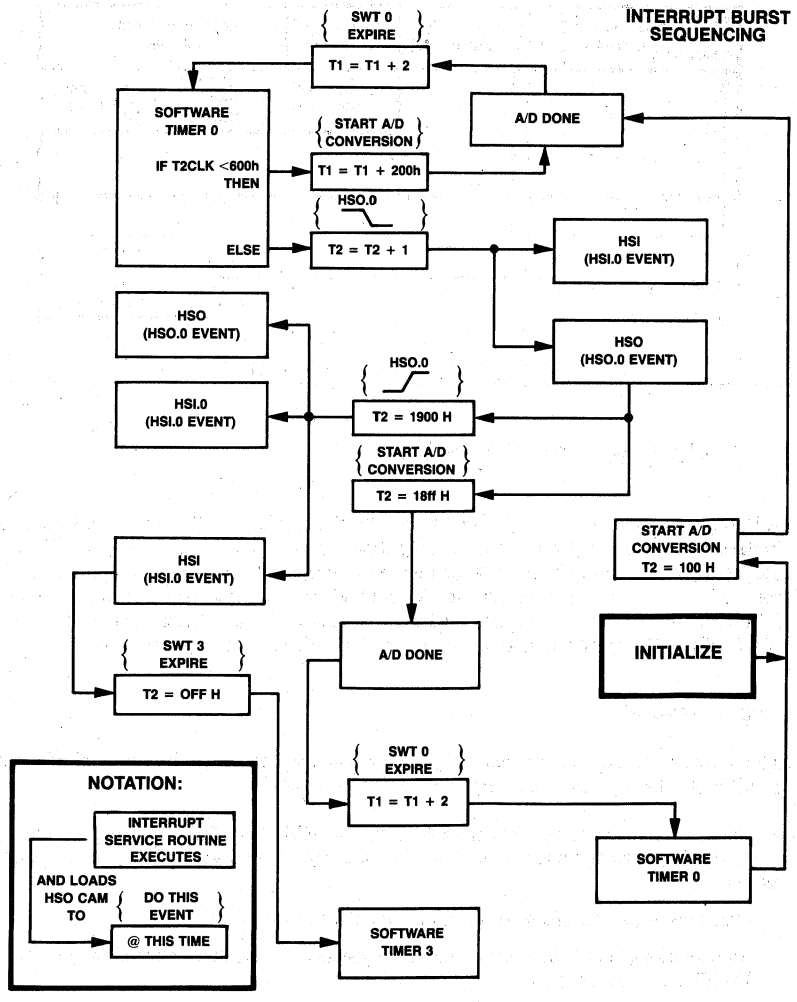

Figure 8. Interrupt BURST Sequencing

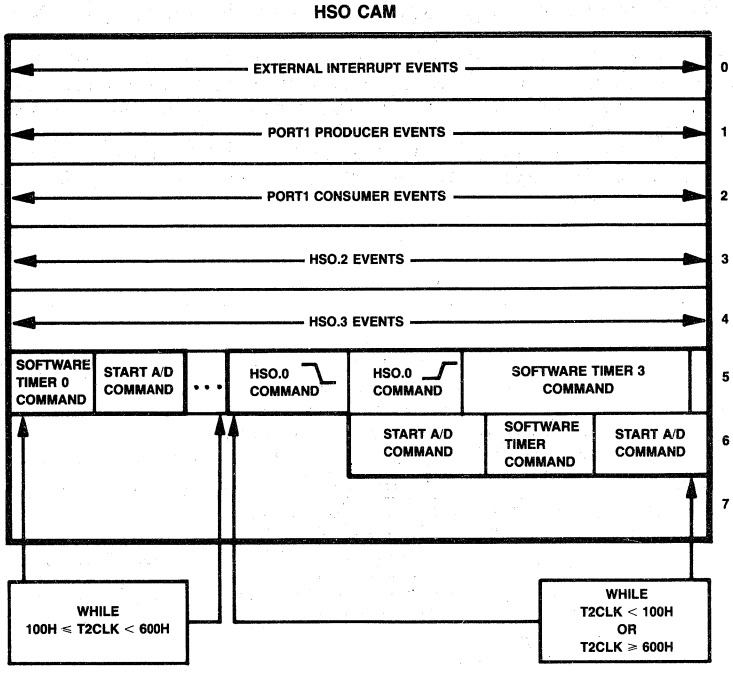

Figure 9. HSO CAM Loading

4.1 How to Use DST96

All program modules that are needed to run the **Dynamic Stability Test** are contained in the DST96 Library (DST96.LIB). This Library is also a part of DIAG96.LIB. To use the test, one or two 8097s must be configured as previously shown. A background task for the Dynamic Stability interrupt service routines must also be provided and linked to DIAG96.LIB. For those who don't wish to write a background task, one is provided (DSTUSR). But, any code may be written which follows some simple rules.

The Software

The software constraints are relatively minor, but they do create incompatibility with PLM96. All background tasks should be written in ASM96.

Minimally, the background task must load the STACK POINTER, PUSH parameters, CALL DSTISR, and go into a loop. Any other code may come after the CALL to DSTISR, as long as:

- Interrupts are never disabled for more than a few instructions;
- No operations to or from special function registers occur (with the exception of reading TIMER1 or T2CLK), and

Other less grave limitations on the main task are that it:

- Be CSEGed at 2080h;

- Write only to EREG1, EREG2, OSEG registers from 40h to 5Ch, or external RAM, (the OSEG is an RL96 technicality, once DSTISR returns control to the MAIN TASK, locations 40h to 5Ch are not touched by the Tests); other registers can be read, but not written to;
- Communicate to the outside world through Port3 and Port4, (these Ports are untouched by the tests), or memory mapped I/O registers;

To provide the **Dynamic Stability Test** modules for linkage to your program, modify the batch file DSTRL.BAT to suit your system with respect to memory mapping and invoke the batch file with the appropriate background task filename. For example, type:

```
DSTRL DSTUSR
```

The Hardware

The **Dynamic Stability Test** has been designed to allow flexibility in the way output from the tests is used.

Minimally, no output device (printer, terminal) or function generators need to be attached to the test. If the LED attached to Port 2.7 is not flashing, the test failed. However, no other information may be gained.

To support a greater level of debugging (of the test code initially), the test was designed to output status and error information to one 4800 and one 300 baud device. The baud rates are derived from the function generators if present. Figure 10 shows how both devices can be attached to the test.

With this configuration, the test outputs an initialization message to both devices, then selects just the 4800 baud line for monitoring the Serial Port Producer/Consumer transactions. If an error is detected, the 300 baud line is selected for an error information dump.

A diagram of the circuit used in developing the **Dynamic Stabilty Test** appears in Figure 11. It is sufficiently general purpose for use in either the single or double chip modes, with or without printers or terminals attached.

The circuit requires that the 8097 I/O signals be present on an SBE-96 compatible 50 pin connector. The circuit also assumes that the analog voltage reference is provided through the cable. Therefore, if you are using the SBE-96, the jumpers to do this need to be in place (jumper numbers vary with the SBE-96 version).

Figure 12 describes how to jumber the **Dynamic Stability Test** board for one or two chip tests. Figure 13 shows the SBE-96 50 pin connector pinout. The following sections describe in detail the actions of each interrupt service routine in implementing the Producer/Consumer transactions.

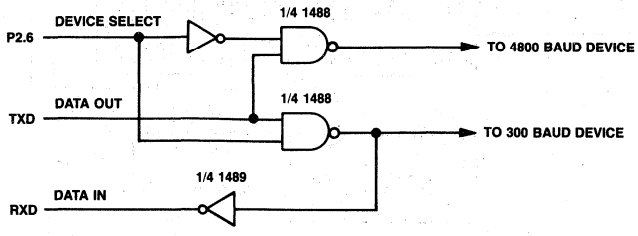

Figure 10. Output Device Selection Circuit

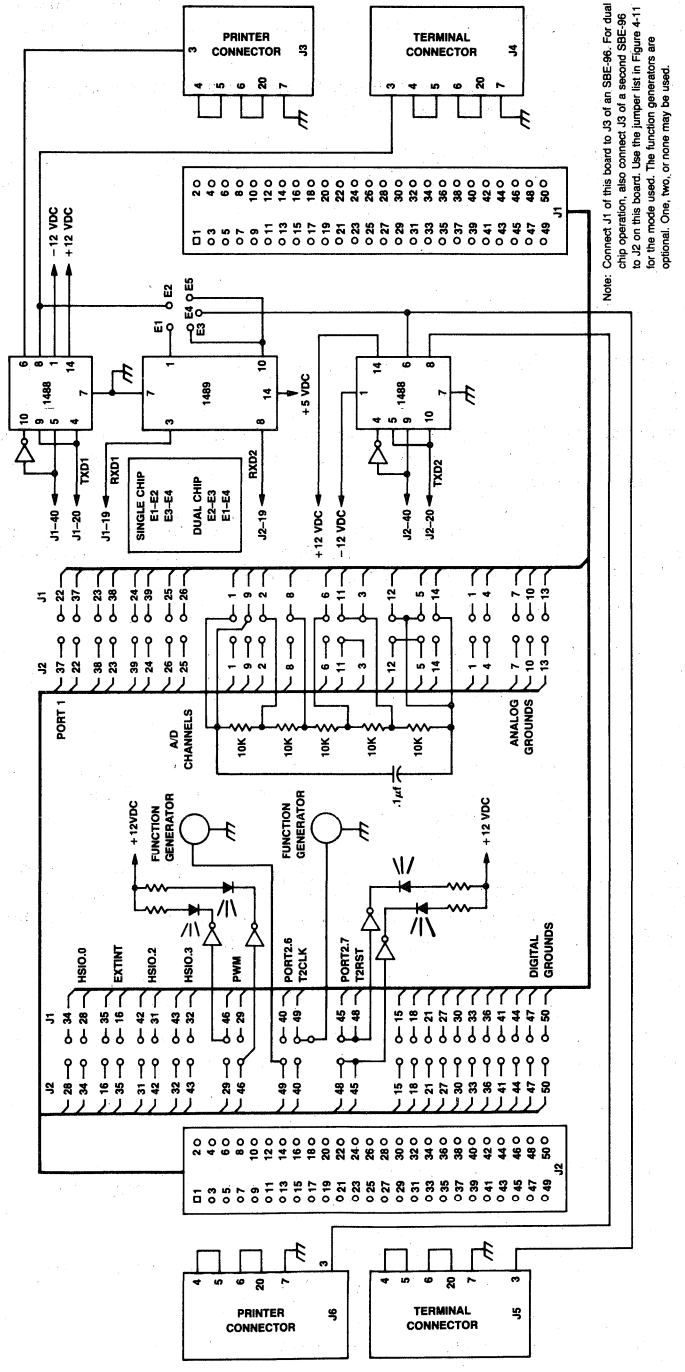

Figure 11. MCS®-96 Dynamic Stability Test Strapback Configuration

Jumper Connections for Single Chip Mode

J1	
22 – 37	34 – 28
23 – 38	35 – 16
24 – 39	42 – 31
25 – 26	43 – 32
45 – 48	46 – 29

Also
E1 – E2
E3 – E4

1 – 4 – 7 – 10 – 13

15 – 18 – 21 – 27 – 30 – 33 – 36 – 41 – 44 – 47 – 50

Jumper Connections for Dual Chip Mode

J1 – J2	J1 – J2	J1 – J2
22 – 37	33 – 33	14 – 14
23 – 38	36 – 36	4 – 4
24 – 39	41 – 41	5 – 5
25 – 26	44 – 44	7 – 7
42 – 31	47 – 47	10 – 10
43 – 32	50 – 50	13 – 13
15 – 15	1 – 1	
18 – 18	9 – 9	
21 – 21	2 – 2	
27 – 27	8 – 8	
30 – 30	6 – 6	
	11 – 11	
	3 – 3	
	12 – 12	

J1
34 – 28
45 – 48
46 – 29
35 – 16

J2
34 – 28
45 – 48
46 – 29
35 – 16

Also
E2 – E5
E1 – E4

J2 – J1
22 – 37
23 – 38
24 – 39
25 – 26
42 – 31
43 – 32

Figure 12. Dynamic Stability Board Jumper List

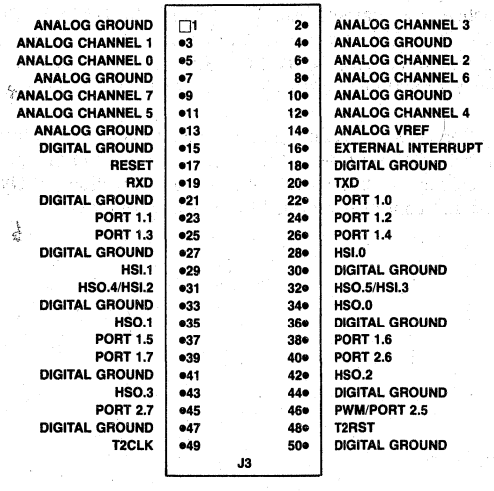

Figure 13. SBE-96 J3 Pinout

4.2 Test Module Descriptions

DST Initialization (DSTISR)

Brief Description:

This module is the invocation and initialization code for the Dynamic Stability Test.

Assembly Language Calling Sequence:

```
PUSH    <RAM segment1 starting address>
PUSH    <RAM segment1 ending address>
PUSH    <RAM segment2 starting address>
PUSH    <RAM segment2 ending address>
PUSH    <random seed>
PUSH    <random test length>
PUSH    <top of code address>
PUSH    <argument1 for Multiply/Divide Core test>
PUSH    <argument2 for Multiply/Divide Core test>
PUSH    <bit pattern for memory test>
CALL    DSTISR
```

When All Tests Pass:

EREG1 := 0040h
EREG2 := 0000h

When a Test Fails:

EREG1 := 0140h on abnormal RESET	**EREG2** := TIMER1
EREG1 := 0240h if T2CLK won't change	**EREG2** := xxxxh
EREG1 := 0340h if T2RST did not work	**EREG2** := xxxxh
EREG1 := 0440h if IOC0.1 did not work	**EREG2** := xxxxh

Detailed Description:

This module initializes the registers used by **Dynamic Stability Test** Modules, checks to see if there is an external clock present, tests T2CLK counting and reset functionality, and outputs initialization messages to the two output devices. The selected tests module (D96FST) from the **General Diagnostics** is also executed using the parameters specified.

When all initialization tests are passed, then a synchronization is performed to place the two processors in a dual-chip mode test in close sync. The PORT1 pins are used as to perform the handshaking synchronization. After synchronization, all **Dynamic Stability Tests** are activated and control is returned to the user program.

External Interrupts (DSTEXI)

Brief Description:

This module executes every time there is a rising edge on the EXTINT pin. The test resets the WATCHDOG TIMER and verifies execution of all Dynamic Stability routines.

If Test Fails:

EREG1 := 01A0h if a test did not execute
EREG2 := Number of Shifts done

Detailed Description:

This routine executes every time there is a rising edge on the EXTINT pin, causing an external interrupt. Each execution, the WATCHDOG TIMER is reset and an HSO command to clear the HSO.1 pin in 1000h TIMER1 counts is loaded into the CAM. The HSO routine that responds to that event will cause HSO.1 to go high, thus causing another vector to DSTEXI.

Every 30h executions of this module, the Test Status Words are NOTed and then NORMaLized to see if any test did not execute. If any bit in the Test Status Words is left set after being complemented, the NORML instruction will leave the most significant bit set, indicating an error. If there was no error, the TSWORDs are cleared. The user can change a mask in DSTEXI to enable checking of any of the currently spare bits in TSWORD. The TSWORD bit map is as follows:

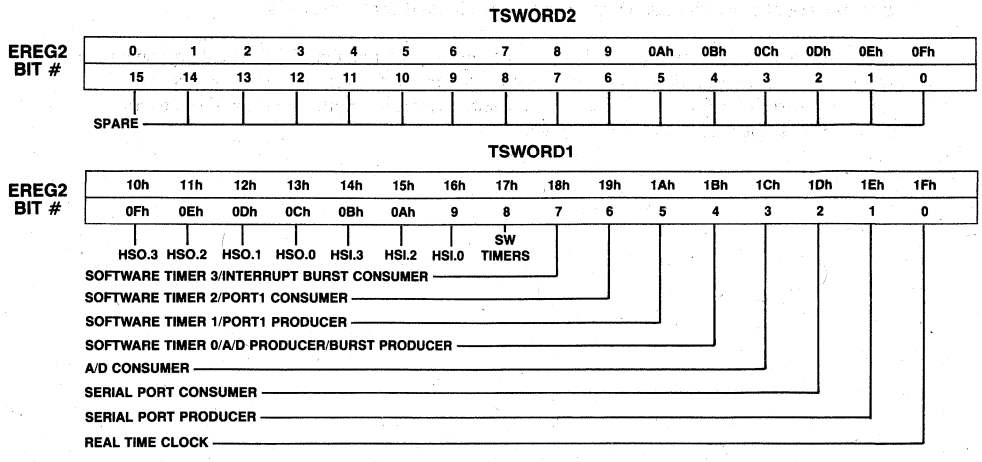

Figure 14. Test Status Word Bit Map

Serial Port (DSTSER)

Brief Description:

This module contains the Serial Port Consumer and Producer routines for the **Dynamic Stability Tests.** It is executed on every Serial Interrupt.

If Test Fails:

EREG1 := 01B0h if a bad character was received
EREG2 := actual received character

EREG1 := 02B0h if an incorrect number of characters came between carriage returns
EREG2 := actual count

Detailed Description:

This interrupt service routine executes every time there is a Serial Interrupt. The data that is transmitted and checked by the test consists of first, the alphabet and some special characters; second, the current REAL TIME; and finally, the bit representation of the Test Status Words. The receiver verifies the alphabet and funny characters and counts characters until a carriage return. The following is an example of what the output looks like.

```
ABCDEFGHIJKLMNOPQRSTUVWXYZ*#%&[]@001:23:59.61 11111101110111111000111 1
```

The code first checks for a Receive Done flag. If a receive just completed, the receive buffer is emptied and checked for validity. If the received character is a carriage return, then the count since the last carriage return is checked for correctness.

After the receive service has finished, or if there was no receive, DSTSER then checks for the Transmit Done flag. If more transmits can be made, the next data byte is loaded into the transmit buffer. If the data is exhausted, a carriage return is sent, and the routine is set to transmit the first data byte again.

Software Timers (DSTSWT)

Brief Description:

This module is executed every time a Software Timer Interrupt expires. The routine includes the Port1 Producer and Consumer, the A/D producer, and the Interrupt Burst control and verification code.

If a Test Fails:

EREG1 := 01D0h If an unexpected value is found on Port 1
EREG2 := expected value in high byte, actual value in low byte

EREG1 := 02D0h A/D Done interrupt did not occur within BURST window
EREG2 := Time between A/D done and Software Timer 0

EREG1 := 03D0H REAL TIME update did not occur within BURST window
EREG2 := Time between REAL TIME update and Software Timer 0

EREG1 := 04D0H HSO.0 response did not occur within BURST window
EREG2 := Time between HSO.0 interrupt and Software Timer 0

EREG1 := 05D0H HSI(.0) response did not occur within BURST window
EREG2 := Time between HSI(.0) service and Software Timer 0

EREG1 := 01D1H Invalid T2CLK value reached
EREG2 := T2CLK found

EREG1 := 02D1H Test reached an illegal Software Timer 0 state
EREG2 := the illegal case jump that was made

Detailed Description:

This module is called every time a Software Timer expires and causes and interrupt. Software timers are used by the A/D Done — A/D Trigger Sequence, the Interrupt Burst Sequence, and the Port1 Producer and Port1 Consumer.

When Software Timer 0 expires, a case jump is done on the BURST_STATE variable to sequence the A/D and interrupt BURST process to the appropriate state. Depending upon the value of T2CLK and the state of the A/D converter, either an A/D conversion is initiated or HSO.0 is set to go low to begin the interrupt BURST events.

When Software Timer1 expires, a new value is written to Port1 from a table constructed to test all combinations of input/output states on the quasi-bidirectional port pins. The HSO CAM is also loaded with a command to cause Software Timer1 to overflow again in 5000h TIMER1 counts.

When Software Timer 2 expires, Port1 is read and compared to a table of expected entries. If the value is correct, then an HSO command is loaded into the CAM to cause another Software Timer 2 expiration in 1000h TIMER1 counts. If the value is not correct, the next entry in the Table is checked. If there is still no match, an error is reported. If there is a match, the CAM loading occurs and Software Timer 3 is checked for expiration.

If Software Timer 3 has expired, then the flurry of BURST interrupts should have just occurred. The routine checks to see that each event happened within a reasonable time window. If the checks pass, then the routine exists with no further action.

Real Time Clock (HSI0) (DSTHI0)

Brief Description:

This routine executes every time there is a rising edge on HSI.0 and updates the real time clock value.

When Module Executes:

REAL_TIME := REAL_TIME + .204 seconds

Detailed Description:

This module is the HSI.0 interrupt service routine. On each rising edge of HSI.0, the value in the REAL TIME clock buffer is updated to reflect the passing of 1900h T2CLK counts. Since the PWM output is tied to T2CLK, and the average time between edges is 31.875 μs in a 12 MHz system, then 1900h T2CLK counts represents .204 seconds.

Execution of this module occurs during the interrupt BURST events. No action other than updating the REAL TIME clock is taken in this routine.

High Speed Outputs (DSTHSO)

Brief Description:

This module manages the pulse width outputs on HSO.2 and HSO.3, and causes the Manager test to execute.

Detailed Description:

Every time an HSO command is executed that has the Interrupt bit set, this program executes. The routine manages the pulse widths on HSO lines two and three, and causes the Manager module to execute at the right time.

When a falling edge has been caused on either HSO.2 or HSO.3, DSTHSO loads a command into the CAM to cause a rising edge on the same line at a time that gives the line a low pulse width equal to a predetermined table value. Rising edges cause analogous responses. The tables used cause low and high pulse widths that vary from 1000h and 0C000h. The length of the tables differ by one so that all combinations of low and high table times occur.

When a falling edge was caused on HSO.1, the routine loads a command into the CAM to cause a rising edge on the same line two TIMER1 counts later. Since HSO.1 is tied to the EXTINT pin, rising edges cause the Manager Routine to execute.

High Speed Inputs (DSTHSI)

Brief Description:

This module does the verification of events on the HSI lines and initiates some interrupt BURST events when appropriate.

If a Test Fails:

EREG1 := 0161h if a high pulse on HSI.2 had an unexpected width
EREG2 := difference between actual and expected pulse width

EREG1 := 0261h if a low pulse on HSI.2 had an unexpected width
EREG2 := difference between actual and expected pulse width

EREG1 := 0361h if a high pulse on HSI.3 had an unexpected width
EREG2 := difference between actual and expected pulse width

EREG1 := 0461h if a low pulse on HSI.3 had an unexpected width
EREG2 := difference between actual and expected pulse width

EREG1 := 0561h if the HSI unit indicated that an HSI.1 event occurred
EREG2 := the time recorded in the FIFO

Detailed Description:

This module executes every time an event is loaded into the HSI Holding Register. Verification of pulse widths on HSI.2 and HSI.3 is done from tables of expected values. Any deviation is reported as an error.

If the test detects a negative transition on HSI.0, then commands are loaded into the HSO CAM to start an A/D at T2CLK = 18ffh and to set HSO.0 high at T2CLK = 1900h. This results in an HSO, HSI, HSI.0 and A/D Done interrupt requests to occur at approximately the same time — approaching a full demand on interrupt service.

When a rising edge on HSI.0 is detected, an HSO command is loaded into the CAM to cause a Software Timer 3 interrupt when T2CLK = 100h. The Software Timer 3 interrupt service will check to see that all burst events happened fast enough.

HSI.1 events are disabled from the FIFO. Any event detected on this line is reported as an error.

A/D Conversion Complete (DSTA2D)

Brief Description:

This module executes every time an A/D conversion is complete. The conversion result is checked for correctness, the A/D converter is setup to convert on the next channel when initiated by an HSO command, and an HSO command to cause a Software Timer 0 expiration is loaded.

If Test Fails:

EREG1 := 01C0h on a conversion error
EREG2 := channel on which error occurred

Detailed Description:

This module executes every time an A/D conversion is complete. The conversion result is checked against a test table for correctness, and the A/D converter is setup to convert on the next channel when initiated by an HSO command. An HSO command to cause a Software Timer 0 expiration in 0002h TIMER1 counts is loaded just prior to exiting the module.

While T2CLK has a value between 100h and 600h, A/D conversions are initiated by the Software Timer 0 Interrupt service routine. When T2CLK goes above 600h, an A/D conversion is initiated by the HSO.0 interrupt service routine.

Given the possibility of additive error in 5% resistors, the conversion is tested to only six bits of accuracy.

Timer Overflows (DSTTOV)

Brief Description:

This module toggles a port pin tied to an LED, manages the PWM output, performs some simple tests, and is expandable to allow inclusion of user written tests.

If Test Fails:

EREG1 := 0190h if T2CLK had an overflow indication
EREG2 := T2CLK a the time the error was found

Detailed Description:

This module executes every time TIMER1 or T2CLK overflow. Only TIMER1 overflows are valid however, so T2CLK overflows are flagged as an error. Each overflow, a new period is loaded into the PWMCONTROL register from a table of pulse periods. If an LED is connected, it will appear to slowly change in intensity. Port2.7 is also toggled in this routine to light another LED.

This interrupt routine can be expanded with special tests that are to execute on a periodic basis. Any of the spare bits in the Test Status Words can also be used by specialized tests. They will be checked by the External Interrupt service routine with a simple change in a bit mask.

Macro Module (DSTMAC)

Brief Description:

This module contains four macros used by the **Dynamic Stability Test.**

Assembly Language Invocation:

```
SPSTATUS          Temp_Register
  or
SPWAIT            (RI,TI)
  or
BR_ON_ERROR       Label
  or
RESET_WATCHDOG
```

Detailed Description:

The SPSTATUS Macro is used to ORB the Serial Port Status Register to a temp register. The Macro needs to be used to work around a bug in the 809x-90.

The SPWAIT Macro is used to cause program execution to halt and wait for an RI or TI flag, depending upon which is specified.

The BR_ON_ERROR Macro tests the high byte of EREG1 and jumps to the label if the byte is not zero. This can be used every time a **General Diagnostic** completes since the detection of any error will cause the high byte of EREG1 to be non-zero.

The RESET_WATCHDOG Macro does just what it says. The WATCHDOG TIMER is reset by writing the correct sequence to location 0Ah.

To access a DSTMAC macro, this module must be $INCLUDEd.

Error Procedure (DSTERR)

Brief Description:

This module is called if any error is detected in the **Dynamic Stability Test.** Information about the error is output over the serial port, and the test is restarted.

Assembly Language Calling Sequence:

```
CALL    Error_Proc
```

Detailed Description:

This module is CALLed on detection of any error in the **Dynamic Stability Test.** When CALLed, the procedure:

- disables interrupts,
- saves any rapidly changing values (TIMER1,T2CLK,HSO_STATUS, . . .),
- waits for a serial transmit in progress to complete,
- waits for the current serial receive to complete,
- empties eight entries from the HSI_FIFO,
- transmits an open loop sync sequence in case a co-controller is stuck in the sync routine, and
- waits a few hundred milliseconds to ensure that a co-controller has also detected a failure.

After these steps have been taken, the DSTERR de-selects the 4800 baud line, selects the 300 baud line, and outputs error messages. These messages include the Error Code (EREG1), the Detail Code (EREG2), the address of the line in the test which found the error, and the REAL TIME since reset.

Following the error messages, the procedure dumps the data contained in the registers and the external error buffer out over the serial port to the 300 baud device.

Finally, a RST instruction followed by a branch to the RST instruction is executed. If the WATCHDOG TIMER is externally disabled, the test will stay in this loop. If the WATCHDOG TIMER is not disabled, the test chip will reset, and the **Dynamic Stability Test** will reinitialize.

DST Example User Code (DSTUSR)

Brief Description:

This is an example program that initiates the **Dynamic Stability Test** and then executes some **General Diagnostics** as a background task.

Detailed Description:

DSTUSR sends parameters defined at assembly time to the DST initialization routine (DSTISR). When control returns to DSTUSR, the example repeatedly executes ALU01, ALU02, ALU04, ALU05 and MEM0A. It takes two minutes (with the given memory parameters) for the DSTUSR background task to cycle once while interrupts are running.

When creating a custom background task, using this example program as a template will speed development.

APPENDICES

APPENDIX A • DIAG96.LIB Error Messages by EREG1 Code

APPENDIX B • DIAG96.LIB Error Messages by Module Name

APPENDIX C • Description of DIAG96.LIB Batch Files

APPENDIX D • Example Program Listings
- **D96A96**
- **D96P96**
- **D96FST**
- **DSTUSR**

APPENDIX A

DIAG96.LIB Error Messages by EREG1 Code

0000 No Message
EREG2 = 0ffffh
MODULE = SYS01/Common Symbols

0002 All Tests Passed
EREG2 = 0000
MODULE = SYS02/System Power-up

0003 All Tests Passed
EREG2 = 0000
MODULE = SYS03/Program Counter

0011 All Tests Passed
EREG2 = 0000
MODULE = ALU01/Add/Subtract

0012 All Tests Passed
EREG2 = 0000
MODULE = ALU02/MULUB

0013 All Tests Passed
EREG2 = 0000
MODULE = ALU03/Multiply/Divide Table

0014 All Tests Passed
EREG2 = 0000
MODULE = ALU04/Multiply/Divide Random

0015 All Tests Passed
EREG2 = 0000
MODULE = ALU05/Multiply/Divide Core

0021 All Tests Passed
EREG2 = 0000
MODULE – MEM01/Complementary Address (Registers)

0022 All Tests Passed
EREG2 = 0000
MODULE = MEM02/Walking Ones/Zeros (Registers)

0023 All Tests Passed
EREG2 = 0000
MODULE = MEM03/Galloping Ones/Zeros (Registers)

0024 No bits were set in the byte tested
EREG2 = 0000
MODULE = MEM04/Bits Set

0025 All Tests Passed
EREG2 = 0000
MODULE = MEM05/Checkerboard Pattern (Registers)

0026 All Tests Passed
EREG2 = 0000
MODULE = MEM06/Complementary Address

0027
All Tests Passed
EREG2 = 0000
MODULE = MEM07/Walking Ones

0028
All Tests Passed
EREG2 = 0000
MODULE = MEM08/Galloping Ones

0029
All Tests Passed
EREG2 = 0000
MODULE = MEM09/Walking Ones/Zeros

002A
All Tests Passed
EREG2 = 0000
MODULE = MEM0A/Galloping Ones/Zeros

002C
All Tests Passed
EREG2 = 0000
MODULE = MEM0C/User Pattern (Registers)

002D
All Tests Passed
EREG2 = 0000
MODULE = MEM0D/User Pattern

0030
All Tests Passed, checksum is ready
EREG2 = 16-bit checksum
MODULE = D96A96/ALL Tests in ASM96

0040
Initialization completed satisfactorily
EREG2 = 0000
MODULE = DSTISR/DST Initialization

00E0
All Tests Passed, checksum is over range specified
EREG = 16-bit checksum
MODULE = D96FST/Selected Tests in ASM

00F0
All Tests Passed, checksum is ready
EREG2 = 16-bit checksum
MODULE = D96P96/ALL Tests in PLM96

0102
I/O Status Registers were unexpected
EREG2 = I0S0 in low byte, I0S1 in high byte
MODULE = SYS02/System Power-up

0103
Test Code Returned Early
EREG2 = Early Time
MODULE = SYS03/Program Counter

0111
An Addition error occurred
EREG2 = offending argument when the error occurred
MODULE = ALU01/Add/Subtract

0112
Incorrect multiplication result was detected
EREG2 = Multiplier/Multiplicand
MODULE = ALU02/MULUB

0115
A signed operation failed
EREG2 = offending argument on error
MODULE = ALU03/Multiply/Divide Table

0115 A signed operation failed
EREG2 = offending argument on error
MODULE = ALU04/Multiply/Divide Random

0115 A signed operation failed
EREG2 = offending argument on error
MODULE = ALU05/Multiply/Divide Core

0121 A memory location failed
EREG2 = address of the error
MODULE = MEM01/Complementary Address (Registers)

0122 A memory location failed
EREG2 = address of the error
MODULE = MEM02/Walking Ones/Zeros (Registers)

0123 A memory location failed
EREG2 = address of the error
MODULE = MEM03/Galloping Ones/Zeros (Registers)

0124 At least one bit was set in the byte tested
EREG2 = number of bits set
MODULE = MEM04/Bits Set

0125 A memory location failed
EREG2 = address of the error
MODULE = MEM05/Checkerboard Pattern (Registers)

0126 A memory location failed
EREG2 = address of error
MODULE = MEM06/Complementary Address

0127 A memory location failed
EREG2 = address of the error
MODULE = MEM07/Walking Ones

0128 A memory location failed
EREG2 = address of the error
MODULE = MEM08/Galloping Ones

0129 A memory location failed
EREG2 = address of the error
MODULE = MEM09/Walking Ones/Zero

012A A memory location failed
EREG2 = address of the error
MODULE = MEM0A/Galloping Ones/Zeros

012B 16-bit Checksum is ready
EREG2 = 16-bit Checksum
MODULE = MEM0B/Checksum

012C A memory location failed
EREG2 = address of the error
MODULE = MEM0C/User Pattern (Registers)

012D A memory location failed
EREG2 = address of the error
MODULE = MEM0D/User Pattern

0140 An abnormal RESET occurred
EREG2 = TIMER1
MODULE = DSTISR/DST Initialization

0161 A high pulse on HSI.2 had an unexpected width
EREG2 = difference between actual and expected pulse width
MODULE = DSTHSI/High Speed Inputs

0190 An overflow of T2CLK was indicated
EREG2 = TIMER1
MODULE = DSTTOV/Timer Overflows

01A0 One or more DST Module did not execute on time
EREG2 = Number of SHIFTs done
MODULE = DSTEXI/External Interrupt (Supervisor)

01B0 An unexpected serial character was received
EREG2 = Bad character received
MODULE = DSTSER/Serial Port

01C0 An unexpected A/D conversion result was found
EREG2 = Channel number of unexpected result
MODULE = DSTA2D/A/D Conversion Complete

01D0 Found unexpected value on PORT1
EREG2 = expected value in high byte, actual in low byte
MODULE = DSTSWT/Software Timers

01D1 Invalid T2CLK value reached
EREG2 = T2CLK
MODULE = DSTSWT/Software Timers

0202 TIMER1 did not change over time
EREG2 = TIMER1
MODULE = SYS02/System Power-up

0203 Test Code Returned Late
EREG2 = Late Time
MODULE = SYS03/Program Counter

0211 A Subtraction error occurred
EREG2 = offending argument when the error occurred
MODULE = ALU01/Add/Subtract

0215 An unsigned operation failed
EREG2 = offending argument on error
MODULE = ALU03/Multiply/Divide Table

0215 An unsigned operation failed
EREG2 = offending argument on error
MODULE = ALU04/Multiply/Divide Random

0215 An unsigned operation failed
EREG2 = offending argument on error
MODULE = ALU05/Multiply/Divide Core

0240 T2CLK will not change
EREG2 = xxxx
MODULE = DSTISR/DST Initialization

0261 A low pulse on HSI.2 had an unexpected width
EREG2 = difference between actual and expected pulse width
MODULE = DSTHSI/High Speed Inputs

02B0 A carriage return was received out of sequence
EREG2 = number of characters since a carriage return
MODULE = DSTSER/Serial Port

02D0 A/D Done did not occur within BURST window
EREG2 = Time between A/D done and Software Timer 0
MODULE = DSTSWT/Software Timers

02D1 Test reached an illegal Software Timer 0 state
EREG2 = Illegal case jump made
MODULE = DSTSWT/Software Timers

0302 Zero Register was found to change
EREG2 = Program Status Word At Failure
MODULE = SYS02/System Power-up

0303 Counter Register contained unexpected value
EREG2 = Erroneous Counter Value
MODULE = SYS03/Program Counter

0311 A flag error occurred
EREG2 = offending argument when the error occurred
MODULE = ALU01/Add/Subtract

0315 A flag error occurred
EREG2 = offending argument on error
MODULE = ALU03/Multiply/Divide Table

0315 A flag error occurred
EREG2 = offending argument on error
MODULE = ALU04/Multiply/Divide Random

0315 A flag error occurred
EREG2 = offending argument on error
MODULE = ALU05/Multiply/Divide Core

0340 T2RST pin would not RESET T2CLK
EREG2 = xxxx
MODULE = DSTISR/DST Initialization

0361 A high pulse on HSI.3 had an unexpected width
EREG2 = difference between actual and expected pulse width
MODULE = DSTHSI/High Speed Inputs

0391 Illegal Opcode

03D0 REAL TIME update did not occur within BURST window
EREG2 = Time between REAL TIME update and Software Timer 0
MODULE = DSTSWT/Software Timers

0402 PUSHF or POPF failed
EREG2 = Erroneous PUSHed or POPed value found
MODULE = SYS02/System Power-up

0440 I0C0.1 would not RESET T2CLK
EREG2 = xxxx
MODULE = DSTISR/DST Initialization

0461 A low pulse on HSI.3 had an unexpected width
EREG2 = difference between actual and expected pulse width
MODULE = DSTHSI/High Speed Inputs

04D0 HSO.0 response did not occur within BURST window
EREG2 = Time between HSO.0 update and Software Timer 0
MODULE = DSTSWT/Software Timers

0502 Sticky Bit would not set
EREG2 = 3fffh
MODULE = SYS02/System Power-up

0502 Sticky Bit would not clear
EREG2 = 0000
MODULE = SYS02/System Power-up

0561 HSI unit indicated an HSI.1 event occurred
EREG2 = Time recorded in HSI FIFO
MODULE = DSTHSI/High Speed Inputs

05D0 HSI(.0) response did not occur within BURST window
EREG2 = Time between HSI(.0) service and Software Timer 0
MODULE = DSTSWT/Software Timers

0602 Carry Flag Test Failed
EREG2 = xxxx
MODULE = SYS02/System Power-up

0702 Overflow flags would not set correctly
EREG2 = 0002h
MODULE = SYS02/System Power-up

0702 Overflow flags would not clear correctly
EREG2 = xxxx
MODULE = SYS02/System Power-up

0802 Interrupt Pending Register failed read/write test
EREG2 = offending Interrupt Pending byte
MODULE = SYS02/System Power-up

xx91 ⟨user defined⟩
EREG2 = ⟨user defined⟩
MODULE = DSTTOV/Timer Overflows

APPENDIX B

DIAG96.LIB Error Messages by Module Name

ALU01 Add/Subtract

0011 All Tests Passed
EREG2 = 0000

0111 An Addition error occurred
EREG2 = offending argument when the error occurred

0211 A Subtraction error occurred
EREG2 = offending argument when the error occurred

0311 A flag error occurred
EREG2 = offending argument when the error occurred

ALU02 MULUB

0012 All Tests Passed
EREG2 = 0000

0112 Incorrect multiplication result was detected
EREG2 = Multiplier/Multiplicand

ALU03 Multiply/Divide Table

0013 All Tests Passed
EREG2 = 0000

0115 A signed operation failed
EREG2 = offending argument on error

0215 An unsigned operation failed
EREG2 = offending argument on error

0315 A flag error occurred
EREG2 = offending argument on error

ALU04 Multiply/Divide Random

0014 All Tests Passed
EREG2 = 0000

0115 A signed operation failed
EREG2 = offending argument on error

0215 An unsigned operation failed
EREG2 = offending argument on error

0315 A flag error occurred
EREG2 = offending argument on error

ALU05 Multiply/Divide Core

0015 All Tests Passed
EREG2 = 0000

0115 A signed operation failed
EREG2 = offending argument on error

0215 An unsigned operation failed
EREG2 = offending argument on error

0315 A flag error occurred
EREG2 = offending argument on error

D96A96 All Tests in ASM96
0030 All Tests Passed, checksum is ready
EREG2 = 16-bit checksum

D96FST Selected Tests in ASM
00E0 All Tests Passed, checksum is over range specified
EREG2 = 16-bit checksum

D96P96 ALL Tests in PLM96
00F0 All Tests Passed, checksum is ready
EREG2 = 16-bit checksum

DSTA2D A/D Conversion Complete
01C0 An unexpected A/D conversion result was found
EREG2 = Channel number of unexpected result

DSTEX1 External Interrupt (Supervisor)
01A0 One or more DST Module did not execute on time
EREG2 = Number of SHIFTs done

DSTHSI High Speed Inputs
0161 A high pulse on HSI.2 had an unexpected width
EREG2 = difference between actual and expected pulse width

0261 A low pulse on HSI.2 had an unexpected width
EREG2 = difference between actual and expected pulse width

0361 A high pulse on HSI.3 had an unexpected width
EREG2 = difference between actual and expected pulse width

0461 A low pulse on HSI.3 had an unexpected width
EREG2 = difference between actual and expected pulse width

0561 HSI unit indicated an HSI.1 event occurred
EREG2 = Time recorded in HSI FIFO

DSTISR DST Initialization
0040 Initialization completed satisfactorily
EREG2 = 0000

0140 An abnormal RESET occurred
EREG2 = TIMER1

0240 T2CLK will not change
EREG2 = xxxx

0340 T2RST pin would not RESET T2CLK
EREG2 = xxxx

0440 IOC0.1 would not RESET T2CLK
EREG2 = xxxx

DSTSER Serial Port
01B0 An unexpected serial character was received
EREG2 = Bad character received

02B0 A carriage return was received out of sequence
EREG2 = number of characters since a carriage return

DSTSWT Software Timers

01D0 Found unexpected value on PORT1
EREG2 = expected value in high byte, actual in low byte

01D1 Invalid T2CLK value reached
EREG2 = T2CLK

02D0 A/D Done did not occur within BURST window
EREG2 = Time between A/D done and Software Timer 0

02D1 Test reached an illegal Software Timer 0 state
EREG2 = Illegal case jump made

03D0 REAL TIME update did not occur within BURST window
EREG2 = Time between REAL TIME update and Software Timer 0

04D0 HSO.0 response did not occur within BURST window
EREG2 = Time between HSO.0 update and Software Timer 0

05D0 HSI(.0) response did not occur within BURST window
EREG2 = Time between HSI(.0) service and Software Timer 0

DSTTOV Timer Overflows

0190 An overflow of T2CLK was indicated
EREG2 = TIMER1

xx91 ⟨user defined⟩
EREG2 = ⟨user defined⟩

MEM01 Complementary Address (Registers)

0021 All Tests Passed
EREG2 = 0000

0121 A memory location failed
EREG2 = address of the error

MEM02 Walking Ones/Zeros (Registers)

0022 All Tests Passed
EREG2 = 0000

0122 A memory location failed
EREG2 = address of the error

MEM03 Galloping Ones/Zeros (Registers)

0023 All Tests Passed
EREG2 = 0000

0123 A memory location failed
EREG2 = address of the error

MEM04 Bits Set

0024 No bits were set in the byte tested
EREG2 = 0000

0124 At least one bit was set in the byte tested
EREG2 = number of bits set

MEM05 Checkerboard Pattern (Registers)
0025 All Tests Passed
EREG2 = 0000

0125 A memory location failed
EREG2 = address of the error

MEM06 Complementary Address
0026 All Tests Passed
EREG2 = 0000

0126 A memory location failed
EREG2 = address of error

MEM07 Walking Ones
0027 All Tests Passed
EREG2 = 0000

0127 A memory location failed
EREG2 = address of the error

MEM08 Galloping Ones
0028 All Tests Passed
EREG2 = 0000

0128 A memory location failed
EREG2 = address of the error

MEM09 Walking Ones/Zeros
0029 All Tests Passed
EREG2 = 0000

0129 A memory location failed
EREG2 = address of the error

MEM0A Galloping Ones/Zeros
002A All Tests Passed
EREG2 = 0000

012A A memory location failed
EREG2 = address of the error

MEM0B Checksum
012B 16-bit Checksum is ready
EREG2 = 16-bit Checksum

MEM0C User Pattern (Registers)
002C All Tests Passed
EREG2 = 0000

012C A memory location failed
EREG2 = address of the error

MEM0D User Pattern
002D All Tests Passed
EREG2 = 0000

012D A memory location failed
EREG2 = address of the error

SYS01 Common Symbols

0000 No Message
EREG2 = 0ffffh

SYS02 System Power-up

0002 All Tests Passed
EREG2 = 0000h

0102 I/O Status Registers were unexpected
EREG2 = IOS0 in low byte, IOS1 in high byte

0202 TIMER1 did not change over time
EREG2 = TIMER1

0302 Zero Register was found to change
EREG2 = Program Status Word At Failure

0402 PUSHF or POPF failed
EREG2 = Erroneous PUSHed or POPed value found

0502 Sticky Bit would not set
EREG2 = 3ffffh

0502 Sticky Bit would not clear
EREG2 = 0000

0602 Carry Flag Test Failed
EREG2 = xxxx

0702 Overflow flags would not set correctly
EREG2 = 0002h

0702 Overflow flags would not clear correctly
EREG2 = xxxx

0802 Interrupt Pending Register failed read/write test
EREG2 = offending Interrupt Pending byte

SYS03 Program Counter

0003 All Tests Passed
EREG2 = 0000

0103 Test Code Returned Early
EREG2 = Early Time

0203 Test Code Returned Late
EREG2 = Late Time

0303 Counter Register contained unexpected value
EREG2 = Erroneous Counter Value

APPENDIX C
DESCRIPTION OF DIAG96.LIB BATCH FILES

The batch files that come with the library will help speed the process of either linking to the library as is, or revising library programs to suit custom purposes.

Some batch files require a parameter that provides the extensionless name of a user definable variable file to be included in the action of the batch file.

All DIAG96.LIB batch files assume that both the source and destination files reside in the same directory. Given the size of the library, and the fact that all of the files will not fit on one floppy disk, the command files will need to be edited if the user's system is not equipped with a hard disk.

INSTAL.BAT — Used to install the library on a hard disk system. To install the library, create a directory called \ DIAG96 under the main directory, insert disk 1 into drive a: and type:

a:Instal

DST360K .BAT & DST12MEG.BAT — CAUTION: THEE BATCH FILES WILL FORMAT AND DESTROY ALL INFORMATION ON THE FLOPPIES USED. These command files were created to make the DIAG96.LIB disk set. DST360K was created for use with 360K floppy disks and requires three diskettes. DST12MEG was created for use with 1.2M disks and only needs two diskettes. The batch files will prompt you to change disks. MAKE SURE TO ENTER THE CORRECT DISK DRIVE WHEN INVOKING THESE BATCH FILES. ALSO MAKE SURE TO INCLUDE THE DRIVE ID IN THE COMMAND LINE. THESE BATCH FILES FIRST FORMAT THE DISK, AND WE ALL KNOW WHAT WHEN DOS DEFAULTS TO THE HARD DISK!!!!!!!!!
For example:

DST12MEG a:

SCRUB.BAT — CAUTION: THIS FILE DELETES FILES USING WILDCARDS. All Diagnostic Library related files are delected for the \ DIAG96 directory. SYS?? and MEM?? wildcards are used, so be forewarned. This batch file does not delete itself!!!! To invoke this batch file, type:

Scrub

D96ASM.BAT — Assembles all **General Diagnostic** modules including the PLM compilation of D96P96.P96. To invoke the batch file, get in the \ DIAG96 directory and type:

D96ASM

DSTASM.BAT — Assembles all **Dynamic Stability Test** modules. To invoke the batch file, get in \ DIAG96 directory and type:

DSTASM

D96LP.BAT — Copies all **General Diagnostic list** files to a printer. Invocation must include a device where the printer resides. For example:

D96LP lpt1

DSTLP.BAT — Copies all **Dynamic Stability Test** modules to a printer. Invocation must include a device where the printer resides. For example:

DSTLP.BAT lpt1

LPONLY.BAT — Executes D96LP.BAT and DSTLP.BAT. Invocation must include a device where the printer resides. For example:

LPONLY lpt1

D96LIB.BAT — Deletes the current DIAG96.LIB collection. Also creates a new library of the same name using the files resident in the \ DIAG96 directory bearing the **General Diagnostics** names. The DST96.LIB is not altered, and is included in the new DIAG96.LIB. To invoke the batch file, get in the \ DIAG96 directory and type:

D96LIB

DSTLIB.BAT — Deletes the current DST96.LIB collection. Also creates a new library of the same name using the files resident in the \ DIAG96 directory bearing the **Dynamic Stability Test** names. Since DST96.LIB is included in DIAG96.LIB, DIAG96.LIB is recreated by an invocation of D96LIB.BAT. To invoke this batch file, get in the \ DIAG96 directory and type:

DSTLIB

DSTRL.BAT — This batch file is of most interest to **Dynamic Stability Test** users. It links a specified main task to the library. This file makes assumptions about the hardware memory implementation that may not be correct. Therefore minor changes may need to be made to the DSTRL.BAT RL96 invocation statement. A file name without extension must be provided and that file must reside in the \ DIAG96 directory. The batch file assumes that the extension of the object file to be linked to the library is .OBJ. For example:

DSTRL Example_task

BLASTP.BAT — This batch file assembles the specified input file, then executes D96ASM.BAT, DSTASM.BAT, LPONLY.BAT, DSTLIB.BAT, and DSTRL.BAT. Then, the listfile output of the user's assembly and the print file of the linkage are copied to the printer specified. The batch file assumes that the input file is in the \ DIAG96 directory and has a .A96 extension. For example:

BLASTP Example_ lpt1

BLASTN.BAT — This batch file executes all assemblies, compliations, and linkages executed in BLASTP.BAT, but no copies are sent to the printer. The batch file assumes that the input file is in the \ DIAG96 directory and has a .A96 extension. For example:

BLASTN Example_task

REGEN.BAT — Used to regenerate the library when only one module has changed. Specify the module that has changed when invoking this batch file. For example:

REGEN ALU03

MAKPLM.BAT — Used to make an impostor PLM96.LIB. The library created in not a real PLM96.LIB, and will not work with PLM programs. However, it is what is needed to use DIAG96.LIB. To invoke this batch file, get in the \ DIAG96 director and type:

MAKPLM

MAKBH.BAT — Used to modify the library to run in an 8X9XBH. The 8X9XBH fails a flag test because of the −90 bug relating to the Z flag on add and subtract with carry is inadvertantly verified by a library test. To invoke this batch file, get in the \ DIAG96 directory and type:

MAKBH

D96RL.BAT — A generalized command that links target modules to DIAG96.LIB. It is intended for used when only the **General Diagnostics** are being used. Provide the target object file name and the directory in which it resides. For example:

D96RL \ SOURCE \ Example_

```
SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE: :F5:D96A96.A96
OBJECT FILE: :F5:D96A96.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: NOGEN DEBUG

ERR LOC  OBJECT                  LINE        SOURCE STATEMENT
                                    1
                                    2   ;*************************************************************************
                                    3   ALL_TESTS_ASM96    MODULE STACKSIZE(20)
                                    4   ;************************************************************** 0030
                                    5   ;
                                    6   ; in order to run this module, the STACK must be ALL external, and the
                                    7   ; data ram partitioned for memory test must not include ANY of the STACK
                                    8   ;
                                    9   ;  To call this module
                                   10   ;
                                   11   ;       PUSH    #<RAM segment1 start address>
                                   12   ;       PUSH    #<RAM segment1 ending address>
                                   13   ;       PUSH    #<RAM segment2 start address>
                                   14   ;       PUSH    #<RAM segment2 ending address>
                                   15   ;       PUSH    #<random seed>
                                   16   ;       PUSH    #<number of cycles desired for random test>
                                   17   ;       PUSH    #<address of the last byte of rom>
                                   18   ;       PUSH    #<an argument for mul/div tests>
                                   19   ;       PUSH    #<a second argument for mul/div tests>
                                   20   ;       PUSH    #<a bit pattern for memory tests>
                                   21   ;       CALL    D96A96
                                   22   ;
                                   23   ;
                                   24   ; Remember, this test will take a long time if large memory regions are
                                   25   ; partitioned, or if a large number of cycles of random test numbers is
                                   26   ; requested.  For example, with 8Kbytes of Ram in each region the test
                                   27   ; executes in 3 hours.
                                   28   ;
                                   29   ; It is suggested that for large memory tests, that the complimentary
                                   30   ; address test be done on the whole region at once.  Then, the more
                                   31   ; exhaustive tests done on each memory chip in the system.
                                   32   ;*************************************************************************
                                   33
0000                               34           rseg
                                   35
                                   36   extrn sp,ereg1,ereg2
                                   37
                                   38
3000                               39           cseg at 3000h
                                   40   extrn sys01,sys02,sys03,alu01,alu02,alu03,alu04,alu05
                                   41   extrn mem01,mem02,mem03,mem04,mem05,mem06,mem07,mem08
                                   42   extrn mem09,mem0a,mem0b,mem0c,mem0d
                                   43
                                   44   PUBLIC D96A96
                                   45   $eject
                                   46
                                   47   $include (:f3:dstmac.inc)              ;provides the macro BR_ON_Error
                              =1   48   ;*************************************************************************
                              =1   49   ;DST_Macros     INCLUDE FILE ;*****************************************
                              =1   50   ;*************************************************************************
                              =1   51
```

```
ERR LOC  OBJECT                LINE      SOURCE STATEMENT
                               104
                               105
    0000                       106   D96A96:
                               107
    0000 EF0000          E     108      CALL sys02                    ;CALL the System Power Up Test
                               109
                               110   BR_ON_ERR        Error_Found
                               114
    000A EF0000          E     115      CALL alu01                    ;CALL the Add/Subtract test
                               116
                               117   BR_ON_ERR        Error_Found
                               121
    0014 EF0000          E     122      CALL alu02                    ;CALL the MULUB test
                               123
                               124   BR_ON_ERR        Error_Found
                               128
    001E EF0000          E     129      CALL alu03                    ;CALL the Multiply/Divide Table
                               130                                    ;driven test
                               131   BR_ON_ERR        Error_Found
                               135
    0028 CB000C          E     136        PUSH       0ch[sp]         ;PUSH a random seed
    002B CB000C          E     137        PUSH       0ch[sp]         ;PUSH the number of tests desired
    002E EF0000          E     138      CALL alu04                    ;CALL the Multiply/Divide Random test
                               139
                               140   BR_ON_ERR        Error_Found
                               144
    0038 CB0006          E     145        PUSH       06h[sp]         ;PUSH an argument
    003B CB0006          E     146        PUSH       06h[sp]         ;PUSH another argument
    003E EF0000          E     147      CALL alu05                    ;CALL the Multiply/Divide Core Test
                               148
                               149   BR_ON_ERR        Error_Found
                               153
    0048 EF0000          E     154      CALL mem01                    ;CALL a Complementary Address test
                               155                                    ;on the internal registers
                               156   BR_ON_ERR        Error_Found
                               160
    0052 EF0000          E     161      CALL mem02                    ;CALL a Walking 1s/0s test on
                               162                                    ;the internal registers
                               163   BR_ON_ERR        Error_Found
                               167
    005C EF0000          E     168      CALL mem03                    ;CALL a Galloping 1s/0s test on
                               169                                    ;the internal registers
                               170   BR_ON_ERR        Error_Found
                               174
    0066 C800            E     175        PUSH       zero            ;PUSH a zero
    0068 EF0000          E     176      CALL mem04                    ;CALL the Bits Set Test
                               177
                               178   BR_ON_ERR        Error_Found
                               182
    0072 EF0000          E     183      CALL mem05                    ;CALL a Checkerboard Pattern test
                               184                                    ;for internal registers
                               185   BR_ON_ERR        Error_Found
                               189
    007C CB0014          E     190        PUSH       14h[sp]         ;PUSH the start address
    007F CB0014          E     191        PUSH       14h[sp]         ; and the end address of a RAM area
    0082 EF0000          E     192      CALL mem06                    ; and CALL a Complementary Address test
                               193
```

```
ERR LOC  OBJECT                LINE      SOURCE STATEMENT
                                194   BR_ON_ERR       Error_Found
                                198
     008C CB0010          E     199       PUSH        10h[sp]          ;PUSH a second start and end address
     008F CB0010          E     200       PUSH        10h[sp]          ; and repeat the
     0092 EF0000          E     201     CALL mem06                     ;Complementary Address test
                                202
                                203   BR_ON_ERR       Error_Found
                                207
     009C CB0014          E     208       PUSH        14h[sp]          ;PUSH a start address
     009F CB0014          E     209       PUSH        14h[sp]          ;PUSH an ending address
     00A2 EF0000          E     210     CALL mem07                     ;CALL a Walking Ones test
                                211
                                212   BR_ON_ERR       Error_Found
                                216
     00AC CB0010          E     217       PUSH        10h[sp]          ;PUSH the start and end address
     00AF CB0010          E     218       PUSH        10h[sp]          ; for another section of RAM
     00B2 EF0000          E     219     CALL mem07                     ; and repeat the Walking Ones test
                                220
                                221   BR_ON_ERR       Error_Found
                                225
     00BC CB0014          E     226       PUSH        14h[sp]          ;PUSH a start address
     00BF CB0014          E     227       PUSH        14h[sp]          ;PUSH an ending address
     00C2 EF0000          E     228     CALL mem08                     ;CALL a Galloping Ones test
                                229
                                230   BR_ON_ERR       Error_Found
                                234
                                235
     00CC CB0010          E     236       PUSH        10h[sp]          ;PUSH a second start and end address
     00CF CB0010          E     237       PUSH        10h[sp]          ; for another region of RAM and
     00D2 EF0000          E     238     CALL mem08                     ;CALL the Galloping Ones test again
                                239
                                240   BR_ON_ERR       Error_Found
                                244
     00DC CB0014          E     245       PUSH        14h[sp]          ;PUSH the start and end address of
     00DF CB0014          E     246       PUSH        14h[sp]          ; a region of RAM
     00E2 EF0000          E     247     CALL mem09                     ;CALL the Walking 1s/0s test
                                248
                                249   BR_ON_ERR       Error_Found
                                253
                                254
     00EC CB0010          E     255       PUSH        10h[sp]          ;PUSH the start and end address of
     00EF CB0010          E     256       PUSH        10h[sp]          ; another region of RAM
     00F2 EF0000          E     257     CALL mem09                     ;CALL the Walking 1s/0s test again
                                258
                                259   BR_ON_ERR       Error_Found
                                263
     00FC CB0014          E     264       PUSH        14h[sp]          ;PUSH the start and end address of
     00FF CB0014          E     265       PUSH        14h[sp]          ; a region of RAM
     0102 EF0000          E     266     CALL mem0a                     ;CALL a Galloping 1s/0s test
                                267
                                268   BR_ON_ERR       Error_Found
                                272
                                273
     010C CB0010          E     274       PUSH        10h[sp]          ;PUSH the start and end address of
     010F CB0010          E     275       PUSH        10h[sp]          ; another region of RAM
     0112 EF0000          E     276     CALL mem0a                     ;CALL the Galloping 1s/0s test again
                                277
```

```
ERR LOC  OBJECT                LINE      SOURCE STATEMENT
                               278   BR_ON_ERR       Error_Found
                               282
                               283
     011A CB0002          E    284       PUSH       02h[sp]              ;PUSH a bit pattern to use and
     011D EF0000          E    285     CALL mem0c                        ;CALL the Checkerboard Pattern test
                               286                                       ; for internal registers
                               287   BR_ON_ERR       Error_Found
                               291
     0125 CB0014          E    292       PUSH       14h[sp]              ;PUSH the start and end address
     0128 CB0014          E    293       PUSH       14h[sp]              ; of a region of RAM, then
     012B CB0006          E    294       PUSH       06h[sp]              ;PUSH a bit pattern to use, then
     012E EF0000          E    295     CALL mem0d                        ;CALL the Checkerboard Pattern test
                               296                                       ; for external memory
                               297   BR_ON_ERR       Error_Found
                               301
     0136 CB0010          E    302       PUSH       10h[sp]              ;PUSH the start and end address
     0139 CB0010          E    303       PUSH       10h[sp]              ; of another region of RAM, then
     013C CB0006          E    304       PUSH       06h[sp]              ;PUSH a bit pattern to use, then
     013F EF0000          E    305     CALL mem0d                        ;CALL the Checkerboard Pattern test
                               306                                       ; for external memory
                               307   BR_ON_ERR       Error_Found
                               311
     0147 CB0014          E    312       PUSH       14h[sp]              ;PUSH a starting address, and
     014A CB0014          E    313       PUSH       14h[sp]              ;PUSH an ending address for
     014D EF0000          E    314     CALL sys03                        ; the Program Counter Module
                               315
                               316   BR_ON_ERR       Error_Found
                               320
     0155 CB0010          E    321       PUSH       10h[sp]              ;PUSH the start and end addresses
     0158 CB0010          E    322       PUSH       10h[sp]              ;for a second test region for
     015B EF0000          E    323     CALL sys03                        ; for the Program Counter Module
                               324
                               325   BR_ON_ERR       Error_Found
                               329
     0163 C98020               330       PUSH       #2080h               ;PUSH the code starting address
     0166 CB000A          E    331       PUSH       0ah[sp]              ;PUSH the ending code address
     0169 EF0000          E    332     CALL mem0b                        ;CALL the Checksum routine
                               333
     016C A1300000        E    334          LD      EREG1,#0030h         ;ALL DIAG96 TESTS PASSED
                               335                                       ; load the appropriate error code
                               336
     0170 CF0014          E    337          POP 14h[sp]            ; clean off the stack
     0173 65120000        E    338          ADD sp,#12h
     0177 F0                   339          RET                    ; return to the calling program
                               340
     0178                      341   Error_Found:
                               342
     0178 CF0014          E    343          POP 14h[sp]            ; clean off the stack
     017B 65120000        E    344          ADD sp,#12h
     017F F0                   345          RET                    ; return to the calling program
                               346   ;*************************************************************************
     0180                      347   end
```

```
SYMBOL TABLE LISTING
--------------------

 N A M E                          VALUE    ATTRIBUTES

ALL_TESTS_ASM96 . . . . . .       -----    MODULE STACKSIZE(20)
ALU01 . . . . . .                 -----    CODE EXTERNAL
ALU02 . . . . . .                 -----    CODE EXTERNAL
ALU03 . . . . . .                 -----    CODE EXTERNAL
ALU04 . . . . . .                 -----    CODE EXTERNAL
ALU05 . . . . . .                 -----    CODE EXTERNAL
BR_ON_ERR . . . . . .             -----    MACRO
D96A96. . . . . .                 0000H    CODE REL PUBLIC ENTRY
EREG1 . . . . . .                 -----    REG EXTERNAL
EREG2 . . . . . .                 -----    REG EXTERNAL
ERROR_FOUND . . . . . .           0178H    CODE REL ENTRY
MACRO_TEMP. . . . . .             0000H    REG REL BYTE
MEM01 . . . . . .                 -----    CODE EXTERNAL
MEM02 . . . . . .                 -----    CODE EXTERNAL
MEM03 . . . . . .                 -----    CODE EXTERNAL
MEM04 . . . . . .                 -----    CODE EXTERNAL
MEM05 . . . . . .                 -----    CODE EXTERNAL
MEM06 . . . . . .                 -----    CODE EXTERNAL
MEM07 . . . . . .                 -----    CODE EXTERNAL
MEM08 . . . . . .                 -----    CODE EXTERNAL
MEM09 . . . . . .                 -----    CODE EXTERNAL
MEM0A . . . . . .                 -----    CODE EXTERNAL
MEM0B . . . . . .                 -----    CODE EXTERNAL
MEM0C . . . . . .                 -----    CODE EXTERNAL
MEM0D . . . . . .                 -----    CODE EXTERNAL
RESET_WATCHDOG. . . . . .         -----    MACRO
RI. . . . . .                     0006H    NULL ABS
SP. . . . . .                     -----    REG EXTERNAL
SP_STAT . . . . . .               -----    REG EXTERNAL
SPSTATUS. . . . . .               -----    MACRO
SPWAIT. . . . . .                 -----    MACRO
SYS01 . . . . . .                 -----    CODE EXTERNAL
SYS02 . . . . . .                 -----    CODE EXTERNAL
SYS03 . . . . . .                 -----    CODE EXTERNAL
TI. . . . . .                     0005H    NULL ABS
ZERO. . . . . .                   -----    REG EXTERNAL

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

```
SERIES-III PL/M-96 V1.0 COMPILATION OF MODULE ALLDIAG96TESTS
OBJECT MODULE PLACED IN :F2:D96P96.OBJ
COMPILER INVOKED BY:  PLM96.86 :F2:D96P96.P96 CODE DEBUG


  1          All$Diag96$Tests:
             DO;


  2   1          SYS02:  PROCEDURE DWORD EXTERNAL;
  3   2              END SYS02;

  4   1          SYS03:  PROCEDURE (parm1,parm2) DWORD EXTERNAL;
  5   2              DECLARE   (parm1,parm2) WORD;
  6   2              END SYS03;

  7   1          ALU01:  PROCEDURE DWORD EXTERNAL;
  8   2              END ALU01;

  9   1          ALU02:  PROCEDURE DWORD EXTERNAL;
 10   2              END ALU02;

 11   1          ALU03:  PROCEDURE DWORD EXTERNAL;
 12   2              END ALU03;

 13   1          ALU04:  PROCEDURE (parm1,parm2) DWORD EXTERNAL;
 14   2              DECLARE   (parm1,parm2) WORD;
 15   2              END ALU04;

 16   1          ALU05:  PROCEDURE (parm1,parm2) DWORD EXTERNAL;
 17   2              DECLARE   (parm1,parm2) WORD;
 18   2              END ALU05;

 19   1          MEM01:  PROCEDURE DWORD EXTERNAL;
 20   2              END MEM01;

 21   1          MEM02:  PROCEDURE DWORD EXTERNAL;
 22   2              END MEM02;

 23   1          MEM03:  PROCEDURE DWORD EXTERNAL;
 24   2              END MEM03;

 25   1          MEM04:  PROCEDURE (parm1) DWORD EXTERNAL;
 26   2              DECLARE   (parm1) WORD;
 27   2              END MEM04;

 28   1          MEM05:  PROCEDURE DWORD EXTERNAL;
 29   2              END MEM05;

 30   1          MEM06:  PROCEDURE (parm1,parm2) DWORD EXTERNAL;
 31   2              DECLARE   (parm1,parm2) WORD;
 32   2              END MEM06;

 33   1          MEM07:  PROCEDURE (parm1,parm2) DWORD EXTERNAL;
 34   2              DECLARE   (parm1,parm2) WORD;
 35   2              END MEM07;
```

```
36   1          MEM08:  PROCEDURE (parm1,parm2) DWORD EXTERNAL;
37   2              DECLARE    (parm1,parm2) WORD;
38   2              END MEM08;

39   1          MEM09:  PROCEDURE (parm1,parm2) DWORD EXTERNAL;
40   2              DECLARE    (parm1,parm2) WORD;
41   2              END MEM09;

42   1          MEM0A:  PROCEDURE (parm1,parm2) DWORD EXTERNAL;
43   2              DECLARE    (parm1,parm2) WORD;
44   2              END MEM0A;

45   1          MEM0B:  PROCEDURE (parm1,parm2) DWORD EXTERNAL;
46   2              DECLARE    (parm1,parm2) WORD;
47   2              END MEM0B;

48   1          MEM0C:  PROCEDURE (parm1) DWORD EXTERNAL;
49   2              DECLARE    (parm1) WORD;
50   2              END MEM0C;

51   1          MEM0D:  PROCEDURE (parm1,parm2,parm3) DWORD EXTERNAL;
52   2              DECLARE    (parm1,parm2,parm3) WORD;
53   2              END MEM0D;

54   1          DECLARE result DWORD;
55   1          DECLARE error$codes STRUCTURE (number WORD,detail WORD) AT (.result);


56   1      D96P96: PROCEDURE (ram1$start,ram1$stop,
                       ram2$start,ram2$stop,
                       random$seed,random$length,
                       top$of$code,
                       argument1,argument2,
                       bit$pattern) DWORD PUBLIC;

57   2          DECLARE (ram1$start,ram1$stop,
                       ram2$start,ram2$stop,
                       random$seed,random$length,
                       top$of$code,
                       argument1,argument2,
                       bit$pattern) WORD SLOW;


58   2          result=SYS02;
59   2          IF error$codes.number > 255 THEN GOTO end$tests;

61   2          result=ALU01;
62   2          IF error$codes.number > 255 THEN GOTO end$tests;

64   2          result=ALU02;
65   2          IF error$codes.number > 255 THEN GOTO end$tests;

67   2          result=ALU03;
68   2          IF error$codes.number > 255 THEN GOTO end$tests;

70   2          result=ALU04(47efH,1000H);
```

```
 71   2          IF error$codes.number > 255 THEN GOTO end$tests;

 73   2          result=ALU05(argument1,argument2);
 74   2          IF error$codes.number > 255 THEN GOTO end$tests;

 76   2          result=MEM01;
 77   2          IF error$codes.number > 255 THEN GOTO end$tests;

 79   2          result=MEM02;
 80   2          IF error$codes.number > 255 THEN GOTO end$tests;

 82   2          result=MEM03;
 83   2          IF error$codes.number > 255 THEN GOTO end$tests;

 85   2          result=MEM04(0);
 86   2          IF error$codes.number > 255 THEN GOTO end$tests;

 88   2          result=MEM05;
 89   2          IF error$codes.number > 255 THEN GOTO end$tests;

 91   2          result=MEM06(ram1$start,ram1$stop);
 92   2          IF error$codes.number > 255 THEN GOTO end$tests;

 94   2          result=MEM06(ram2$start,ram2$stop);
 95   2          IF error$codes.number > 255 THEN GOTO end$tests;

 97   2          result=MEM07(ram1$start,ram1$stop);
 98   2          IF error$codes.number > 255 THEN GOTO end$tests;

100   2          result=MEM07(ram2$start,ram2$stop);
101   2          IF error$codes.number > 255 THEN GOTO end$tests;

103   2          result=MEM08(ram1$start,ram1$stop);
104   2          IF error$codes.number > 255 THEN GOTO end$tests;

106   2          result=MEM08(ram2$start,ram2$stop);
107   2          IF error$codes.number > 255 THEN GOTO end$tests;

109   2          result=MEM09(ram1$start,ram1$stop);
110   2          IF error$codes.number > 255 THEN GOTO end$tests;

112   2          result=MEM09(ram2$start,ram2$stop);
113   2          IF error$codes.number > 255 THEN GOTO end$tests;

115   2          result=MEM0A(ram1$start,ram1$stop);
116   2          IF error$codes.number > 255 THEN GOTO end$tests;

118   2          result=MEM0A(ram2$start,ram2$stop);
119   2          IF error$codes.number > 255 THEN GOTO end$tests;

121   2          result=MEM0C(bit$pattern);
122   2          IF error$codes.number > 255 THEN GOTO end$tests;

124   2          result=MEM0D(ram1$start,ram1$stop,bit$pattern);
125   2          IF error$codes.number > 255 THEN GOTO end$tests;

127   2          result=MEM0D(ram2$start,ram2$stop,bit$pattern);
```

```
128  2        IF error$codes.number > 255 THEN GOTO end$tests;

130  2        result=SYS03(ram1$start,ram1$stop);
131  2        IF error$codes.number > 255 THEN GOTO end$tests;

133  2        result=SYS03(ram2$start,ram2$stop);
134  2        IF error$codes.number > 255 THEN GOTO end$tests;

136  2        result=MEM0B(2080h,top$of$code);

137  2        error$codes.number=00f0h;

138  2     end$tests:  RETURN  result;

139  2        END D96P96;

140  1     END All$Diag96$Tests;
```

```
                                        ;   STATEMENT     56
0000                                D96P96:
0000  C800                  E             PUSH  ?FRAME01
0002  A01800                E             LD    ?FRAME01,SP
                                        ;   STATEMENT     58
0005  EF0000                E             CALL  SYS02
0008  A01E02                R             LD    RESULT+2H,TMP2
000B  A01C00                R             LD    RESULT,TMP0
                                        ;   STATEMENT     59
000E  89FF0000              R             CMP   ERRORCODES,#0FFH
0012  D102                               BNH   @0001
                                        ;   STATEMENT     60
0014  2226                               BR    ENDTESTS
                                        ;   STATEMENT     61
0016                                @0001:
0016  EF0000                E             CALL  ALU01
0019  A01E02                R             LD    RESULT+2H,TMP2
001C  A01C00                R             LD    RESULT,TMP0
                                        ;   STATEMENT     62
001F  89FF0000              R             CMP   ERRORCODES,#0FFH
0023  D102                               BNH   @0002
                                        ;   STATEMENT     63
0025  2215                               BR    ENDTESTS
                                        ;   STATEMENT     64
0027                                @0002:
0027  EF0000                E             CALL  ALU02
002A  A01E02                R             LD    RESULT+2H,TMP2
002D  A01C00                R             LD    RESULT,TMP0
                                        ;   STATEMENT     65
0030  89FF0000              R             CMP   ERRORCODES,#0FFH
0034  D102                               BNH   @0003
                                        ;   STATEMENT     66
0036  2204                               BR    ENDTESTS
                                        ;   STATEMENT     67
0038                                @0003:
0038  EF0000                E             CALL  ALU03
003B  A01E02                R             LD    RESULT+2H,TMP2
003E  A01C00                R             LD    RESULT,TMP0
                                        ;   STATEMENT     68
0041  89FF0000              R             CMP   ERRORCODES,#0FFH
0045  D102                               BNH   @0004
                                        ;   STATEMENT     69
0047  21F3                               BR    ENDTESTS
                                        ;   STATEMENT     70
0049                                @0004:
0049  C9EF47                             PUSH  #47EFH
004C  C90010                             PUSH  #1000H
004F  EF0000                E             CALL  ALU04
0052  A01E02                R             LD    RESULT+2H,TMP2
0055  A01C00                R             LD    RESULT,TMP0
                                        ;   STATEMENT     71
0058  89FF0000              R             CMP   ERRORCODES,#0FFH
005C  D102                               BNH   @0005
                                        ;   STATEMENT     72
005E  21DC                               BR    ENDTESTS
                                        ;   STATEMENT     73
```

```
0060                            @0005:
0060  CB0008              E             PUSH  ARGUMENT1[?FRAME01]
0063  CB0006              E             PUSH  ARGUMENT2[?FRAME01]
0066  EF0000              E             CALL  ALU05
0069  A01E02              R             LD    RESULT+2H,TMP2
006C  A01C00              R             LD    RESULT,TMP0
                                        ;   STATEMENT     74
006F  89FF0000            R             CMP   ERRORCODES,#0FFH
0073  D102                              BNH   @0006
                                        ;   STATEMENT     75
0075  21C5                              BR    ENDTESTS
                                        ;   STATEMENT     76
0077                            @0006:
0077  EF0000              E             CALL  MEM01
007A  A01E02              R             LD    RESULT+2H,TMP2
007D  A01C00              R             LD    RESULT,TMP0
                                        ;   STATEMENT     77
0080  89FF0000            R             CMP   ERRORCODES,#0FFH
0084  D102                              BNH   @0007
                                        ;   STATEMENT     78
0086  21B4                              BR    ENDTESTS
                                        ;   STATEMENT     79
0088                            @0007:
0088  EF0000              E             CALL  MEM02
008B  A01E02              R             LD    RESULT+2H,TMP2
008E  A01C00              R             LD    RESULT,TMP0
                                        ;   STATEMENT     80
0091  89FF0000            R             CMP   ERRORCODES,#0FFH
0095  D102                              BNH   @0008
                                        ;   STATEMENT     81
0097  21A3                              BR    ENDTESTS
                                        ;   STATEMENT     82
0099                            @0008:
0099  EF0000              E             CALL  MEM03
009C  A01E02              R             LD    RESULT+2H,TMP2
009F  A01C00              R             LD    RESULT,TMP0
                                        ;   STATEMENT     83
00A2  89FF0000            R             CMP   ERRORCODES,#0FFH
00A6  D102                              BNH   @0009
                                        ;   STATEMENT     84
00A8  2192                              BR    ENDTESTS
                                        ;   STATEMENT     85
00AA                            @0009:
00AA  C800                              PUSH  R0
00AC  EF0000              E             CALL  MEM04
00AF  A01E02              R             LD    RESULT+2H,TMP2
00B2  A01C00              R             LD    RESULT,TMP0
                                        ;   STATEMENT     86
00B5  89FF0000            R             CMP   ERRORCODES,#0FFH
00B9  D102                              BNH   @000A
                                        ;   STATEMENT     87
00BB  217F                              BR    ENDTESTS
                                        ;   STATEMENT     88
00BD                            @000A:
00BD  EF0000              E             CALL  MEM05
00C0  A01E02              R             LD    RESULT+2H,TMP2
```

```
00C3  A01C00          R         LD    RESULT,TMP0
                                ;   STATEMENT     89
00C6  89FF0000        R         CMP   ERRORCODES,#0FFH
00CA  D102                      BNH   @000B
                                ;   STATEMENT     90
00CC  216E                      BR    ENDTESTS
                                ;   STATEMENT     91
00CE                    @000B:
00CE  CB0016          E         PUSH  RAM1START[?FRAME01]
00D1  CB0014          E         PUSH  RAM1STOP[?FRAME01]
00D4  EF0000          E         CALL  MEM06
00D7  A01E02          R         LD    RESULT+2H,TMP2
00DA  A01C00          R         LD    RESULT,TMP0
                                ;   STATEMENT     92
00DD  89FF0000        R         CMP   ERRORCODES,#0FFH
00E1  D102                      BNH   @000C
                                ;   STATEMENT     93
00E3  2157                      BR    ENDTESTS
                                ;   STATEMENT     94
00E5                    @000C:
00E5  CB0012          E         PUSH  RAM2START[?FRAME01]
00E8  CB0010          E         PUSH  RAM2STOP[?FRAME01]
00EB  EF0000          E         CALL  MEM06
00EE  A01E02          R         LD    RESULT+2H,TMP2
00F1  A01C00          R         LD    RESULT,TMP0
                                ;   STATEMENT     95
00F4  89FF0000        R         CMP   ERRORCODES,#0FFH
00F8  D102                      BNH   @000D
                                ;   STATEMENT     96
00FA  2140                      BR    ENDTESTS
                                ;   STATEMENT     97
00FC                    @000D:
00FC  CB0016          E         PUSH  RAM1START[?FRAME01]
00FF  CB0014          E         PUSH  RAM1STOP[?FRAME01]
0102  EF0000          E         CALL  MEM07
0105  A01E02          R         LD    RESULT+2H,TMP2
0108  A01C00          R         LD    RESULT,TMP0
                                ;   STATEMENT     98
010B  89FF0000        R         CMP   ERRORCODES,#0FFH
010F  D102                      BNH   @000E
                                ;   STATEMENT     99
0111  2129                      BR    ENDTESTS
                                ;   STATEMENT    100
0113                    @000E:
0113  CB0012          E         PUSH  RAM2START[?FRAME01]
0116  CB0010          E         PUSH  RAM2STOP[?FRAME01]
0119  EF0000          E         CALL  MEM07
011C  A01E02          R         LD    RESULT+2H,TMP2
011F  A01C00          R         LD    RESULT,TMP0
                                ;   STATEMENT    101
0122  89FF0000        R         CMP   ERRORCODES,#0FFH
0126  D102                      BNH   @000F
                                ;   STATEMENT    102
0128  2112                      BR    ENDTESTS
                                ;   STATEMENT    103
012A                    @000F:
```

```
012A  CB0016          E         PUSH   RAM1START[?FRAME01]
012D  CB0014          E         PUSH   RAM1STOP[?FRAME01]
0130  EF0000          E         CALL   MEM08
0133  A01E02          R         LD     RESULT+2H,TMP2
0136  A01C00          R         LD     RESULT,TMP0
                                ;    STATEMENT    104
0139  89FF0000        R         CMP    ERRORCODES,#0FFH
013D  D102                       BNH    @0010
                                ;    STATEMENT    105
013F  20FB                       BR     ENDTESTS
                                ;    STATEMENT    106
0141                        @0010:
0141  CB0012          E         PUSH   RAM2START[?FRAME01]
0144  CB0010          E         PUSH   RAM2STOP[?FRAME01]
0147  EF0000          E         CALL   MEM08
014A  A01E02          R         LD     RESULT+2H,TMP2
014D  A01C00          R         LD     RESULT,TMP0
                                ;    STATEMENT    107
0150  89FF0000        R         CMP    ERRORCODES,#0FFH
0154  D102                       BNH    @0011
                                ;    STATEMENT    108
0156  20E4                       BR     ENDTESTS
                                ;    STATEMENT    109
0158                        @0011:
0158  CB0016          E         PUSH   RAM1START[?FRAME01]
015B  CB0014          E         PUSH   RAM1STOP[?FRAME01]
015E  EF0000          E         CALL   MEM09
0161  A01E02          R         LD     RESULT+2H,TMP2
0164  A01C00          R         LD     RESULT,TMP0
                                ;    STATEMENT    110
0167  89FF0000        R         CMP    ERRORCODES,#0FFH
016B  D102                       BNH    @0012
                                ;    STATEMENT    111
016D  20CD                       BR     ENDTESTS
                                ;    STATEMENT    112
016F                        @0012:
016F  CB0012          E         PUSH   RAM2START[?FRAME01]
0172  CB0010          E         PUSH   RAM2STOP[?FRAME01]
0175  EF0000          E         CALL   MEM09
0178  A01E02          R         LD     RESULT+2H,TMP2
017B  A01C00          R         LD     RESULT,TMP0
                                ;    STATEMENT    113
017E  89FF0000        R         CMP    ERRORCODES,#0FFH
0182  D102                       BNH    @0013
                                ;    STATEMENT    114
0184  20B6                       BR     ENDTESTS
                                ;    STATEMENT    115
0186                        @0013:
0186  CB0016          E         PUSH   RAM1START[?FRAME01]
0189  CB0014          E         PUSH   RAM1STOP[?FRAME01]
018C  EF0000          E         CALL   MEM0A
018F  A01E02          R         LD     RESULT+2H,TMP2
0192  A01C00          R         LD     RESULT,TMP0
                                ;    STATEMENT    116
0195  89FF0000        R         CMP    ERRORCODES,#0FFH
0199  D102                       BNH    @0014
```

```
                                        ;   STATEMENT   117
019B  209F                              BR    ENDTESTS
                                        ;   STATEMENT   118
019D                            @0014:
019D  CB0012            E               PUSH  RAM2START[?FRAME01]
01A0  CB0010            E               PUSH  RAM2STOP[?FRAME01]
01A3  EF0000            E               CALL  MEM0A
01A6  A01E02            R               LD    RESULT+2H,TMP2
01A9  A01C00            R               LD    RESULT,TMP0
                                        ;   STATEMENT   119
01AC  89FF0000          R               CMP   ERRORCODES,#0FFH
01B0  D102                              BNH   @0015
                                        ;   STATEMENT   120
01B2  2088                              BR    ENDTESTS
                                        ;   STATEMENT   121
01B4                            @0015:
01B4  CB0004            E               PUSH  BITPATTERN[?FRAME01]
01B7  EF0000            E               CALL  MEM0C
01BA  A01E02            R               LD    RESULT+2H,TMP2
01BD  A01C00            R               LD    RESULT,TMP0
                                        ;   STATEMENT   122
01C0  89FF0000          R               CMP   ERRORCODES,#0FFH
01C4  D102                              BNH   @0016
                                        ;   STATEMENT   123
01C6  2074                              BR    ENDTESTS
                                        ;   STATEMENT   124
01C8                            @0016:
01C8  CB0016            E               PUSH  RAM1START[?FRAME01]
01CB  CB0014            E               PUSH  RAM1STOP[?FRAME01]
01CE  CB0004            E               PUSH  BITPATTERN[?FRAME01]
01D1  EF0000            E               CALL  MEM0D
01D4  A01E02            R               LD    RESULT+2H,TMP2
01D7  A01C00            R               LD    RESULT,TMP0
                                        ;   STATEMENT   125
01DA  89FF0000          R               CMP   ERRORCODES,#0FFH
01DE  D102                              BNH   @0017
                                        ;   STATEMENT   126
01E0  205A                              BR    ENDTESTS
                                        ;   STATEMENT   127
01E2                            @0017:
01E2  CB0012            E               PUSH  RAM2START[?FRAME01]
01E5  CB0010            E               PUSH  RAM2STOP[?FRAME01]
01E8  CB0004            E               PUSH  BITPATTERN[?FRAME01]
01EB  EF0000            E               CALL  MEM0D
01EE  A01E02            R               LD    RESULT+2H,TMP2
01F1  A01C00            R               LD    RESULT,TMP0
                                        ;   STATEMENT   128
01F4  89FF0000          R               CMP   ERRORCODES,#0FFH
01F8  D102                              BNH   @0018
                                        ;   STATEMENT   129
01FA  2040                              BR    ENDTESTS
                                        ;   STATEMENT   130
01FC                            @0018:
01FC  CB0016            E               PUSH  RAM1START[?FRAME01]
01FF  CB0014            E               PUSH  RAM1STOP[?FRAME01]
0202  EF0000            E               CALL  SYS03
```

```
0205  A01E02            R         LD    RESULT+2H,TMP2
0208  A01C00            R         LD    RESULT,TMP0
                                  ;   STATEMENT   131
020B  89FF0000          R         CMP   ERRORCODES,#0FFH
020F  D102                        BNH   @0019
                                  ;   STATEMENT   132
0211  2029                        BR    ENDTESTS
                                  ;   STATEMENT   133
0213                          @0019:
0213  CB0012            E         PUSH  RAM2START[?FRAME01]
0216  CB0010            E         PUSH  RAM2STOP[?FRAME01]
0219  EF0000            E         CALL  SYS03
021C  A01E02            R         LD    RESULT+2H,TMP2
021F  A01C00            R         LD    RESULT,TMP0
                                  ;   STATEMENT   134
0222  89FF0000          R         CMP   ERRORCODES,#0FFH
0226  D102                        BNH   @001A
                                  ;   STATEMENT   135
0228  2012                        BR    ENDTESTS
                                  ;   STATEMENT   136
022A                          @001A:
022A  C98020                      PUSH  #2080H
022D  CB000A            E         PUSH  TOPOFCODE[?FRAME01]
0230  EF0000            E         CALL  MEM0B
0233  A01E02            R         LD    RESULT+2H,TMP2
0236  A01C00            R         LD    RESULT,TMP0
                                  ;   STATEMENT   137
0239  ADF000            R         LDBZE ERRORCODES,#0F0H
                                  ;   STATEMENT   138
023C                          ENDTESTS:
023C  A0021E            R         LD    TMP2,RESULT+2H
023F  A0001C            R         LD    TMP0,RESULT
0242  CC00              E         POP   ?FRAME01
0244  A21822                     LD    TMP6,[SP]
0247  65160018                   ADD   SP,#16H
024B  E322                        BR    [TMP6]
                                  ;   STATEMENT   139
                                  ;   STATEMENT   140
                                  END
```

```
MODULE INFORMATION:

     CODE AREA SIZE              = 024DH    589D
     CONSTANT AREA SIZE          = 0000H      0D
     DATA AREA SIZE              = 0000H      0D
     STATIC REGS AREA SIZE       = 0004H      4D
     OVERLAYABLE REGS AREA SIZE  = 0000H      0D
     MAXIMUM STACK SIZE          = 000AH     10D
     183 LINES READ

PL/M-96 COMPILATION COMPLETE.      0 WARNINGS,     0 ERRORS
```

```
MCS-96 MACRO ASSEMBLER    SELECTED_TESTS_ASM96

SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE: :F5:D96FST.A96
OBJECT FILE: :F5:D96FST.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: NOGEN DEBUG

ERR LOC  OBJECT                 LINE        SOURCE STATEMENT
                                   1
                                   2   ;*************************************************************************
                                   3   Selected_Tests_ASM96    MODULE   STACKSIZE(20)
                                   4   ;************************************************************** 0031
                                   5   ;
                                   6   ; In order to run this module, the STACK must be ALL external, and the
                                   7   ; data ram partitioned for memory test must not include ANY of the STACK
                                   8   ;
                                   9   ;  To call this module
                                  10   ;
                                  11   ;       PUSH    #<RAM segment1 start  address>
                                  12   ;       PUSH    #<RAM segment1 ending address>
                                  13   ;       PUSH    #<RAM segment2 start  address>
                                  14   ;       PUSH    #<RAM segment2 ending address>
                                  15   ;       PUSH    #<random seed>
                                  16   ;       PUSH    #<number of cycles desired for random test>
                                  17   ;       PUSH    #<address of the last byte of rom>
                                  18   ;       PUSH    #<an argument for mul/div tests>
                                  19   ;       PUSH    #<a second argument for mul/div tests>
                                  20   ;       PUSH    #<a bit pattern for memory tests>
                                  21   ;       CALL    D96FST
                                  22   ;
                                  23   ;
                                  24   ;*************************************************************************
                                  25
    0000                          26           rseg
                                  27
                                  28   extrn sp,ereg1,ereg2
                                  29
                                  30
    0000                          31           cseg
                                  32   extrn sys01,sys02,sys03,alu01,alu02,alu03,alu04,alu05
                                  33   extrn mem01,mem02,mem03,mem04,mem05,mem06,mem07,mem08
                                  34   extrn mem09,mem0a,mem0b,mem0c,mem0d
                                  35
                                  36   PUBLIC D96FST
                                  37   $eject
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                                 38
                                 39   $include (:f3:dstmac.inc)
                               =1  40   ;*******************************************************************************
                               =1  41   ;DST_Macros      INCLUDE FILE ;*************************************************
                               =1  42   ;*******************************************************************************
                               =1  43
                    0000       =1  44   rseg
                               =1  45
                    0000       =1  46   macro_temp:      DSB 1
                               =1  47   extrn zero,sp_stat
                               =1  48
                    0000       =1  49   cseg
                      0005     =1  50   ti equ 5
                      0006     =1  51   ri equ 6
                               =1  52
                               =1  53
                               =1  54   ;*******************************************************************************
                               =1  55   RESET_WATCHDOG  MACRO                    ;macro to reset the watchdog
                               =1  56                   LDB      0ah,#1eh
                               =1  57                   LDB      0ah,#0elh
                               =1  58   ENDM
                               =1  59   ;*******************************************************************************
                               =1  60
                               =1  61
                               =1  62   ;*******************************************************************************
                               =1  63   SPSTATUS        MACRO    v1              ; macro to read sp_stat to
                               =1  64                    LOCAL    Sp_read         ; work around the ri/ti bug
                               =1  65   Sp_read:                                 ; on the 8x9x-90.
                               =1  66                LDB      macro_temp,sp_stat
                               =1  67                ORB      v1,macro_temp
                               =1  68                ANDB     macro_temp,#01100000B
                               =1  69                JNE      Sp_read
                               =1  70   ENDM
                               =1  71   ;*******************************************************************************
                               =1  72
                               =1  73
                               =1  74
                               =1  75   ;*******************************************************************************
                               =1  76   SPWAIT          MACRO    v2              ; macro to wait for ri/ti set
                               =1  77                                            ; and avoid 8x9x-90 bug.
                               =1  78                                            ; NOTE!! this macro won't work
                               =1  79                   JBC      sp_stat,v2,$    ; with a full duplex line.
                               =1  80                   LDB      zero,sp_stat
                               =1  81
                               =1  82   ENDM
                               =1  83   ;*******************************************************************************
                               =1  84
                               =1  85
                               =1  86
                               =1  87   ;*******************************************************************************
                               =1  88   BR_ON_ERR       MACRO    Label           ; macro to test high byte of
                               =1  89                                            ; EREG1 and branch away if
                               =1  90          CMPB     ereg1+1h,zero           ; the byte is non-zero (which
                               =1  91          BNE      Label                   ; means there was an error).
                               =1  92   ENDM
                               =1  93   ;*******************************************************************************
                               =1  94
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                                96
    0000                        97    D96FST:
                                98
    0000 EF0000           E     99       CALL sys02.A96                    ;CALL the Power Up Test
                               100
                               101    BR_ON_ERR       Error_Found
                               105
    000A EF0000           E    106       CALL alu01                        ;CALL the Add/Subtract test
                               107
                               108    BR_ON_ERR       Error_Found
                               112
    0014 EF0000           E    113       CALL alu02                        ;CALL the MULUB test
                               114
                               115    BR_ON_ERR       Error_Found
                               119
    001E EF0000           E    120       CALL alu03                        ;CALL the Multiply/Divide Table
                               121                                         ; driven test
                               122    BR_ON_ERR       Error_Found
                               126
    0028 CB000C           E    127         PUSH      0ch[sp]               ;PUSH a seed and test length
    002B CB000C           E    128         PUSH      0ch[sp]               ; for the random number based
    002E EF0000           E    129       CALL alu04                        ; Multiply/Divide Random test
                               130
                               131    BR_ON_ERR       Error_Found
                               135
    0038 CB0006           E    136         PUSH      06h[sp]               ;PUSH an argument
    003B CB0006           E    137         PUSH      06h[sp]               ;PUSH another argument
    003E EF0000           E    138       CALL alu05                        ;CALL the Multiply/Divide Core test
                               139
                               140    BR_ON_ERR       Error_Found
                               144
    0048 EF0000           E    145       CALL mem01                        ;CALL the Complementary Address test
                               146                                         ; for internal registers
                               147    BR_ON_ERR       Error_Found
                               151
    0052 EF0000           E    152       CALL mem03                        ;CALL the Galloping 1s/0s test
                               153                                         ; for internal registers
                               154    BR_ON_ERR       Error_Found
                               158
    005C EF0000           E    159       CALL mem05                        ;CALL the Chekerboard Pattern test
                               160                                         ; for internal registers
                               161    BR_ON_ERR       Error_Found
                               165
    0066 CB0014           E    166         PUSH      14h[sp]               ;PUSH a start and end address
    0069 CB0014           E    167         PUSH      14h[sp]               ; for a region of RAM to conduct
    006C EF0000           E    168       CALL mem06                        ; the Complementary Address test for
                               169                                         ; external RAM
                               170    BR_ON_ERR       Error_Found
                               174
    0074 CB0010           E    175         PUSH      10h[sp]               ;PUSH a start and end address
    0077 CB0010           E    176         PUSH      10h[sp]               ; for another region of RAM to conduct
    007A EF0000           E    177       CALL mem06                        ; the Complementary Address test for
                               178                                         ; external RAM
                               179    BR_ON_ERR       Error_Found
                               183
    0082 CB0014           E    184         PUSH      14h[sp]               ;PUSH a start and end address
    0085 CB0014           E    185         PUSH      14h[sp]               ; for a region of RAM, and PUSH
```

```
ERR LOC   OBJECT                LINE        SOURCE STATEMENT
    0088 CB0006             E    186          PUSH        06h[sp]              ; a bit pattern to use in the
    008B EF0000             E    187       CALL mem0d                         ; Checkerboard Pattern test for
                                 188                                          ; external RAM
                                 189    BR_ON_ERR        Error_Found
                                 193
    0093 CB0010             E    194          PUSH        10h[sp]              ;PUSH a start and end address for
    0096 CB0010             E    195          PUSH        10h[sp]              ; another region of RAM, and PUSH
    0099 CB0006             E    196          PUSH        06h[sp]              ; a bit pattern to use in the
    009C EF0000             E    197       CALL mem0d                         ; Checkerboard Pattern test for
                                 198                                          ; external RAM
                                 199    BR_ON_ERR        Error_Found
                                 203
    00A4 CB0014             E    204          PUSH        14h[sp]              ;PUSH a start and end address
    00A7 CB0014             E    205          PUSH        14h[sp]              ; for a region of RAM to conduct
    00AA EF0000             E    206       CALL sys03                         ; the Program Counter test
                                 207
                                 208    BR_ON_ERR        Error_Found
                                 212
    00B2 CB0010             E    213          PUSH        10h[sp]              ;PUSH a start and end address
    00B5 CB0010             E    214          PUSH        10h[sp]              ; for another region of RAM to conduct
    00B8 EF0000             E    215       CALL sys03                         ; the Program Counter test
                                 216
                                 217    BR_ON_ERR        Error_Found
                                 221
    00C0 C98020                  222          PUSH        #2080h               ;PUSH the code starting address
    00C3 CB000A             E    223          PUSH        0ah[sp]              ;PUSH the code ending address
    00C6 EF0000             E    224       CALL mem0b                         ; CALL the checksum routine
                                 225
    00C9 A1310000           E    226            LD        eregl,#0031h         ;ALL DIAG96 TESTS PASSED
                                 227                                          ; load appropriate error code
                                 228
    00CD CF0014             E    229            POP       14h[sp]              ; clean off the stack
    00D0 65120000           E    230            ADD       sp,#12h
    00D4 F0                      231            RET                            ; return to the calling program
                                 232
    00D5                         233    Error_Found:
                                 234
    00D5 CF0014             E    235            POP       14h[sp]              ; clean off the stack
    00D8 65120000           E    236            ADD       sp,#12h
    00DC F0                      237            RET                            ; return to the calling program
                                 238
                                 239    ;*******************************************************************************
    00DD                         240    end
```

SYMBOL TABLE LISTING

N A M E	VALUE	ATTRIBUTES
ALU01	-----	CODE EXTERNAL
ALU02	-----	CODE EXTERNAL
ALU03	-----	CODE EXTERNAL
ALU04	-----	CODE EXTERNAL
ALU05	-----	CODE EXTERNAL
BR_ON_ERR	-----	MACRO
D96FST	0000H	CODE REL PUBLIC ENTRY
EREG1	-----	REG EXTERNAL
EREG2	-----	REG EXTERNAL
ERROR_FOUND	00D5H	CODE REL ENTRY
MACRO_TEMP	0000H	REG REL BYTE
MEM01	-----	CODE EXTERNAL
MEM02	-----	CODE EXTERNAL
MEM03	-----	CODE EXTERNAL
MEM04	-----	CODE EXTERNAL
MEM05	-----	CODE EXTERNAL
MEM06	-----	CODE EXTERNAL
MEM07	-----	CODE EXTERNAL
MEM08	-----	CODE EXTERNAL
MEM09	-----	CODE EXTERNAL
MEM0A	-----	CODE EXTERNAL
MEM0B	-----	CODE EXTERNAL
MEM0C	-----	CODE EXTERNAL
MEM0D	-----	CODE EXTERNAL
RESET_WATCHDOG	-----	MACRO
RI	0006H	NULL ABS
SELECTED_TESTS_ASM96	-----	MODULE STACKSIZE(20)
SP	-----	REG EXTERNAL
SP_STAT	-----	REG EXTERNAL
SPSTATUS	-----	MACRO
SPWAIT	-----	MACRO
SYS01	-----	CODE EXTERNAL
SYS02	-----	CODE EXTERNAL
SYS03	-----	CODE EXTERNAL
TI	0005H	NULL ABS
ZERO	-----	REG EXTERNAL

ASSEMBLY COMPLETED, NO ERROR(S) FOUND.

SERIES-III MCS-96 MACRO ASSEMBLER, V1.0

SOURCE FILE: :F2:DSTUSR.A96
OBJECT FILE: :F2:DSTUSR.OBJ
CONTROLS SPECIFIED IN INVOCATION COMMAND: GEN DEBUG

```
ERR LOC  OBJECT                LINE      SOURCE STATEMENT
                                  1  ;*************************************************************************
                                  2  DSTUSR        MODULE  main,stacksize(2)
                                  3  ;*************************************************************************
                                  4
                                  5
    0040                          6          oseg at 40h
    0040                          7  User_Registers: DSB     1ch
      0040                        8          temp    set     User_Registers:WORD
                                  9
    0000                         10          rseg
                                 11  EXTRN sp,zero,timer1,ereg1
                                 12
                                 13
    0100                         14  dseg at 100h                    ;to ensure that the STACK does not get
                                 15                                  ; located in an area of RAM that will be
    0100                         16  DSEG1:  DSB     700h            ; memory tested, reserve those regions
                                 17                                  ; as data segments.
    4200                         18  dseg at 4200h
                                 19
    4200                         20  DSEG2:  DSB     1e00h
                                 21
                                 22
                                 23
    2080                         24  cseg at 2080h
                                 25
                                 26  extrn   alu04,alu01,alu02,mem06,mem0a,error_proc,alu05
                                 27  EXTRN DSTISR
                                 28
    2080 A1FF0040                29          LD      temp,#0ffh
    2084 E040FD                  30          DJNZ    temp,$                  ; wait for sbe96 NMIs to stop
                                 31
    2087 A1000000          E     32          LD      sp,#STACK
                                 33
    208B C90001                  34          PUSH    #100h                   ;RAM segment1 start address
    208E C9FF07                  35          PUSH    #7ffh                   ;RAM segment1 end   address
    2091 C90042                  36          PUSH    #4200h                  ;RAM segment2 start address
    2094 C9FF5F                  37          PUSH    #5fffh                  ;RAM segment2 end   address
    2097 C9EF47                  38          PUSH    #47efh                  ;random seed
    209A C90010                  39          PUSH    #1000h                  ;random test length
    209D C9FF3F                  40          PUSH    #3fffh                  ;top of code address
    20A0 C9429D                  41          PUSH    #9d42h                  ;an argument for mul/div test
    20A3 C98C77                  42          PUSH    #778ch                  ;another argument for mul/div test
    20A6 C95A5A                  43          PUSH    #5a5ah                  ;bit pattern for memory test
    20A9 EF0000            E     44          CALL    DSTISR                  ;CALL the Dynamic Stability Test
                                 45                                          ; initialization routine
                                 46
    20AC                         47  Main_Task:                               ;_____________________________
                                 48
    20AC C98080                  49          push    #8080h
    20AF C90080                  50          push    #8000h                  ; use the multiply/divide core
    20B2 EF0000            E     51          call    alu05                   ; test on the arguments
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    20B5 980001            E     52            cmpb    eregl+1,zero            ; #8080h and #8000h in all
    20B8 DF022074                53  !         bne     error_found             ; combinations
                                    !JE   $+4
                                    !SJMP         error_found             ; combinations
                                54
    20BC C90080                 55            push    #8000h
    20BF C98080                 56            push    #8080h
    20C2 EF0000            E    57            call    alu05
    20C5 980001            E    58            cmpb    eregl+1,zero
    20C8 DF022064               59  !         bne     error_found
                                    !JE   $+4
                                    !SJMP         error_found
                                60
    20CC C90080                 61            push    #8000h
    20CF C90080                 62            push    #8000h
    20D2 EF0000            E    63            call    alu05
    20D5 980001            E    64            cmpb    eregl+1,zero
    20D8 D756                   65            bne     error_found
                                66
    20DA C98080                 67            push    #8080h
    20DD C90080                 68            push    #8000h
    20E0 EF0000            E    69            call    alu05
    20E3 980001            E    70            cmpb    eregl+1,zero
    20E6 D748                   71            bne     error_found
                                72
    20E8 C90001                 73            push    #100h                   ; perform a galloping 1s/0s test
    20EB C9FF07                 74            push    #7ffh                   ; on a small section of RAM
    20EE EF0000            E    75            Call    mem0a
    20F1 980001            E    76            cmpb    eregl+1,zero
    20F4 D73A                   77            bne     error_found
                                78
    20F6 C800              E    79            push    timerl                  ;send a timerl based seed to the
    20F8 C90020                 80            push    #2000h                  ;random number based multiply/divide
    20FB EF0000            E    81            call    alu04                   ; test and let it run for a string
    20FE 980001            E    82            cmpb    eregl+1h,zero           ; of 2000h argument pairs
    2101 D72D                   83            bne     error_found
                                84
    2103 EF0000            E    85            call    alu01                   ;perform the add/subtract test
    2106 980001            E    86            cmpb    eregl+1h,zero
    2109 D725                   87            bne     error_found
                                88
    210B C90042                 89            push    #4200h                  ; perform a Complementary address test
    210E C9FF5F                 90            push    #5fffh                  ; on a large section of RAM
    2111 EF0000            E    91            Call    mem06
    2114 980001            E    92            cmpb    eregl+1,zero
    2117 D717                   93            bne     error_found
                                94
    2119 EF0000            E    95            call    alu02                   ; perform the MULUB test
    211C 980001            E    96            cmpb    eregl+1h,zero
    211F D70F                   97            bne     error_found
                                98
    2121 C800              E    99            push    timerl                  ; send another timerl based seed to
    2123 C90020                100            push    #2000h                  ; the random number based multiply/
    2126 EF0000            E   101            call    alu04                   ; divide test
    2129 980001            E   102            cmpb    eregl+1h,zero
    212C D702                  103            bne     error_found
                               104
```

```
MCS-96 MACRO ASSEMBLER    DSTUSR

ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    212E 277C                   105        BR      Main_task                ; start the main_task tests over
                                106
    2130                        107    Error_found:
    2130 FA                     108            di
    2131 EF0000            E    109            CALL    Error_Proc           ; if an error is found, disable
                                110                                         ; interrupts and call the error
                                111                                         ; procedure in the DST96.LIB.
                                112                                         ; the test that found an error will
                                113                                         ; have placed the appropriate
                                114                                         ; error codes in locations EREG1 and
    2134 27FE                   115    BR $                                 ; EREG2 for output through Error_Proc
                                116    ;*************************************************************************
                                117
    2136                        118    end
```

```
M S-96 MACRO ASSEMBLER    DSTUSR

SYMBOL TABLE LISTING
--------------------

 N A M E                        VALUE    ATTRIBUTES

ALU01 . . . . . .               -----    CODE EXTERNAL
ALU02 . . . . . .               -----    CODE EXTERNAL
ALU04 . . . . . .               -----    CODE EXTERNAL
ALU05 . . . . . .               -----    CODE EXTERNAL
DSEG1 . . . . . .               0100H    DATA ABS BYTE
DSEG2 . . . . . .               4200H    DATA ABS BYTE
DSTISR. . . . . .               -----    CODE EXTERNAL
DSTUSR. . . . . .               -----    MODULE MAIN STACKSIZE(2)
EREG1 . . . . . .               -----    REG EXTERNAL
ERROR_FOUND . . . .             2130H    CODE ABS ENTRY
ERROR_PROC. . . . .             -----    CODE EXTERNAL
MAIN_TASK . . . . .             20ACH    CODE ABS ENTRY
MEM06 . . . . . .               -----    CODE EXTERNAL
MEM0A . . . . . .               -----    CODE EXTERNAL
SP. . . . . .                   -----    REG EXTERNAL
TEMP. . . . . .                 0040H    OVERLAY ABS WORD
TIMER1. . . . . .               -----    REG EXTERNAL
USER_REGISTERS. . . .           0040H    OVERLAY ABS BYTE
ZERO. . . . . .                 -----    REG EXTERNAL

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

80960 Article Reprints

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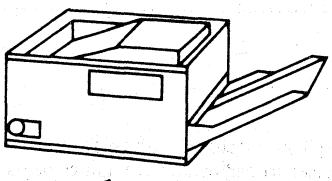

Intel's 80960: An Architecture Optimized for Embedded Control

Intel's internally developed 80960 architecture allows embedded system designers to take advantage of silicon technology advancements without architectural limits. The 80960, developed from scratch for embedded control applications, eliminates architectural obstacles to state-of-the-art implementation techniques that allow parallel and out-of-order instruction execution.

In introducing the 80960 architecture, I distinguish between the architecture and the microarchitecture of an implementation. A microarchitecture is an actual implementation of the architecture's instruction set and programming resources. Different microarchitectures may have different pipeline construction, internal bus widths, register set porting, cache parameterization (two-way, four-way, and so on), and degrees of parallelism, or may not execute instructions out of order. The architecture is specified in such a way that wide latitude is available for future microarchitectural advancements. In this way both very high performance and highly integrated controllers can be built using the 80960 architecture.

Principally, the 80960 architecture allows, for at least the next decade, silicon technology and microarchitectural advances to translate directly into increased performance without architectural limitations. While the common performance target of typical RISC architectures is an execution speed of one instruction per processor clock cycle, the 80960 architecture targets the execution of multiple instructions per clock cycle (fractional clock cycles per instruction). By defining an architecture that supports parallel instruction execution and out-of-order instruction execution, we do not constrain performance advances to the system clock cycle.

Additionally, the 80960 has been optimized for the wide range of applications that are unencumbered by a need to be compatible with an existing embedded control architecture. These applications are often very cost sensitive, require a different mix of instructions than reprogrammable applications, have demanding interrupt response requirements, and use real-time executives rather than full-blown operating systems. With these factors in mind, we developed the 80960 while avoiding architectural constructs that would restrict an implementation's capability to execute multiple instructions in one clock cycle.

Executing instructions in one clock cycle is not fast enough for this standard-core architecture. Its parallelism and out-of-order execution promise fractional clock rates in future implementations.

David P. Ryan
Intel Corporation

June 1988
270671-001

80960 architecture

The architecture also allows application-specific extensions such as:

- instruction set extensions (floating-point operations),
- special registers,
- larger caches,
- multiple caches,
- on-chip program and data memory,
- a memory management and protection unit,
- fault-tolerance support,
- multiprocessing support, and
- real-time peripherals (DMA, analog/digital, serial ports).

The 80960's instruction set has also been optimized for embedded control applications. It offers Boolean operations more powerful than those of the 8051 family. Single instructions access frequently executed functions for increased code density and performance. They include CALL, RET, Compare_and_Branch, Conditional_Compare, Compare_and_Increment or Decrement, and Bit Field Extract.

A priority interrupt structure simplifies the management of real-time events, and, along with a user/supervisor model, supports fast, safe, real-time kernel operation. A generalized fault-handling mechanism simplifies the task of detecting errant arithmetic calculations or other conditions that typically require a significant amount of user code runtime support. The 80960 does not require sophisticated, optimizing high-level-language compilers to achieve high performance. However, no obstacles to performance enhancements via a good optimizing compiler exist.

Since products based on the 80960 have high performance levels, even without code optimization, many users will attain their required system performance with 80960 products without having to understand the parallelism of the implementation they are using.

Architecture overview

The 80960 can best be described as a register-rich, load/store architecture with an instruction set designed to let implementations exploit pipelining and parallel execution strategies. Direct embedded control support includes:

- an optimized instruction set,
- a flexible interrupt structure,
- a user-supervisor model,
- a powerful fault-handling structure, and
- multiprocessing hooks and debug support.

The architecture extends easily.

Figure 1 shows a logical block diagram of the architecture's programming resources. The 32-bit memory space is flat. Data moves between memory and registers via load and store instructions. Processing elements surrounding the registers manipulate parallel data; they receive their instructions from the

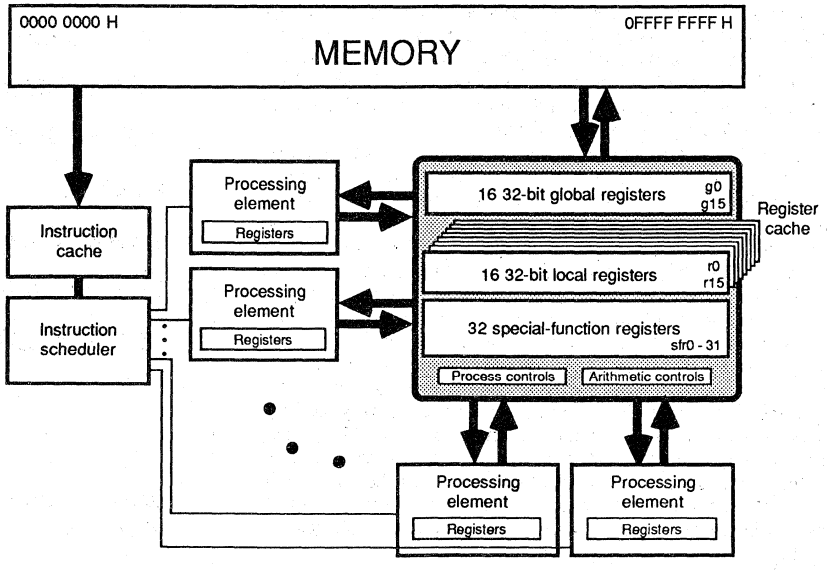

Figure 1. Block diagram of the 80960 architecture.

instruction sequencer.

The instruction sequencer reads multiple instructions simultaneously from an instruction cache and presents the instructions in parallel to the processing elements as appropriate. When the instruction stream or an asynchronous event requires a context switch, the local variables from the suspended procedure move to the register cache. Memory accesses to save previously suspended register sets occur only when the register cache is filled. The implementation determines the number of architecturally transparent register sets that can be cached.

We expect different implementations of the processing elements in an 80960-based controller—optimized for specific applications—will evolve. We defined a standard core architecture to maintain binary-compatible instruction sets across all implementations for leveraging compiler and real-time kernel development. Subsequent references to the 80960, without an alpha suffix, refer to the architecture. References to an 80960*XY* pertain to actual implementations of the core architecture, which may contain architectural extensions and/or on-chip peripherals. (See the accompanying box for a discussion of three implementations.)

Implementations of the 80960

As an example of an actual implementation of the core architecture, consider the first 80960 implementation, the 80960KB controller. The KB provides architectural extensions such as floating-point operations (Figure A). Its on-chip floating-point unit implements the IEEE floating-point standard, including transcendental support. Floating-point performance exceeds 4 million Whetstone operations per second at 20 MHz. The 80960KB integrates a 512-byte instruction cache and an interrupt controller on chip.

Another member of the family, the 80960KA controller, fits the KB socket but lacks the on-chip floating-point unit. The 80960MC controller, a military-qualified version similar to the KB, adds Ada tasking support and a memory management and protection unit.

The 80960KA, KB, and MC microarchitecture sustains execution of up to one instruction per clock cycle at 20 MHz (20 native MIPS). It performs a variety of benchmark programs seven to 10 times faster than a VAX 11/780 (7 to 10 VAX MIPS).

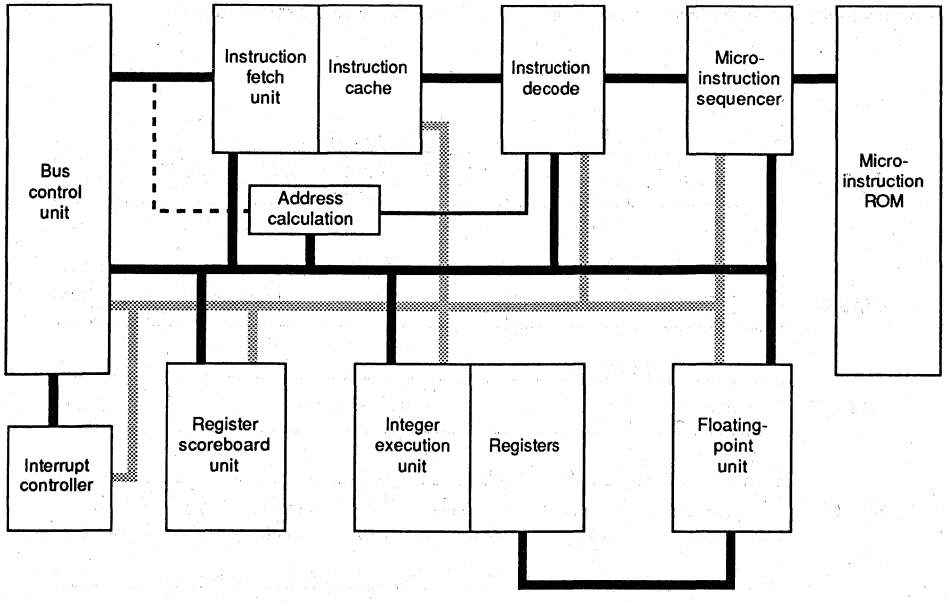

Figure A. Block diagram of the 80960KB controller.

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80960 architecture

Register model

The user directly accesses thirty-two 32-bit general-purpose registers and 32 special-function registers (SFRs). (Refer to Figure 1.) Of the 32 general registers, 16 are global registers and 16 are local registers. Data in the 16 global registers remain visible and unchanged when crossing procedure boundaries, characteristics exhibited by "normal" registers in other architectures. The CALL instruction caches the local registers and the RET instruction restores them. The SFRs provide a real-time register interface to on-chip peripherals. The SFRs, the contents of which are not defined by the architecture, control implementation-specific hardware.

When a procedure call occurs, data in the local registers automatically move to a register cache. Thus, the called procedure is not required to explicitly save the local registers. When the called procedure executes a return instruction, the data in the local registers prior to the call are restored. The call/return sequence does not affect the global registers, which can be used to pass parameters and results between procedures.

A large, general-purpose register set greatly reduces the number of memory requests required to perform a task. Various optimization techniques can use large-register sets to remove data dependencies that would otherwise prohibit parallel instruction execution. For example, a hypothetical implementation of the architecture could provide parallel execution of two ADD instructions. Having many general-purpose registers with which to work simplifies code optimization so that neither ADD instruction references a source that was the destination of the other ADD instruction. Under such circumstances, two ADD instructions per cycle could be sustained.

Note that such program optimizations are not required. Any program using the architecture's core instruction set and not referencing the SFR address space or external I/O, whether optimized or not, will function correctly on any implementation without modification. Even if the optimization rules are radically different between implementations, code that is optimized for one implementation will run correctly on another implementation without modification or recompilation.

The architecture also guarantees that data dependencies will be correctly handled without programmer intervention. For example, execution of an arithmetic instruction will be delayed if it uses a register that is waiting for data to be loaded from memory. However, other instructions that do not use the register in question could be executed immediately with all data dependencies automatically maintained. This capability is only beneficial when a large register set is present to remove avoidable data dependencies.

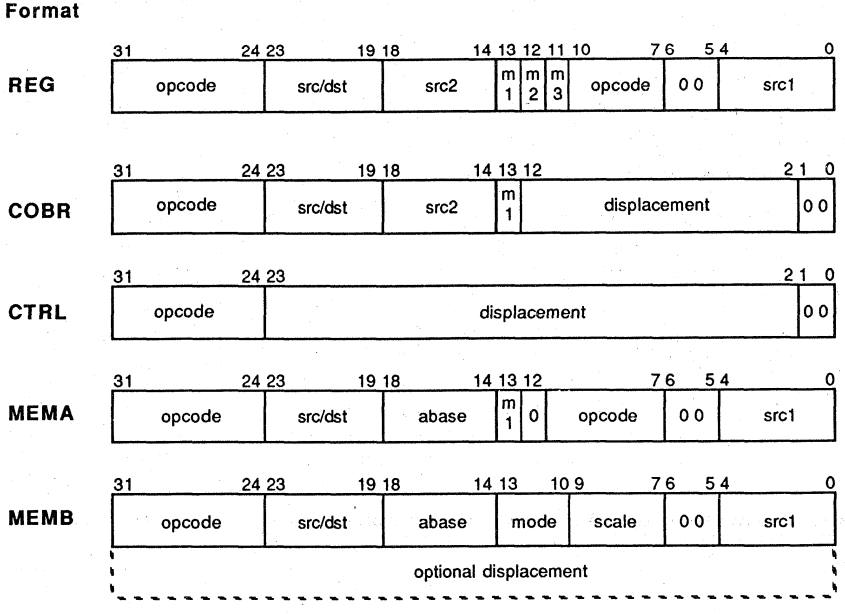

Figure 2. Opcode encodings.

Core instruction set

The 80960 instruction set is similar in design to engines in reduced instruction set computers. Because the 80960 was designed to avoid performance bottlenecks resulting from instruction decoding times, all opcodes are 32 bits (one word) in length and must be aligned on word boundaries. The only two-word (64-bit) instruction format loads 32-bit immediate constants and assists effective address calculations. Generally, load, store, and control instructions access memory. All other instructions access only registers.

Thirty-two-bit opcodes provide tremendous flexibility in instruction encoding. However, performance penalties associated with code size can occur when often-used complex instruction sequences are not available in a one-word format. Large code size not only increases system cost due to larger memory requirements but also results in penalties in cache utilization and bus-bandwidth requirements.

The 80960 includes one-word multifunction instructions to avoid such code density problems that increase memory requirements and to allow complex functions to be parallelized. For example, the CALL and RET instructions provide one-word encodings for sequences that otherwise require several instructions. Implementations of the architecture could perform the CALL/RET operations in parallel with other instruction execution. Or, the processor could execute from an on-chip ROM a similar sequence of simple 80960 instructions that the user would have to write if CALL/RET instructions were not in the architecture. Executing the code from permanent on-chip storage results in higher performance than does requiring the instructions to be fetched and cached every time they are used. In addition to ensuring higher performance, or possibly parallel performance, implementations of such functions as ROMed assembly code sequences—triggered by a one-word opcode—are more silicon efficient than are increases of on-chip cache sizes to deal with poor code density. For example, a ROM cell is typically one fourth the size of a RAM cell.

The availability of complex instructions in the architecture does not prohibit the programmer from bypassing them if simpler functions are desired. For example, a BAL (Branch_and_Link) instruction can be used to call a procedure that does not require a new set of local registers. The BAL instruction saves the next instruction pointer in a register and branches to the specified destination. When the procedure is ready to return, it executes an indirect branch to the return instruction pointer that was saved. It is likely that BAL will always be faster than CALL since no local registers are being saved. The programmer can use whichever method best suits the circumstances.

Figure 2 shows the 80960 instruction encodings. Most instructions appear in the REG format, which specifies an opcode and three registers/literals (one of 32 registers, or a constant value in the range 0 to 31). The COBR format specifies a set of compare and branch instructions. The CRTL format covers branch and call instructions. The MEM formats support load and store instructions.

Much of the instruction set is what one would expect to encounter in all processors (ADD, MUL, SHIFT, BRANCH); however, some instructions deserve special mention.

- The register-register move instructions transfer one, two, three, or four register values. The same is true for the load and store instructions (for example, LDQ loads four words into four registers).
- In addition to the normal shift instructions, the SHRDI instruction provides an adjustment to the result so the instruction can be used to divide a value by a power of two. (Normal right-shift instructions do not divide correctly when the value is negative and odd.)
- All logical operations of two operands are provided (AND, NOTAND, ANDNOT, NOR).
- An extensive set of bit instructions exists (SET BIT, CLEAR BIT, NOT BIT, SCAN a register for the first 0, or 1, BRANCH on bits set or clear), as well as instructions for accessing bit fields (MODIFY, EXTRACT).
- Single-instruction COMPARE_AND_BRANCH encodings optimize code density for these frequently executed operations.
- Conditional compare (CONCOMP) instructions speed bounds checking.

Table 1 on the next page summarizes the 80960 core architecture instruction set.

The architecture directly supports integer (signed) and ordinal (unsigned) data types. Bits, bit fields, bytes, short words, words, and double words can be manipulated in registers and transferred to and from memory. Triple words and quad words can also move between the registers and memory.

Register operations

Most 80960 instructions operate on registers. The architecture provides arithmetic, logical, bit and fit field, data movement, and comparison operations. To take full advantage of the large register set, three-operand instructions specify any register as one or both sources and/or the destination of an operation.

Arithmetic and logical. The architecture supports both standard and extended arithmetic operations. Add, subtract, multiply, and divide operations are available on 32-bit integers and ordinals. Extended multiply operates on two 32-bit ordinals and generates a 64-bit result. Extended divide divides a 64-bit ordinal by a 32-bit ordinal, producing a 32-bit quotient and 32-bit remainder. Addition and subtraction with carry allow 32-bit ordinals to provide extended precision adds and subtracts.

Table 1.
80960 instruction summary.

REGISTER OPERATIONS

ARITHMETICS

add[i | o]	Add
addc	Add with Carry
sub[i | o]	Subtract
subc	Subtract with Borrow
mul[i | o]	Multiply
emul	Extended Multiply
div[i | o]	Divide
ediv	Extended Divide
rem[i | o]	Remainder
modi	Modulo Integer
sh[lo | ro | li | ri | di]	Shift

MOVEMENT

mov[l | t | q]	Move registers to registers
lda	Load Address

COMPARISON

cmp[i | o]	Compare
cmpdec[i | o]	Compare and Decrement
cmpinc[i | o]	Compare and Increment
concmp [i | o]	Conditional Compare
test [*]	Test for condition
scanbyte	Scan for matching byte

LOGICAL

and	dst := src1 & src2
andnot	dst := src2 & (~src1)
notand	dst := (~src2) & src1
nand	dst := ~(src2 & src 1)
or	dst := src1 | src2
nor	dst := ~(src2 | src1)
ornot	dst := src2 | (~src1)
notor	dst:= (~src2) | src1
xnor	dst:= (src2 | src1) & ~(src2 & src1)
xor	dst := ~(src2 | src1) | (src2 & src1)
not	dst := ~src
rotate	Rotate Bits

BIT AND BIT FIELD

setbit	Set a Bit
clrbit	Clear a Bit
notbit	Toggle (invert) a Bit
chkbit	Check a Bit and set condition code
alterbit	Change a Bit according to an operand
scanbit	Search src for most significant set bit
spanbit	Search src for most significant cleared bit
extract	Extract specified bit pattern from a word
modify	Modify selected bits in dst with src

CONTROL OPERATIONS

BRANCH

b	Branch (± 2 MByte relative offset)
bx	Branch Extended (32-Bit Indirect Branch)
bal[x]	Branch and Link ("RISC Branch")
b[*]	Branch on Condition
cmpib[*]	Compare Integer and Branch on Condition
cmpob[*]	Compare Ordinal and Branch on Condition

FAULT

fault[*]	Fault on Condition
syncf	Synchronize Faults

PROCEDURE

call	Procedure Call (± 2 MByte relative offset)
callx	Call Extended (32-Bit Indirect Call)
calls	System Procedure Call
ret	Return

ENVIRONMENT

modpc	Modify Process Controls
modac	Modify Arithmetic Controls
modtc	Modify Trace Controls
flushregs	Flush Local Register Cache to Memory

DEBUG

mark	Conditionally generate Trace Fault
fmark	Unconditionally generate Trace Fault

MEMORY OPERATIONS

LOAD/STORE

ld[b | s | l | t | q]	Load
st[b | s | l | t | q]	Store

READ/MODIFY/WRIITE

atadd	Atomic Add (Locked RMW Cycles)
atmod	Atomic Modify (Locked RMW Cycles)

i = integer, o = ordinal, b = byte, s = short, w = word (32-bits), l = long, t = triple, q = quad,
lo = left ordinal, li = left integer, ro = right ordinal, ri = right integer, di = right dividing integer
dst = destination, src = source, x = extended,
* = Conditions: If [equal | not equal | less | less or equal | greater | greater or equal | ordered | unordered]

Arithmetic shift operations support 32-bit ordinals. Logical shift instructions operate on 32-bit integers, and a 32-bit register value can also be rotated. In addition, all possible two-operand, bitwise Boolean operations exist: AND, NOTAND, ANDNOT, XOR, OR NOR, XNOR, NOT, NOTOR, ORNOT, and NAND.

Bit and bit field. Bit operations allow bits in the registers to be set, cleared, toggled, and moved to or from the condition codes. SCAN and SPAN operations provide ways to find the most significant set or cleared bit in a register.

The 80960 contains two bit field instructions, EXTRACT and MODIFY. The EXTRACT instruction shifts a bit field in a register to the right and fills in the bits to the left of the bit field with zeros. The MODIFY instruction moves a specified bit field from one register to another when no adjustment change in bit position is required.

Data movement. A set of data movement (MOV) instructions allows register values to be copied to other registers. The MOV instructions can move from one to four registers at once. The load and store operations described later move data to and from memory.

Comparison. These instructions compare operands and set the resulting condition codes in the arithmetic controls register (Figure 3). The 80960's condition codes listed in Table 2 provide the arithmetic flag function of other architectures, in a way that allows maximum parallel execution.

In general, only compare instructions set the 80960's condition codes and conditional instructions use them. To perform an ADD followed by a conditional branch when the result is zero, a Compare_and_Branch instruction must be executed after the ADD because arithmetic instructions do not alter the condition codes.

Table 2.
Condition code encodings.

Condition code	Condition
000	Unordered *
001	Greater Than
010	Equal (True)
011	Greater Than or Equal
100	Less Than
101	Not Equal (False)
110	Less Than or Equal
111	Ordered

* Used with floating-point data types.

Although not generally noticed in a sequential execution environment, a parallel environment mandates the decoupling of the condition codes from the instruction set. The 80960 allows multiple instructions to execute simultaneously, thus giving ambiguous meaning to a set of condition codes that are altered by multiple arithmetic instructions in the same clock cycle. The 80960 approach separates condition checking and decision making from all other instructions to provide flexibility in reordering instructions for parallel execution.

The 80960 compare instructions compare both integers and ordinals. A subset of the compare instructions increments or decrements an operand after the comparison.

Memory operations

The load/store nature of the architecture decouples memory references from instruction execution. Register set and memory instructions can be executed simultaneously. Since the load data may take some time to

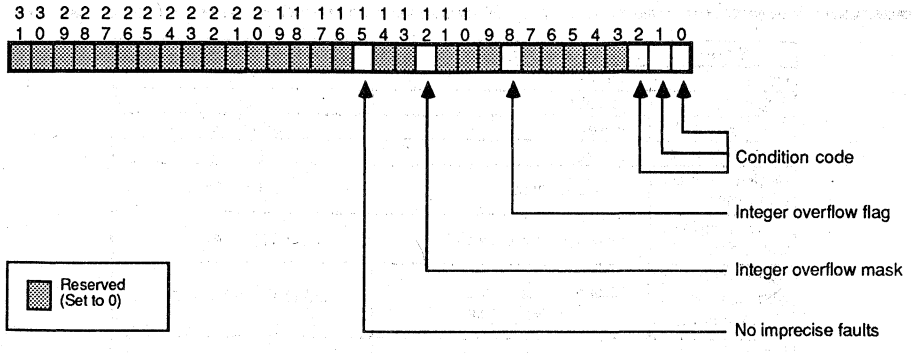

Figure 3. Arithmetic controls register.

arrive at the CPU, the load requests can be advanced in the instruction stream to overlap memory access time with other data-independent CPU operations.

Load/store. The load and store instructions copy bytes, short words, words, or multiple words to or from memory and registers. When a load integer is specified for an 8-bit or 16-bit quantity, the CPU extends the data's sign to fill 32 bits before writing the destination register. When a load ordinal is specified for an 8-bit or 16-bit quantity, the CPU attaches leading zeros to the data to fill 32 bits before writing the destination register. The store instructions allow the destination data width to be a byte, short word, word, or multiple words. When a store byte, or short word is performed, the CPU automatically formats the data being written according to the data type (integer or ordinal).

Addressing modes. The architecture supports 11 addressing modes for memory operations, as summarized in Table 3. The addressing modes selected for support provide a broad range of most-often-used simple modes. We chose a rich set of addressing modes to allow optimization for code density as well as speed.

Literals are immediate 5-bit numbers that can range from 0 to 31. Literals may be used as operands in any register operation.

The *Register* address mode is used when an operand specifies a register number (g0, r5).

The *Absolute Offset* address mode specifies the absolute address of the target as an offset from the current instruction pointer. The offset is encoded in the memory instruction opcode. If the offset is outside the range of 0 to 2048, the assembler generates a two-word instruction in which the second word is a 32-bit displacement.

Register Indirect addressing allows the address of the target to be specified by the contents of a register. An immediate offset or displacement can be added to the register to form the effective address. An index (scaled by 2, 4, 8, or 16) may also be added.

Memory operations can also specify target addresses relative to the instruction pointer, a capability useful in creating relocatable data and code.

Atomic memory operations. Two atomic memory operations support multiprocessing environments with more than one processor accessing the same memory, atomic add (ATADD) and atomic modify (ATMOD). The ATADD instruction causes an operand to be added to the value in the specified memory location. The ATMOD causes bits in the specified memory location to be modified under control of a mask. These instructions perform their memory-to-memory, read-modify-write operations with a locked bus to prevent data corruption.

Control operations

Control operations include those instructions that could result in the redirection of program flow. CALL, RET, BRANCH, and COMPARE_AND_BRANCH instructions fall into this category.

Procedure calls. The CALL instruction causes the local registers to be preserved and redirects program flow to a point indicated by an offset encoded in the instruction. The Call Extended (CALLX) instruction dif-

Table 3. Addressing modes.

Mode	Description	Assembler Example
Literal	value	0x12
Register	register	r6
Absolute offset	offset	Label + 3
Register Indirect	abase	(r6)
Register Indirect with offset	abase + offset	Label + 3 (r6)
Register Indirect with index	abase + (index • scale)	(r6) [r7 * 4]
Register Indirect with index and displacement	abase + (index • scale) + displacement	Label + 3 (r6) [r7 * 4]
Index with displacement	(index • scale) + displacement	Label [r6 * 4]
IP with displacement	IP + displacement + 8	Label (IP)

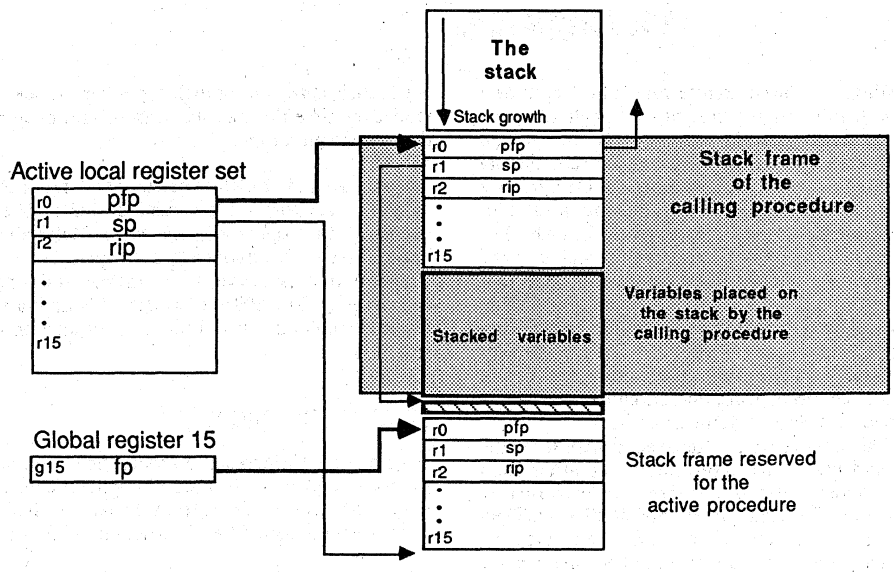

Figure 4. Procedure stack structure.

fers in that it allows a 32-bit value to provide the CALL destination. The destination can either be encoded in the instruction or specified by a register value (for example, indirect call). The Call System (CALLS) instruction gets its target address from a table of system procedure addresses explained later. The Return (RET) instruction returns control to the calling procedure and restores the local registers of the calling procedure.

The semantics of the CALL/RET allow an optimization known as register caching. A register cache keeps the context (local registers) of the most recently executing subroutines on chip so that CALL/RET instructions do not have to access memory to save or restore the local registers.

When a CALL instruction executes, the 80960 allocates a new set of 16 local registers from a pool of register sets for the called procedure. If the pool is depleted, a new register set is allocated by taking one associated with an earlier procedure and saving it in memory. A RET instruction causes the most recently cached local register set to be restored, freeing a register cache location.

The register cache contributes to performance in four ways:

- It significantly reduces the saving and restoring of registers that are usually performed when crossing subroutine boundaries.
- Since the local register sets are mapped into the stack frames, the linkage information that normally appears in stack frames (pointer to previous frame, saved instruction pointer) is contained in the local registers. Most call and return instructions execute without causing any references to off-chip memory.
- It allows compilers to map most or all of a procedure's local variables directly into registers.
- It provides a large number of registers (16 local and 16 global), which can be exploited by optimizing compilers.

The procedure stack (see Figure 4) reserves space for the cached registers of suspended procedures. When a register set must be flushed from the register cache to memory, it moves to the reserved stack frame space.

When a new procedure is entered, the 80960 allocates space for the procedure's register set as the only contents of its stack frame, although no memory accesses will occur unless the register cache is full. If the procedure desires more space on the stack for autovariables or parameter passing, it adjusts the stack pointer to reserve as much space as it needs. The procedure can then access this space using stack pointer relative addressing so long as the procedure is active. When the procedure returns, its stack is automatically reclaimed.

Branch and Link (BAL) performs a procedure call without saving the local registers. The 80960 saves the return instruction pointer in a global register and redirects program flow. To return from a routine that is invoked by a BAL, a BX (Branch Extended) is performed. BAL allows fast subroutine calls to leaf procedures without allocating (and possibly displacing) a new register set. Since a leaf procedure calls no other procedure, its registers can be allocated out of those remaining in the current set.

Branching. Advanced architectures have yet to deal cleanly with the dreaded branch, although some existing methods try and minimize the instruction pipeline breaks caused by branches and conditional branches. One method used by other architectures is a delayed branch. This method requires that a valid instruction *always* be placed after every branch. The delayed branch mechanism exposes the pipeline to the programmer and makes it easy to write code that "breaks." Compilers also have a difficult time finding useful instructions to *always* fill the blank pipeline slots following a branch and insert NOPs about 30 percent of the time. Furthermore, in architectures with a delayed branch mechanism, microarchitectures will be constrained in their enhancement choices.

The 80960 alternative to a delayed branch hides the pipeline and microarchitecture implementation from the programmer and allows transparent performance enhancements. For example, an 80960 microarchitecture that detects branches ahead of the executing code could fetch the branch destination to keep the pipeline full. In essence, "branch lookahead" allows branches to be executed in zero clock cycles.

Branches can be unconditional or conditional. The Branch and Branch Extended instructions perform unconditional redirection of program flow without linkage. Branch and Branch Extended differ in the width of the target address offset provided. The Branch instruction includes an encoded offset in the one-word instruction (MEMA format), whereas Branch Extended branches to the location pointed to by a register or an encoded 32-bit displacement (MEMB format).

The conditional branches use the condition codes in the arithmetic controls register to determine whether or not to take the branch. The 80960 provides all combinations of branch conditions.

Branch lookahead works well with unconditional branches but would be of marginal benefit on conditional branches since the branch target, or the instruction after the branch, cannot be executed until after evaluation of the branch condition. Pipeline breaks would, therefore, be inevitable even if the microarchitecture implemented some sort of hardware prediction mechanism. To reduce the effect of the conditional branch on performance, the 80960 defines two types of conditional branches, those that are usually taken and those that aren't usually taken. The implementation can then guess which way the branch is going to go, based upon an excellent resource capable of prediction—the programmer. Only in the case of a programmer's wrong prediction would a pipeline stall occur. Furthermore, compilers will take advantage of branch prediction when they detect loops.

It is either obvious, or uncertain, at the time the program is written which way the branches will branch most often during execution. If the likely branch outcome is obvious, the type of branch to use will be obvious. In the cases where runtime factors determine the branch path, the branch types can be selected to reduce the time through the longest path or to reduce the average path time.

Compare and branch. The compare and branch instructions support integers and ordinals. The CPU compares two operands; the result determines the branch taken. This frequently used operation is one instruction that increases performance and improves code density. The 80960 provides all combinations of branch conditions, in addition to branch-on-bit instructions.

Instruction cache

As processors increase in speed, the traffic between processor and memory becomes a significant performance bottleneck. To effectively reduce this bottleneck, we incorporated an instruction cache within the processor.

An on-chip instruction cache is highly desirable for two reasons. Caching instructions on chip greatly reduces system bus loading and the criticality of the system's memory access speed in a parallel execution environment. However, an instruction cache plays an additional role. The only way to cause multiple instructions to execute simultaneously is to decode multiple instructions simultaneously. An on-chip instruction cache gives instruction decode the capability of looking downstream and decoding and dispatching multiple instructions simultaneously for parallel execution.

The advantage of an instruction cache over a prefetch queue, a technique used in most high-performance microprocessors to date, is that a queue does not reduce the memory traffic for instructions. It only attempts to distribute the traffic more efficiently. A cache's most obvious effect occurs with execution loops, common in embedded control applications. After a loop is first executed, successive iterations of the loop generate no memory references for instruction fetches. Likewise, when a small, low-level procedure concludes and executes a RET instruction, the code for the high-level routine to which it is returning likely still resides in the cache. Thus, we reduce the sensitivity of instruction execution speed to slow memory and free valuable bus bandwidth for other operations.

Having an instruction cache requires special considerations in applications that employ self-modifying code or uploadable programs. In general, embedded applications are unaffected. However, for 80960 chips targeted at embedded applications in which volatile code exists, we will provide implementation-specific cache features. For example, implementations could provide a bus input pin that prohibits the data being read from being cached, a method for flushing the cache, a transparent instruction cache, a cache disable bit, or some other feature tuned to the application.

To allow implementations of the 80960 latitude in the amount and type of cache provided, the architecture does not specify the instruction cache parameterization.

User-supervisor protection

The architecture provides a mode and stack switching mechanism called the user-supervisor protection model. This protection model allows a system design in which the kernel code and data reside in the same address space as the user code and data. However, the access to the kernel procedures (called supervisor procedures) occurs through a specified interface. A data structure called the System Procedure Table provides this interface (Figure 5).

The 80960 references the System Procedure Table when a System Call (CALLS) instruction executes. This call is similar to a local call, except that the processor gets the location of the called procedure from the System Procedure Table. Figure 6 illustrates the use of the CALLS instruction. CALLS requires a procedure-number operand that is used as an index into the table.

The System Procedure Table entry referenced by CALLS specifies an entry pointer and an entry type for the called procedure. The 80960 invokes two types of system procedures, *local* and *supervisor*. A procedure that is specified as a local procedure is invoked as if it were called by the CALL or CALLX instructions, except that the processor gets the entry point of the called procedure from the System Procedure Table. Referencing a supervisor procedure, on the other hand, switches the processor to the supervisor execution mode and to the supervisor stack.

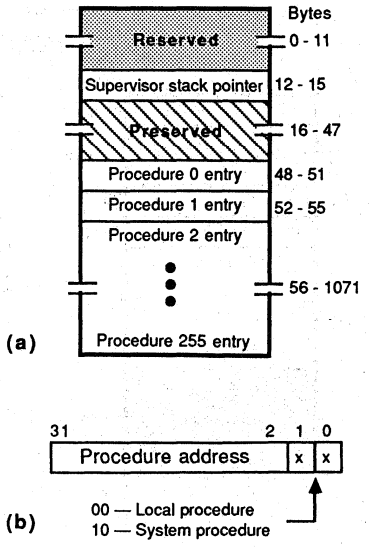

Figure 5. Structure of the System Procedure Table (a) and a procedure entry (b).

Real-time kernel procedures in the supervisor mode execute using a different stack than the one used to execute application programs procedures. Special, supervisor-only instructions also execute in supervisor mode. The MODPC instruction (used to change the processor priority) is always a supervisor instruction. Instruction set extensions that control on-chip hardware are also likely to be restricted to the supervisor mode.

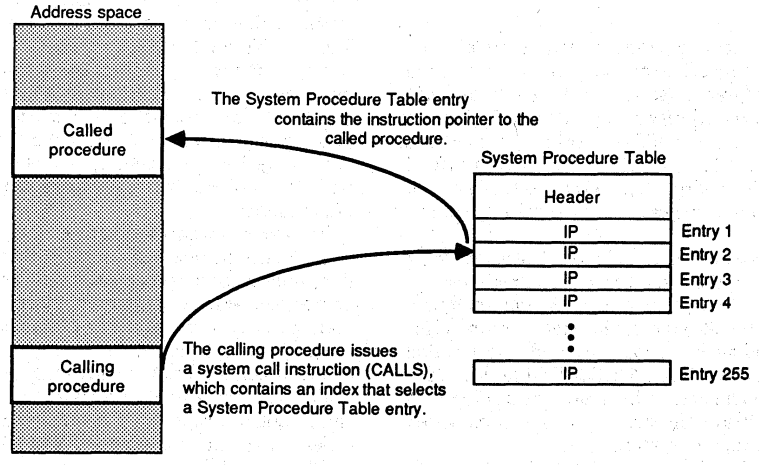

Figure 6. Example of a system procedure call.

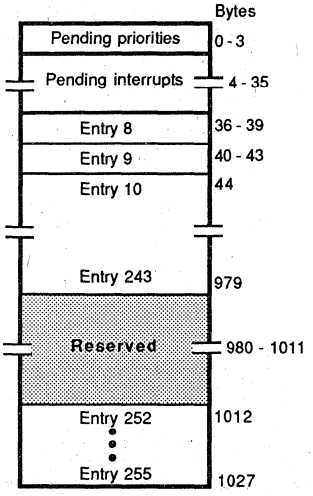

Figure 7. Structure of the interrupt table.

The processor remains in the supervisor mode until the procedure that caused the original mode switch performs a return. Switching stacks and protecting against stack corruption help maintain the integrity of the kernel. For example, the mechanism allows access to system debugging software or a system monitor even if the application crashes.

Interrupts

The 80960 contains a priority interrupt model and a mechanism for queueing pending interrupt requests without user program intervention. When an interrupt is signaled and its priority is higher than the current processor priority, the CPU invokes an interrupt handler and the processor priority changes to that of the interrupt. Otherwise, the 80960 saves the interrupt for service until it becomes the highest priority request pending.

The interrupt table seen in Figure 7 holds the 32-bit pending priorities field, the 256-bit pending interrupt field, and the 248 interrupt vectors. Within each processor priority the 80960 contains eight vectors, eight associated pending interrupt bits, and one pending priority bit. The pending priorities field indicates the priorities at which pending interrupts await. The pending interrupt field indicates exactly which requested interrupts have not yet been serviced.

A pending priority bit is simply the OR of all eight pending interrupt bits at a particular priority. This field optimizes checking for pending interrupts by the processor. When an interrupt request will not be serviced immediately, the 80960 sets the bit in the pending interrupt field associated with the request. It also sets the pending priorities bit associated with the priority of the request. When the running priority of the processor drops below that of the pending interrupt, the 80960 services the interrupt and clears the associated pending bit. The CPU also clears the associated pending priority bit if appropriate.

Faults

Processors use fault mechanisms to handle exceptions or errant conditions that a program may or may not be capable of correcting. We defined the 80960's fault mechanism for an environment in which parallel or out-of-order execution occurs. When a fault is generated, the processor calls the appropriate fault handler. The 80960 automatically provides the handler with an extensive set of information about the faulting condition for correction or analysis.

It is possible that when a fault is detected not enough information would exist to determine the exact instruction that faulted. For example, when multiple instructions execute in one clock cycle, multiple faults could occur in a single clock cycle. This "imprecise" condition could generate a fault that we call imprecise. A tightly coupled fault handler may be able to recover proper program execution when an imprecise fault occurs. Precise faults are those from which recovery is easy.

The 80960 provides two controls over the generation of imprecise conditions and faults. The first fault control method, a global control bit, puts the processor in a mode where no imprecise conditions are created (No Imprecise Faults, or NIF mode). In this mode, the 80960 restricts parallel execution. All faults are precise. The NIF bit can be used to create a critical region in which all faults are precise. The second fault control mechanism is the Synchronize_Faults (SYNCF) instruction. This instruction halts execution until all pending operations complete, and all faults up to that point have been signaled. It is useful on Ada block boundaries where different blocks can have different fault handlers.

An 80960 implementation detects various conditions in code or in its internal state (called fault conditions) that could cause the processor to deliver incorrect or inappropriate results, or that could cause it to take an undesirable control path. For example, the 80960 can recognize (if enabled by the user) divide-by-zero and overflow conditions on integer calculations as a fault. The architecture also recognizes inappropriate operand values and attempts to execute unimplemented opcodes, among other conditions, as faults.

When a fault is detected, the system processes it immediately and independently of the program or handler that is executing at the time. The fault mechanism is similar to that used by the interrupts. Several fault

types exist, in which the fault type determines which entry in the Fault Table (Figure 8) is invoked for a particular fault. The Fault Table contains one entry for each fault type. The entry defines a particular fault handler routine as a local procedure or a system procedure. When the fault handler is a local procedure, the Fault Table entry contains the address of the procedure entry point. When the fault handler is a system procedure, the Fault Table entry contains the system procedure number, which selects the correct entry point from the System Procedure Table described earlier.

Figure 9 describes the fault record, which is the information provided to a fault handler when a fault occurs. Table 4 on page 76 summarizes the fault types and subtypes that are currently defined in the 80960 architecture. As extensions to the architecture that consume additional fault types become available, the encoding of fault types and subtypes will occur in such a way that every implementation capable of recognizing similar faulting conditions encodes them identically. For example, the 80960KB adds the floating-point faults (fault type 4). Any other 80960 implementations that also recognize floating-point faults also encode them as fault type 4.

Debug support

Another objective of the architecture is to support software debugging and tracing. A trace-controls register enables most of this support. The trace controls detect any combination of the following events:

- Instruction execution (single step),
- Execution of a Taken Branch instruction,
- Execution of a Call instruction,
- Execution of a Return instruction,

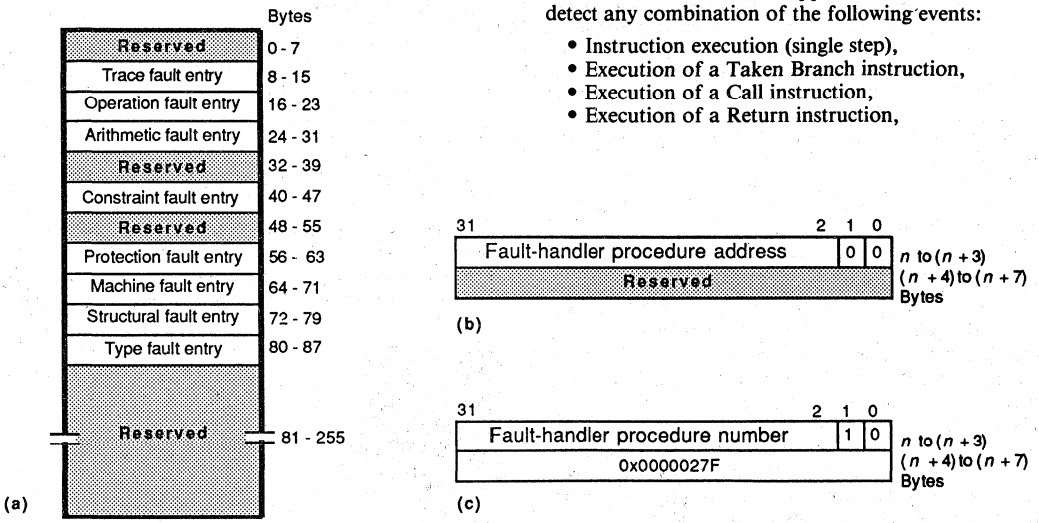

Figure 8. Structure of the fault table (a); an entry to reference a local procedure (b); and an entry to reference a system procedure (c).

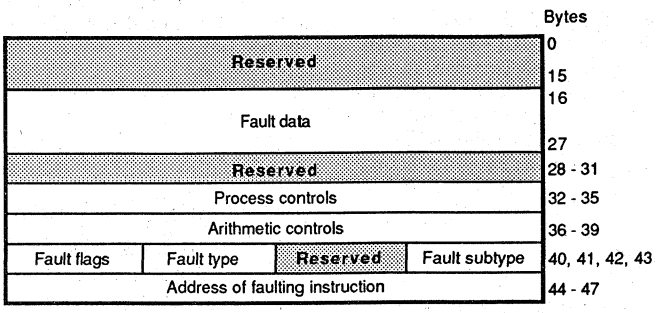

Figure 9. Fault record information. The return pointer r2 is also provided.

Table 4. Fault types and subtypes.

Fault type	Fault Subtypes	Comments
Arithmetic	Overflow, underflow	Integer overflows/ divide by zero
Constraint	Range	If FAULT_IF taken
Protection	Length	Procedure # in CALLS out of range
Machine	Bad access	Memory access failed to complete
Type	Mismatch	Tried to execute supervisor instruction in nonsupervisor mode
Operation	Invalid opcode, Invalid operand	Tried to execute invalid opcode, or an operand in a valid opcode was invalid
Trace	Instruction, branch, call, return, prereturn, supervisor, breakpoint	Trace event occurred

- Detection that the next instruction is a Return instruction,
- Execution of a supervisor or system call, and
- Breakpoint (hardware breakpoint or execution of a breakpoint instruction).

When a trace event is detected, the processor generates a trace fault to give control to a software debugger or monitor. Since all 80960 implementations are likely to have an on-chip cache, external hardware cannot trace the flow of instruction execution by monitoring the external bus. Therefore, to trace instruction execution, a debugger could enable the BRANCH, CALL, and RET trace faults and reconstruct the instruction-by-instruction flow of a program. This method, however, will not provide transparent, or real-time tracing. When noninvasive emulation is desirable, the user should employ an in-circuit emulator.

The 80960, an extensible embedded control architecture, maximizes computational and data processing speed through parallel execution. The first implementation of the architecture (80960KB) achieves single-clock execution of instructions, while fractional clock instruction rates are architecturally unhindered and will be available in future implementations.

Acknowledgments

Too many people contributed to the 80960 effort to list them here. However, I relied upon the following, either in person or through their writings, in developing this article: Dave Budde, Glen Hinton, Mike Imel, Konrad Lai, Glenford J. Myers, Lew Pacely, Fred Pollack, Rob Riches, Frank Smith, and Randy Steck.

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General Microcontroller Application Notes

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intel®

APPLICATION NOTE

AP-125

February 1982

Designing Microcontroller Systems for Electrically Noisy Environments

TOM WILLIAMSON
MCO APPLICATIONS ENGINEER

9

Order Number: 210313-002

DESIGNING MICROCONTROLLER SYSTEMS FOR ELECTRICALLY NOISY ENVIRONMENTS

CONTENTS

Digital circuits are often thought of as being immune to noise problems, but really they're not. Noises in digital systems produce software upsets: program jumps to apparently random locations in memory. Noise-induced glitches in the signal lines can cause such problems, but the supply voltage is more sensitive to glitches than the signal lines.

Severe noise conditions, those involving electrostatic discharges, or as found in automotive environments, can do permanent damage to the hardware. Electrostatic discharges can blow a crater in the silicon. In the automotive environment, in ordinary operation, the "12V" power line can shown + and −400V transients.

This Application Note describes some electrical noises and noise environments. Design considerations, along the lines of PCB layout, power supply distribution and decoupling, and shielding and grounding techniques, that may help minimize noise susceptibility are reviewed. Special attention is given to the automotive and ESD environments.

Symptoms of Noise Problems

Noise problems are not usually encountered during the development phase of a microcontroller system. This is because benches rarely simulate the system's intended environment. Noise problems tend not to show up until the system is installed and operating in its intended environment. Then, after a few minutes or hours of normal operation the system finds itself someplace out in left field. Inputs are ignored and outputs are gibberish. The system may respond to a reset, or it may have to be turned off physically and then back on again, at which point it commences operating as though nothing had happened. There may be an obvious cause, such as an electrostatic discharge from somebody's finger to a keyboard or the upset occurs every time a copier machine is turned on or off. Or there may be no obvious cause, and nothing the operator can do will make the upset repeat itself. But a few minutes, or a few hours, or a few days later it happens again.

One symptom of electrical noise problems is randomness, both in the occurrence of the problem and in what the system does in its failure. All operational upsets that occur at seemingly random intervals are not necessarily caused by noise in the system. Marginal VCC, inadequate decoupling, rarely encountered software conditions, or timing coincidences can produce upsets that seem to occur randomly. On the other hand, some noise sources can produce upsets downright periodically. Nevertheless, the more difficult it is to characterize an upset as to cause and effect, the more likely it is to be a noise problem.

Types and Sources of Electrical Noise

The name given to electrical noises other than those that are inherent in the circuit components (such as thermal noise) is EMI: electromagnetic interference. Motors, power switches, fluorescent lights, electrostatic discharges, etc., are sources of EMI. There is a veritable alphabet soup of EMI types, and these are briefly described below.

SUPPLY LINE TRANSIENTS

Anything that switches heavy current loads onto or off of AC or DC power lines will cause large transients in these power lines. Switching an electric typewriter on or off, for example, can put a 1000V spike onto the AC power lines.

The basic mechanism behind supply line transients is shown in Figure 1. The battery represents any power source, AC or DC. The coils represent the line inductance between the power source and the switchable loads R1 and R2. If both loads are drawing current, the line current flowing through the line inductance establishes a magnetic field of some value. Then, when one of the loads is switched off, the field due to that component of the line current collapses, generating transient voltages, $v = L(di/dt)$, which try to maintain the current at its original level. That's called an "inductive kick." Because of contact bounce, transients are generated whether the switch is being opened or closed, but they're worse when the switch is being opened.

An inductive kick of one type or another is involved in most line transients, including those found in the automotive environment. Other mechanisms for line transients exist, involving noise pickup on the lines. The noise voltages are then conducted to a susceptible circuit right along with the power.

EMP AND RFI

Anything that produces arcs or sparks will radiate electromagnetic pulses (EMP) or radio-frequency interference (RFI).

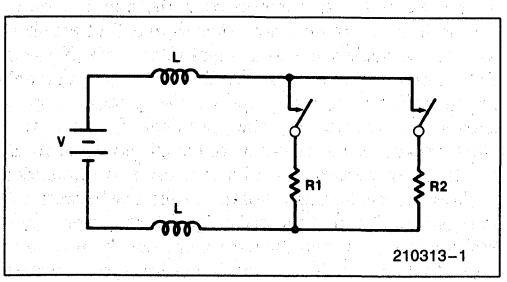

Figure 1. Supply Line Transients

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Spark discharges have probably caused more software upsets in digital equipment than any other single noise source. The upsetting mechanism is the EMP produced by the spark. The EMP induces transients in the circuit, which are what actually cause the upset.

Arcs and sparks occur in automotive ignition systems, electric motors, switches, static discharges, etc. Electric motors that have commutator bars produce an arc as the brushes pass from one bar to the next. DC motors and the "universal" (AC/DC) motors that are used to power hand tools are the kinds that have commutator bars. In switches, the same inductive kick that puts transients on the supply lines will cause an opening or closing switch to throw a spark.

ESD

Electrostatic discharge (ESD) is the spark that occurs when a person picks up a static charge from walking across a carpet, and then discharges it into a keyboard, or whatever else can be touched. Walking across a carpet in a dry climate, a person can accumulate a static voltage of 35kV. The current pulse from an electrostatic discharge has an extremely fast risetime — typically, 4A/ns. Figure 2 shows ESD waveforms that have been observed by some investigators of ESD phenomena.

It is enlightening to calculate the L(di/dt) voltage required to drive an ESD current pulse through a couple of inches of straight wire. Two inches of straight wire has about 50 nH of inductance. That's not very much, but using 50 nH for L and 4A/ns for di/dt gives an L(di/dt) drop of about 200V. Recent observations by W.M. King suggest even faster risetimes (Figure 2b) and the occurrence of multiple discharges during a single discharge event.

Obviously, ESD-sensitivity needs to be considered in the design of equipment that is going to be subjected to it, such as office equipment.

GROUND NOISE

Currents in ground lines are another source of noise. These can be 60 Hz currents from the power lines, or RF hash, or crosstalk from other signals that are sharing this particular wire as a signal return line. Noise in the ground lines is often referred to as a "ground loop" problem. The basic concept of the ground loop is shown in Figure 3. The problem is that true earth-ground is not really at the same potential in all locations. If the two ends of a wire are earth-grounded at different locations, the voltage difference between the two "ground" points can drive significant currents (several amperes) through the wire. Consider the wire to be part of a loop which contains, in addition to the wire, a voltage source that represents the difference in potential between the two ground points, and you have the classical "ground loop." By extension, the term is used to refer to any unwanted (and often unexpected) currents in a ground line.

"Radiated" and "Conducted" Noise

Radiated noise is noise that arrives at the victim circuit in the form of electromagnetic radiation, such as EMP and RFI. It causes trouble by inducing extraneous voltages in the circuit. Conducted noise is noise that arrives at the victim circuit already in the form of an extraneous voltage, typically via the AC or DC power lines.

One defends against radiated noise by care in designing layouts and the use of effective shielding techniques. One defends against conducted noise with filters and

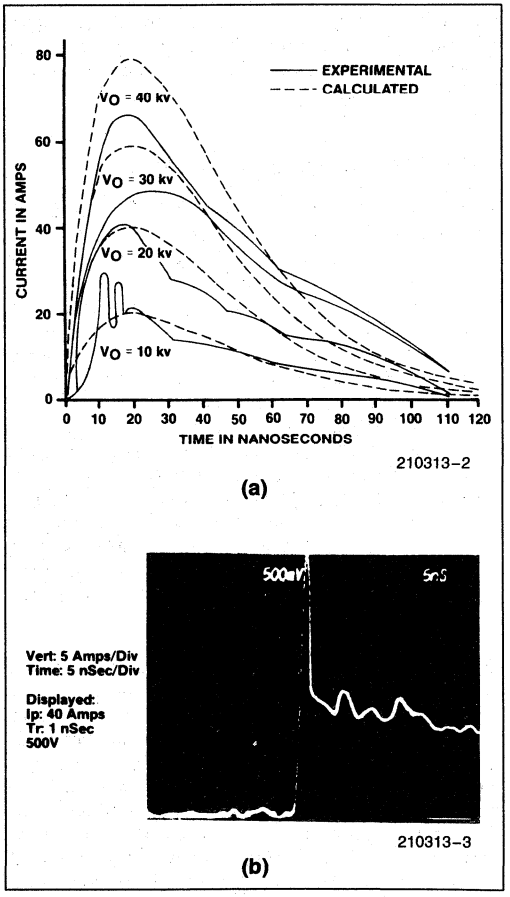


Figure 2. Waveforms of Electrostatic Discharge Currents From a Hand-Held Metallic Object

suppressors, although layouts and grounding techniques are important here, too.

Simulating the Environment

Addressing noise problems after the design of a system has been completed is an expensive proposition. The ill will generated by failures in the field is not cheap either. It's cheaper in the long run to invest a little time and money in learning about noise and noise simulation equipment, so that controlled tests can be made on the bench as the design is developing.

Simulating the intended noise environment is a two-step process: First you have to recognize what the noise environment is, that is, you have to know what kinds of electrical noises are present, and which of them are going to cause trouble. Don't ignore this first step, because it's important. If you invest in an induction coil spark generator just because your application is automotive, you'll be straining at the gnat and swallowing the camel. Spark plug noise is the least of your worries in that environment.

The second step is to generate the electrical noise in a controlled manner. This is usually more difficult than first imagined; one first imagines the simulation in terms of a waveform generator and a few spare parts, and then finds that a wideband power amplifier with a 200V dynamic range is also required. A good source of information on who supplies what noise-simulating equipment is the 1981 "ITEM" Directory and Design Guide (Reference 6).

Types of Failures and Failure Mechanisms

A major problem that EMI can cause in digital systems is intermittent operational malfunction. These software upsets occur when the system is in operation at the time an EMI source is activated, and are usually characterized by a loss of information or a jump in the execution of the program to some random location in memory. The person who has to iron out such problems is tempted to say the program counter went crazy. There is usually no damage to the hardware, and normal operation can resume as soon as the EMI has passed or the source is de-activated. Resuming normal operation usually requires manual or automatic reset, and possibly re-entering of lost information.

Electrostatic discharges from operating personnel can cause not only software upsets, but also permanent ("hard") damage to the system. For this to happen the system doesn't even have to be in operation. Sometimes the permanent damage is latent, meaning the initial damage may be marginal and require further aggravation through operating stress and time before permanent failure takes place. Sometimes too the damage is hidden.

One ESD-related failure mechanism that has been identified has to do with the bias voltage on the substrate of the chip. On some CPU chips the substrate is held at −2.5V by a phase-shift oscillator working into a capacitor/diode clamping circuit. This is called a "charge pump" in chip-design circles. If the substrate wanders too far in either direction, program read errors are noted. Some designs have been known to allow electrostatic discharge currents to flow directly into port pins of an 8048. The resulting damage to the oxide causes an increase in leakage current, which loads down the charge pump, reducing the substrate voltage to a marginal or unacceptable level. The system is then unreliable or completely inoperative until the CPU chip is replaced. But if the CPU chip was subjected to a discharge spark once, it will eventually happen again.

Chips that have a grounded substrate, such as the 8748, can sometimes sustain some oxide damage without actually becoming inoperative. In this case the damage is present, and the increased leakage current is noted; however, since the substrate voltage retains its design value, the damage is largely hidden.

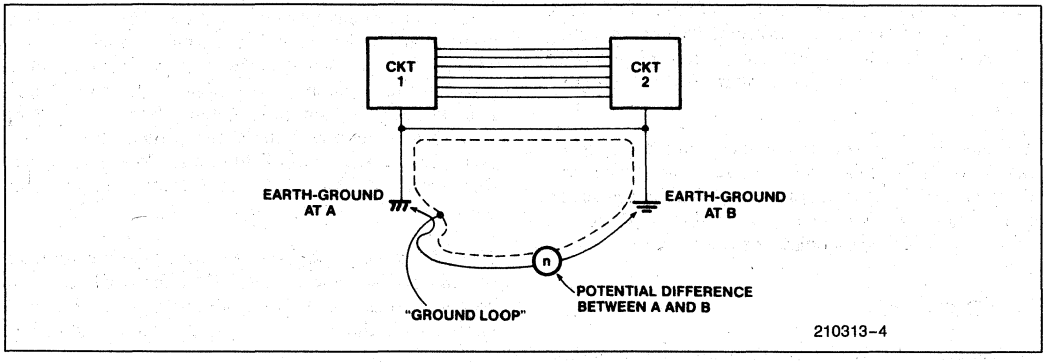


Figure 3. What a Ground Loop Is

It must therefore be recognized that connecting port pins unprotected to a keyboard or to anything else that is subject to electrostatic discharges, makes an extremely dangerous configuration. It doesn't make any difference what CPU chip is being used, or who makes it. If it connects unprotected to a keyboard, it will eventually be destroyed. Designing for an ESD-environment will be discussed further on.

We might note here that MOS chips are not the only components that are susceptible to permanent ESD damage. Bipolar and linear chips can also be damaged in this way. PN junctions are subject to a hard failure mechanism called thermal secondary breakdown, in which a current spike, such as from an electrostatic discharge, causes microscopically localized spots in the junction to approach melt temperatures. Low power TTL chips are subject to this type of damage, as are op-amps. Op-amps, in addition, often carry on-chip MOS capacitors which are directly across an external pin combination, and these are susceptible to dielectric breakdown.

We return now to the subject of software upsets. Noise transients can upset the chip through any pin, even an output pin, because every pin on the chip connects to the substrate through a pn junction. However, the most vulnerable pin is probably the VCC line, since it has direct access to all parts of the chip: every register, gate, flip-flop and buffer.

The menu of possible upset mechanisms is quite lengthy. A transient on the substrate at the wrong time will generally cause a program read error. A false level at a control input can cause an extraneous or misdirected opcode fetch. A disturbance on the supply line can flip a bit in the program counter or instruction register. A short interruption or reversal of polarity on the supply line can actually turn the processor off, but not long enough for the power-up reset capacitor to discharge. Thus when the transient ends, the chip starts up again without a reset.

A common failure mode is for the processor to lock itself into a tight loop. Here it may be executing the data in a table, or the program counter may have jumped a notch, so that the processor is now executing operands instead of opcodes, or it may be trying to fetch opcodes from a nonexistent external program memory.

It should be emphasized that mechanisms for upsets have to do with the arrival of noise-induced transients at the pins of the chips, rather than with the generation of noise pulses within the chip itself, that is, it's not the chip that is picking up noise, it's the circuit.

The Game Plan

Prevention is usually cheaper than suppression, so first we'll consider some preventive methods that might help to minimize the generation of noise voltages in the circuit. These methods involve grounding, shielding, and wiring techniques that are directed toward the mechanisms by which noise voltages are generated in the circuit. We'll also discuss methods of decoupling. Then we'll look at some schemes for making a graceful recovery from upsets that occur in spite of preventive measures. Lastly, we'll take another look at two special problem areas: electrostatic discharges and the automotive environment.

Current Loops

The first thing most people learn about electricity is that current won't flow unless it can flow in a closed loop. This simple fact is sometimes temporarily forgotten by the overworked engineer who has spent the past several years mastering the intricacies of the DO loop, the timing loop, the feedback loop, and maybe even the ground loop. The simple current loop probably owes its apparent demise to the invention of the ground symbol. By a stroke of the pen one avoids having to draw the return paths of most of the current loops in the circuit. Then "ground" turns into an infinite current sink, so that any current that flows into it is gone and forgotten. Forgotten it may be, but it's not gone. It must return to its source, so that its path will by all the laws of nature form a closed loop.

The physical geometry of a given current loop is the key to why it generates EMI, why it's susceptible to EMI, and how to shield it. Specifically, it's the area of the loop that matters.

Any flow of current generates a magnetic field whose intensity varies inversely to the distance from the wire that carries the current. Two parallel wires conducting currents $+I$ and $-I$ (as in signal feed and return lines) would generate a nonzero magnetic field near the wires, where the distance from a given point to one wire is noticeably different from the distance to the other wire, but farther away (relative to the wire spacing), where the distances from a given point to either wire are about the same, the fields from both wires tend to cancel out. Thus, maintaining proximity between feed and return paths is an important way to minimize their interference with other signals. The way to maintain their proximity is essentially to minimize their loop area. And, because the mutual inductance from current loop A to current loop B is the same as the mutual inductance from current loop B to current loop A, a circuit that doesn't radiate interference doesn't receive it either.

Thus, from the standpoint of reducing both generation of EMI and susceptibility to EMI, the hard rule is to keep loop areas small. To say that loop areas should be minimized is the same as saying the circuit inductance

should be minimized. Inductance is by definition the constant of proportionality between current and the magnetic field it produces: $\phi = LI$. Holding the feed and return wires close together so as to promote field cancellation can be described either as minimizing the loop area or as minimizing L. It's the same thing.

Shielding

There are three basic kinds of shields: shielding against capacitive coupling, shielding against inductive coupling, and RF shielding. Capacitive coupling is electric field coupling, so shielding against it amounts to shielding against electric fields. As will be seen, this is relatively easy. Inductive coupling is magnetic field coupling, so shielding against it is shielding against magnetic fields. This is a little more difficult. Strangely enough, this type of shielding does not in general involve the use of magnetic materials. RF shielding, the classical "metallic barrier" against all sorts of electromagnetic fields, is what most people picture when they think about shielding. Its effectiveness depends partly on the selection of the shielding material, but mostly, as it turns out, on the treatment of its seams and the geometry of its openings.

SHIELDING AGAINST CAPACITIVE COUPLING

Capacitive coupling involves the passage of interfering signals through mutual or stray capacitances that aren't shown on the circuit diagram, but which the experienced engineer knows are there. Capacitive coupling to one's body is what would cause an unstable oscillator to change its frequency when the person reaches his hand over the circuit, for example. More importantly, in a digital system it causes crosstalk in multi-wire cables.

The way to block capacitive coupling is to enclose the circuit or conductor you want to protect in a metal shield. That's called an electrostatic or Faraday shield. If coverage is 100%, the shield does not have to be grounded, but it usually is, to ensure that circuit-to-shield capacitances go to signal reference ground rather than act as feedback and crosstalk elements. Besides, from a mechanical point of view, grounding it is almost inevitable.

A grounded Faraday shield can be used to break capacitive coupling between a noisy circuit and a victim circuit, as shown in Figure 4. Figure 4a shows two circuits capacitively coupled through the stray capacitance between them. In Figure 4b the stray capacitance is intercepted by a grounded Faraday shield, so that interference currents are shunted to ground. For example, a grounded plane can be inserted between PCBs (printed circuit boards) to eliminate most of the capacitive coupling between them.

Another application of the Faraday shield is in the electrostatically shielded transformer. Here, a conducting foil is laid between the primary and secondary coils so as to intercept the capacitive coupling between them. If a system is being upset by AC line transients, this type of transformer may provide the fix. To be effective in this application, the shield must be connected to the greenwire ground.

SHIELDING AGAINST INDUCTIVE COUPLING

With inductive coupling, the physical mechanism involved is a magnetic flux density B from some external interference source that links with a current loop in the victim circuit, and generates a voltage in the loop in accordance with Lenz's law: $v = -NA(dB/dt)$, where in this case $N = 1$ and A is the area of the current loop in the victim circuit.

There are two aspects to defending a circuit against inductive pickup. One aspect is to try to minimize the offensive fields at their source. This is done by minimizing the area of the current loop at the source so as to promote field cancellation, as described in the section on current loops. The other aspect is to minimize the inductive pickup in the victim circuit by minimizing the area of that current loop, since, from Lenz's law, the induced voltage is proportional to this area. So the two aspects really involve the same corrective action: minimize the areas of the current loops. In other words, minimizing the offensiveness of a circuit inherently minimizes its susceptibility.

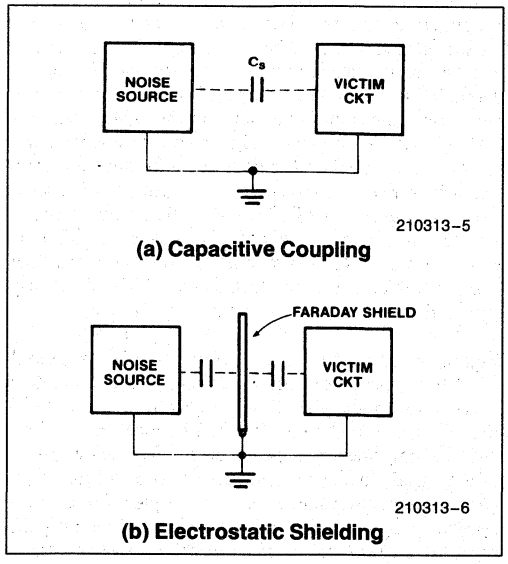


Figure 4. Use of Faraday Shield

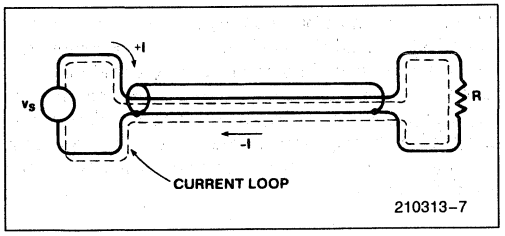


Figure 5. External to the Shield, $\phi = 0$

Shielding against inductive coupling means nothing more nor less than controlling the dimensions of the current loops in the circuit. We must look at four examples of this type of "shielding": the coaxial cable, the twisted pair, the ground plane, and the gridded-ground PCB layout.

The Coaxial Cable—Figure 5 shows a coaxial cable carrying a current I from a signal source to a receiving load. The shield carries the same current as the center conductor. Outside the shield, the magnetic field produced by +I flowing in the center conductor is cancelled by the field produced by −I flowing in the shield. To the extent that the cable is ideal in producing zero external magnetic field, it is immune to inductive pickup from external sources. The cable adds effectively zero area to the loop. This is true only if the shield carries the same current as the center conductor.

In the real world, both the signal source and the receiving load are likely to have one end connected to a common signal ground. In that case, should the cable be grounded at one end, both ends, or neither end? The answer is that it should be grounded at both ends. Figure 6a shows the situation when the cable shield is grounded at only one end. In that case the current loop runs down the center conductor of the cable, then back through the common ground connection. The loop area is not well defined. The shield not only does not carry the same current as the center conductor, but it doesn't carry any current at all. There is no field cancellation at all. The shield has no effect whatsoever on either the generation of EMI or susceptibility to EMI. (It is, however, still effective as an electrostatic shield, or at least it would be if the shield coverage were 100%.)

Figure 6b shows the situation when the cable is grounded at both ends. Does the shield carry all of the return current, or only a portion of it on account of the shunting effect of the common ground connection? The answer to that question depends on the frequency content of the signal. In general, the current loop will follow the path of least impedance. At low frequencies, 0 Hz to several kHz, where the inductive reactance is insignificant, the current will follow the path of least resistance. Above a few kHz, where inductive reactance predominates, the current will follow the path of least inductance. The path of least inductance is the path of

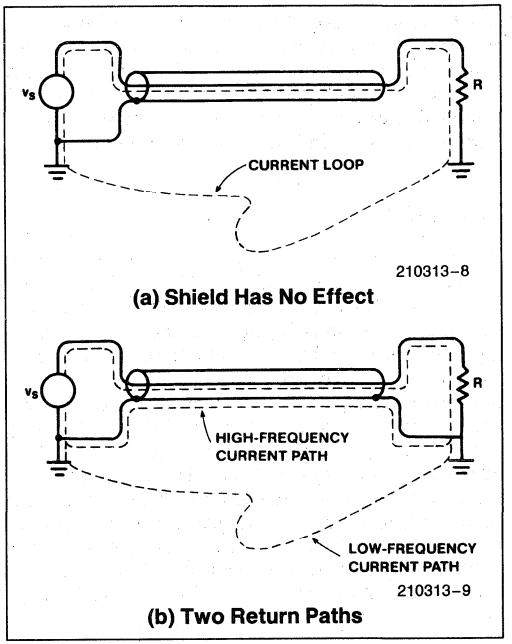


Figure 6. Use of Coaxial Cable

minimum loop area. Hence, for higher frequencies the shield carries virtually the same current as the center conductor, and is therefore effective against both generation and reception of EMI.

Note that we have now introduced the famous "ground loop" problem, as shown in Figure 7a. Fortunately, a digital system has some built-in immunity to moderate ground loop noise. In a noisy environment, however, one can break the ground loop, and still maintain the shielding effectiveness of the coaxial cable, by inserting an optical coupler, as shown in Figure 7b. What the optical coupler does, basically, is allow us to re-define the signal source as being ungrounded, so that that end of the cable need not be grounded, and still lets the shield carry the same current as the center conductor. Obviously, if the signal source weren't grounded in the first place, the optical coupler wouldn't be needed.

The Twisted Pair—A cheaper way to minimize loop area is to run the feed and return wires right next to each other. This isn't as effective as a coaxial cable in minimizing loop area. An ideal coaxial cable adds zero area to the loop, whereas merely keeping the feed and return wires next to each other is bound to add a finite area.

However, two things work to make this cheaper method almost as good as a coaxial cable. First, real coaxial cables are not ideal. If the shield current isn't evenly distributed around the center conductor at every cross-

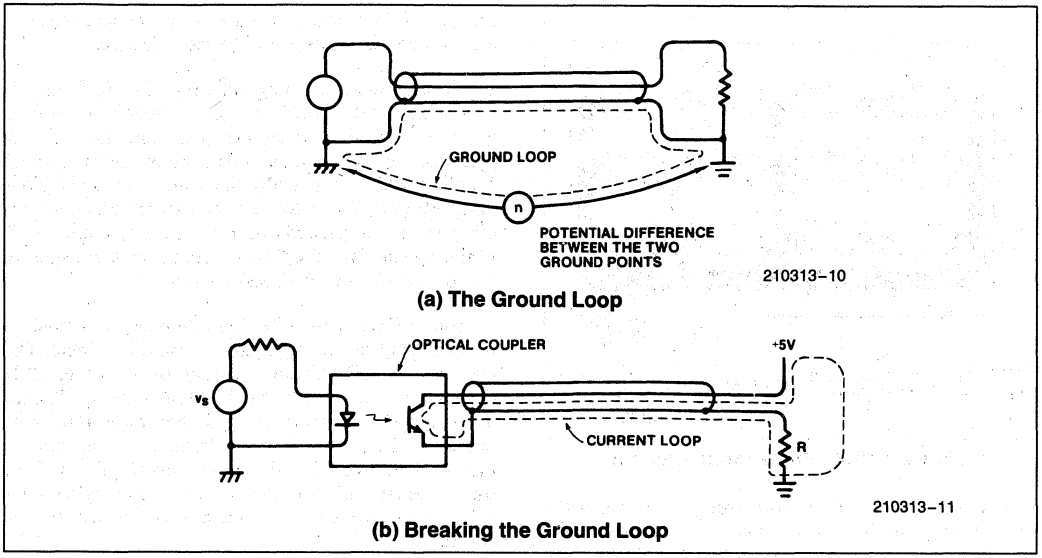


Figure 7. Use of Optical Coupler

section of the cable (it isn't), then field cancellation external to the shield is incomplete. If field cancellation is incomplete, then the effective area added to the loop by the cable isn't zero. Second, in the cheaper method the feed and return wires can be twisted together. This not only maintains their proximity, but the noise picked up in one twist tends to cancel out the noise picked up in the next twist down the line. Thus the "twisted pair" turns out to be about as good a shield against inductive coupling as coaxial cable is.

The twisted pair does not, however, provide electrostatic shielding (i.e., shielding against capacitive coupling). Another operational difference between them is that the coaxial cable works better at higher frequencies. This is primarily because the twisted pair adds more capacitive loading to the signal source than the coaxial cable does. The twisted pair is normally considered useful up to only about 1 MHz, as opposed to near a GHz for the coaxial cable.

The Ground Plane—The best way to minimize loop areas when many current loops are involved is to use a ground plane. A ground plane is a conducting surface that is to serve as a return conductor for all the current loops in the circuit. Normally, it would be one or more layers of a multilayer PCB. All ground points in the circuit go not to a grounded trace on the PCB, but directly to the ground plane. This leaves each current loop in the circuit free to complete itself in whatever configuration yields minimum loop area (for frequencies wherein the ground path impedance is primarily inductive).

Thus, if the feed path for a given signal zigzags its way across the PCB, the return path for this signal is free to zigzag right along beneath it on the ground plane, in such a configuration as to minimize the energy stored in the magnetic field produced by this current loop. Minimal magnetic flux means minimal effective loop area and minimal susceptibility to inductive coupling.

The Gridded-Ground PCB Layout—The next best thing to a ground plane is to lay out the ground traces on a PCB in the form of a grid structure, as shown in Figure 8. Laying horizontal traces on one side of the board and vertical traces on the other side allows the passage of signal and power traces. Wherever vertical and horizontal ground traces cross, they must be connected by a feed-through.

Have we not created here a network of "ground loops"? Yes, in the literal sense of the word, but loops in the ground layout on a PCB are not to be feared. Such inoffensive little loops have never caused as much noise pickup as their avoidance has. Trying to avoid innocent little loops in the ground layout, PCB designers have forced current loops into geometries that could swallow a whale. That is exactly the wrong thing to do.

The gridded ground structure works almost as well as the ground plane, as far as minimizing loop area is concerned. For a given current loop, the primary return path may have to zig once in a while where its feed path zags, but you still get a mathematically optimal dis-

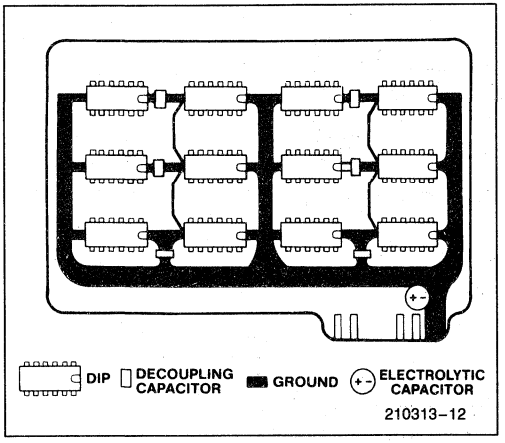


Figure 8. PCB with Gridded Ground

tribution of currents in the grid structure, such that the current loop produces less magnetic flux than if the return path were restrained to follow any single given ground trace. The key to attaining minimum loop areas for all the current loops together is to let the ground currents distribute themselves around the entire area of the board as freely as possible. They want to minimize their own magnetic field. Just let them.

RF SHIELDING

A time-varying electric field generates a time-varying magnetic field, and vice versa. Far from the source of a time-varying EM field, the ratio of the amplitudes of the electric and magnetic fields is always 377Ω. Up close to the source of the fields, however, this ratio can be quite different, and dependent on the nature of the source. Where the ratio is near 377Ω is called the far field, and where the ratio is significantly different from 377Ω is called the near field. The ratio itself is called the wave impedance, E/H.

The near field goes out about 1/6 of a wavelength from the source. At 1 MHz this is about 150 feet, and at 10 MHz it's about 15 feet. That means if an EMI source is in the same room with the victim circuit, it's likely to be a near field problem. The reason this matters is that in the near field an RF interference problem could be almost entirely due to E-field coupling or H-field coupling, and that could influence the choice of an RF shield or whether an RF shield will help at all.

In the near field of a whip antenna, the E/H ratio is higher than 377Ω, which means it's mainly an E-field generator. A wire-wrap post can be a whip antenna. Interference from a whip antenna would be by electric field coupling, which is basically capacitive coupling. Methods to protect a circuit from capacitive coupling, such as a Faraday shield, would be effective against RF interference from a whip antenna. A gridded-ground structure would be less effective.

In the near field of a loop antenna, the E/H ratio is lower than 377Ω, which means it's mainly an H-field generator. Any current loop is a loop antenna. Interference from a loop antenna would be by magnetic field coupling, which is basically the same as inductive coupling. Methods to protect a circuit from inductive coupling, such as a gridded-ground structure, would be effective against RF interference from a loop antenna. A Faraday shield would be less effective.

A more difficult case of RF interference, near field or far field, may require a genuine metallic RF shield. The idea behind RF shielding is that time-varying EMI fields induce currents in the shielding material. The induced currents dissipate energy in two ways: I^2R losses in the shielding material and radiation losses as they re-radiate their own EM fields. The energy for both of these mechanisms is drawn from the impinging EMI fields. Hence the EMI is weakened as it penetrates the shield.

More formally, the I^2R losses are referred to as absorption loss, and the re-radiation is called reflection loss. As it turns out, absorption loss is the primary shielding mechanism for H-fields, and reflection loss is the primary shielding mechanism for E-fields. Reflection loss, being a surface phenomenon, is pretty much independent of the thickness of the shielding material. Both loss mechanisms, however, are dependent on the frequency (ω) of the impinging EMI field, and on the permeability (μ) and conductivity (σ) of the shielding material. These loss mechanisms vary approximately as follows:

$$\text{reflection loss to an E-field (in dB)} \sim \log \frac{\sigma}{\omega\mu}$$

$$\text{absorption loss to an H-field (in dB)} \sim t\sqrt{\omega\sigma\mu}$$

where t is the thickness of the shielding material.

The first expression indicates that E-field shielding is more effective if the shield material is highly conductive, and less effective if the shield if ferromagnetic, and that low-frequency fields are easier to block than high-frequency fields. This is shown in Figure 9.

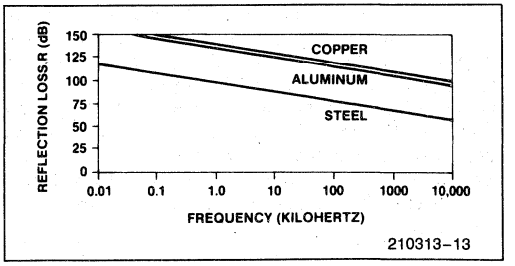


Figure 9. E-Field Shielding

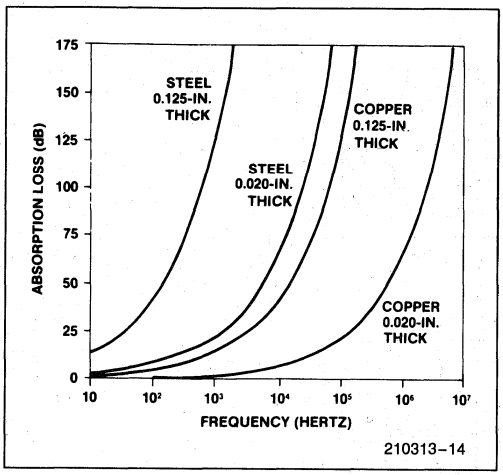


Figure 10. H-Field Shielding

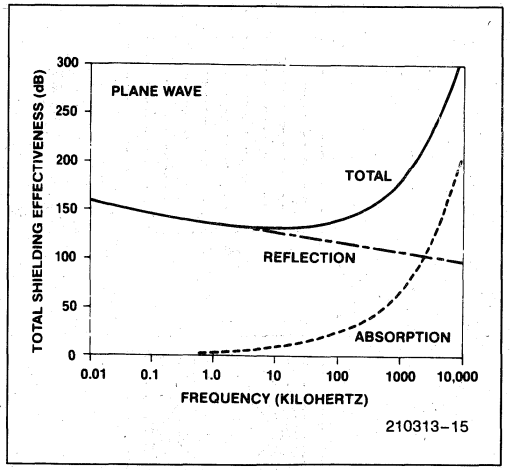


Figure 11. E- and H-Field Shielding

Copper and aluminum both have the same permeability, but copper is slightly more conductive, and so provides slightly greater reflection loss to an E-field. Steel is less effective for two reasons. First, it has a somewhat elevated permeability due to its iron content, and second, as tends to be the case with magnetic materials, it is less conductive.

On the other hand, according to the expression for absorption loss to an H-field, H-field shielding is more effective at higher frequencies and with shield material that has both high conductivity and high permeability. In practice, however, selecting steel for its high permeability involves some compromise in conductivity. But the increase in permeability more than makes up for the decrease in conductivity, as can be seen in Figure 10. This figure also shows the effect of shield thickness.

A composite of E-field and H-field shielding is shown in Figure 11. However, this type of data is meaningful only in the far field. In the near field the EMI could be 90% H-field, in which case the reflection loss is irrelevant. It would be advisable then to beef up the absorption loss, at the expense of reflection loss, by choosing steel. A better conductor than steel might be less expensive, but quite ineffective.

A different shielding mechanism that can be taken advantage of for low frequency magnetic fields is the ability of a high permeability material such as mumetal to divert the field by presenting a very low reluctance path to the magnetic flux. Above a few kHz, however, the permeability of such materials is the same as steel.

In actual fact the selection of a shielding material turns out to be less important than the presence of seams, joints and holes in the physical structure of the enclosure. The shielding mechanisms are related to the induction of currents in the shield material, but the currents must be allowed to flow freely. If they have to detour around slots and holes, as shown in Figure 12, the shield loses much of its effectiveness.

As can be seen in Figure 12, the severity of the detour has less to do with the area of the hole than it does with the geometry of the hole. Comparing Figure 12c with 12d shows that a long narrow discontinuity such as a seam can cause more RF leakage than a line of holes with larger total area. A person who is responsible for designing or selecting rack or chassis enclosures for an EMI environment needs to be familiar with the techniques that are available for maintaining electrical continuity across seams. Information on these techniques is available in the references.

Grounds

There are two kinds of grounds: earth-ground and signal ground. The earth is not an equipotential surface, so earth ground potential varies. That and its other electrical properties are not conducive to its use as a return conductor in a circuit. However, circuits are often connected to earth ground for protection against shock hazards. The other kind of ground, signal ground, is an arbitrarily selected reference node in a circuit—the node with respect to which other node voltages in the circuit are measured.

9

SAFETY GROUND

The standard 3-wire single-phase AC power distribution system is represented in Figure 13. The white wire is earth-grounded at the service entrance. If a load circuit has a metal enclosure or chassis, and if the black wire develops a short to the enclosure, there will be a shock hazard to operating personnel, unless the enclosure itself is earth-grounded. If the enclosure is earth-

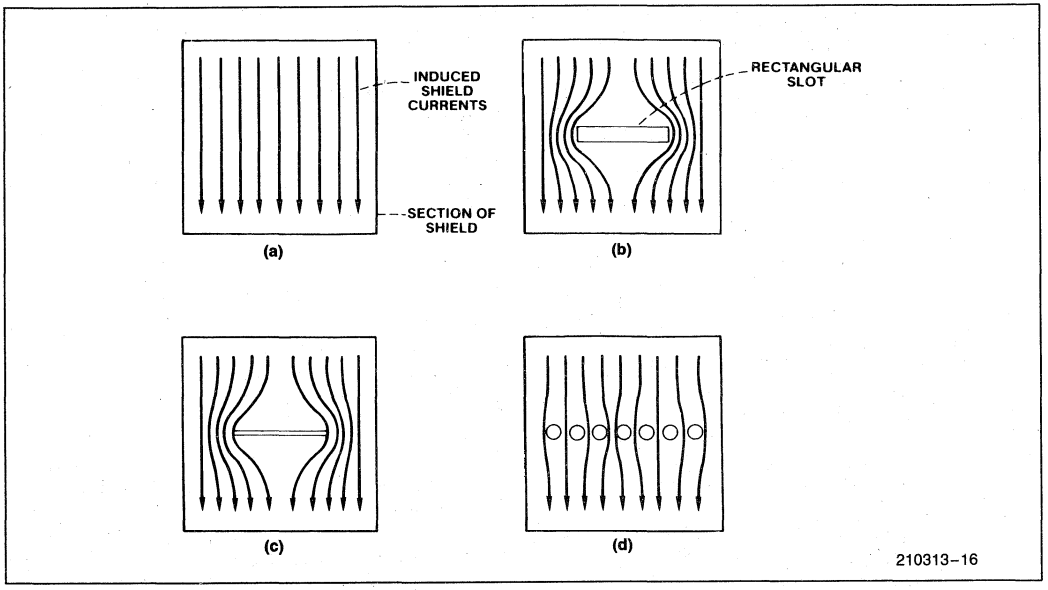


Figure 12. Effect of Shield Discontinuity on Magnetically Induced Shield Current

grounded, a short results in a blown fuse rather than a "hot" enclosure. The earth-ground connection to the enclosure is called a safety ground. The advantage of the 3-wire power system is that it distributes a safety ground along with the power.

Note that the safety-ground wire carries no current, except in case of a fault, so that at least for low frequencies it's at earth-ground potential along its entire length. The white wire, on the other hand, may be several volts off ground, due to the IR drop along its length.

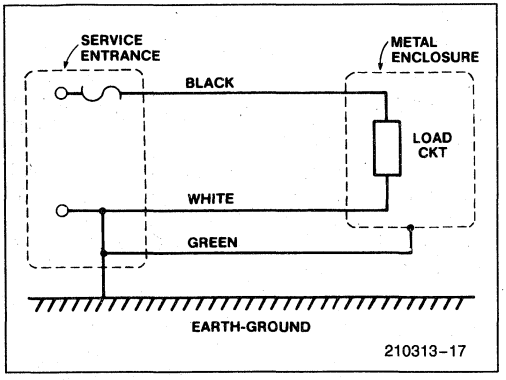


Figure 13. Single-Phase Power Distribution

SIGNAL GROUND

Signal ground is a single point in a circuit that is designated to be the reference node for the circuit. Commonly, wires that connect to this single point are also referred to as "signal ground." In some circles "power supply common" or PSC is the preferred terminology for these conductors. In any case, the manner in which these wires connect to the actual reference point is the basis of distinction among three kinds of signal-ground wiring methods: series, parallel, and multipoint. These methods are shown in Figure 14.

The series connection is pretty common because it's simple and economical. It's the noisiest of the three, however, due to common ground impedance coupling between the circuits. When several circuits share a ground wire, currents from one circuit, flowing through the finite impedance of the common ground line, cause variations in the ground potential of the other circuits. Given that the currents in a digital system tend to be spiked, and that the common impedance is mainly inductive reactance, the variations could be bad enough to cause bit errors in high current or particularly noisy situations.

The parallel connection eliminates common ground impedance problems, but uses a lot of wire. Other disadvantages are that the impedance of the individual ground lines can be very high, and the ground lines themselves can become sources of EMI.

In the multipoint system, ground impedance is minimized by using a ground plane with the various circuits connected to it by very short ground leads. This type of connection would be used mainly in RF circuits above 10 MHz.

PRACTICAL GROUNDING

A combination of series and parallel ground-wiring methods can be used to trade off economic and the various electrical considerations. The idea is to run series connections for circuits that have similar noise properties, and connect them at a single reference point, as in the parallel method, as shown in Figure 15.

In Figure 15, "noisy signal ground" connects to things like motors and relays. Hardware ground is the safety ground connection to chassis, racks, and cabinets. It's a mistake to use the hardware ground as a return path for signal currents because it's fairly noisy (for example, it's the hardware ground that receives an ESD spark) and tends to have high resistance due to joints and seams.

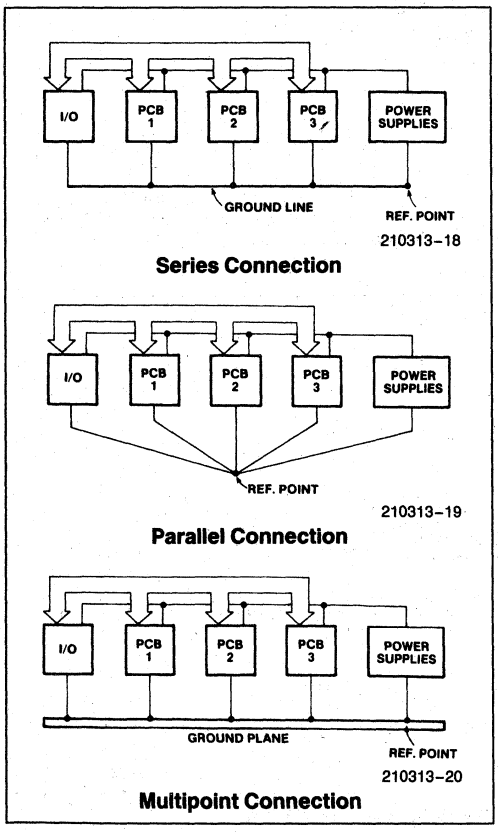


Figure 14. Three Ways to Wire the Grounds

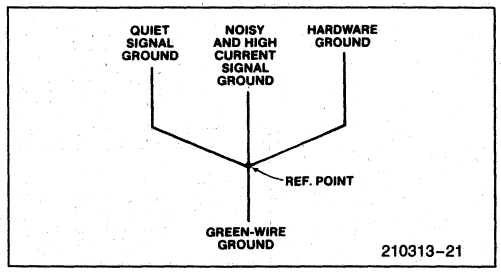


Figure 15. Parallel Connection of Series Grounds

Screws and bolts don't always make good electrical connections because of galvanic action, corrosion, and dirt. These kinds of connections may work well at first, and then cause mysterious maladies as the system ages.

Figure 16 illustrates a grounding system for a 9-track digital tape recorder, showing an application of the series/parallel ground-wiring method.

Figure 17 shows a similar separation of grounds at the PCB level. Currents in multiplexed LED displays tend to put a lot of noise on the ground and supply lines because of the constant switching and changing involved in the scanning process. The segment driver ground is relatively quiet, since it doesn't conduct the LED currents. The digit driver ground is noisier, and should be provided with a separate path to the PCB ground terminal, even if the PCB ground layout is gridded. The LED feed and return current paths should be laid out on opposite sides of the board like parallel flat conductors.

Figure 18 shows right and wrong ways to make ground connections in racks. Note that the safety ground connections from panel to rack are made through ground straps, not panel screws. Rack 1 correctly connects signal ground to rack ground only at the single reference point. Rack 2 incorrectly connects signal ground to rack ground at two points, creating a ground loop around points 1, 2, 3, 4, 1.

Breaking the "electronics ground" connection to point 1 eliminates the ground loop, but leaves signal ground in rack 2 sharing a ground impedance with the relatively noisy hardware ground to the reference point; in fact, it may end up using hardware ground as a return path for signal and power supply currents. This will probably cause more problems than the ground loop.

BRAIDED CABLE

Ground impedance problems can be virtually eliminated by using braided cable. The reduction in impedance is due to skin effect: At higher frequencies the current tends to flow along the surface of a conductor rather

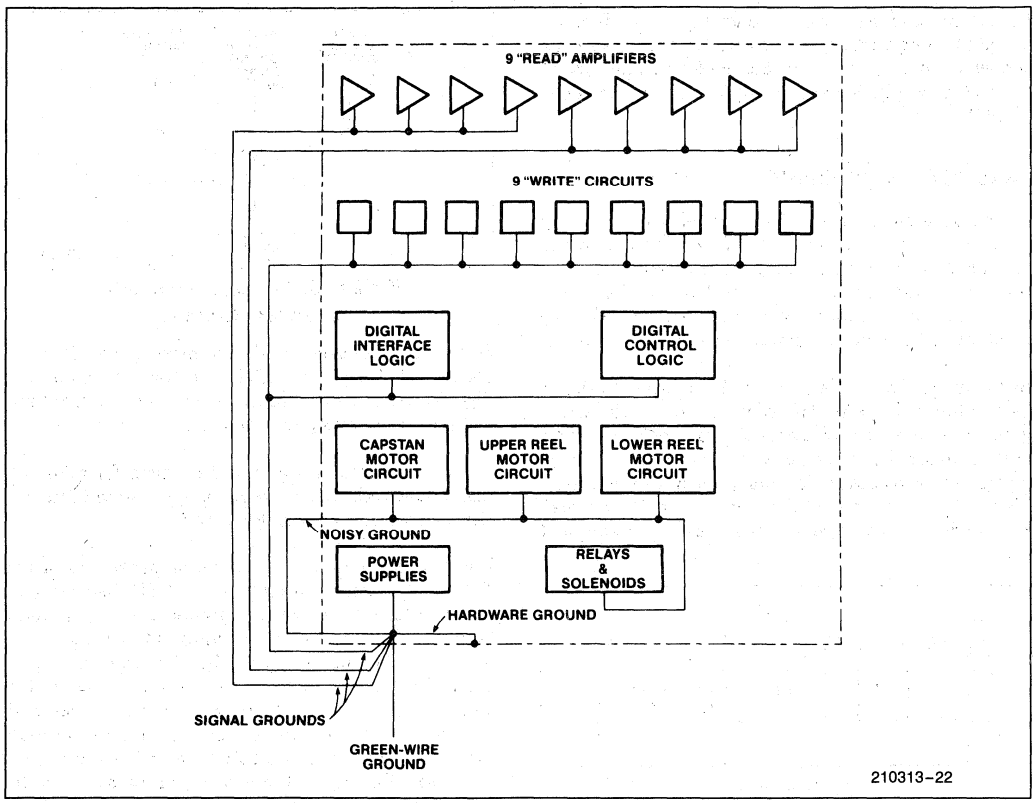


Figure 16. Ground System in a 9-Track Digital Recorder

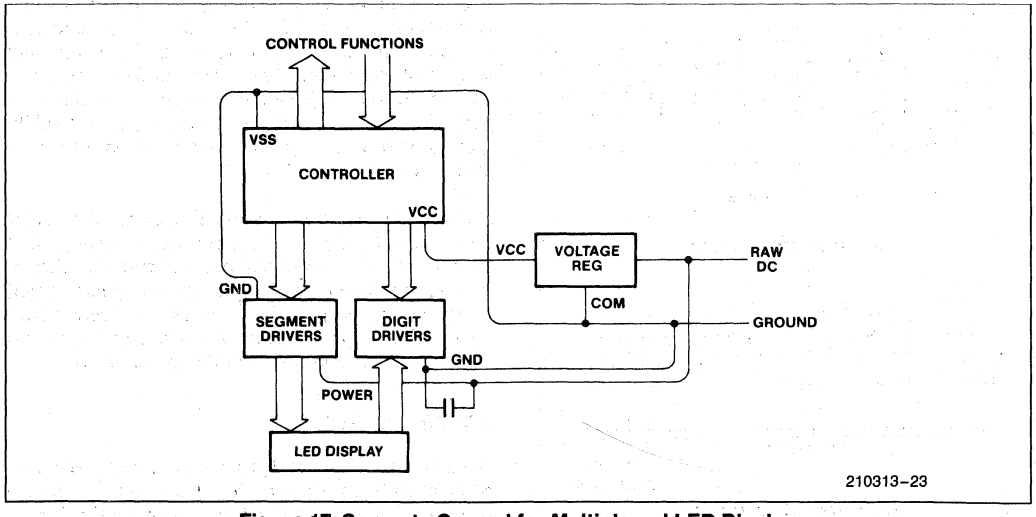


Figure 17. Separate Ground for Multiplexed LED Display

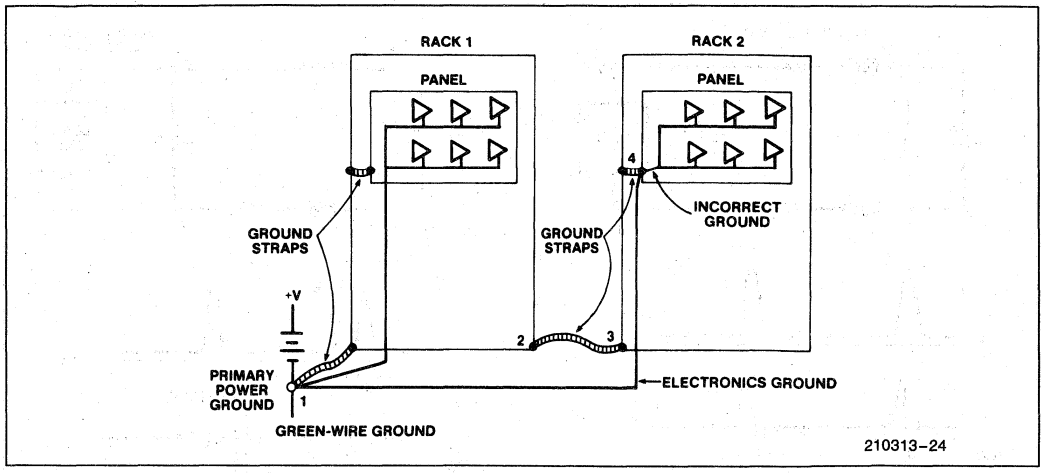


Figure 18. Electronic Circuits Mounted in Equipment Racks Should Have Separate Ground Connections. Rack 1 Shows Correct Grounding, Rack 2 Shows Incorrect Grounding.

than uniformly through its bulk. While this effect tends to increase the impedance of a given conductor, it also indicates the way to minimize impedance, and that is to manipulate the shape of the cross-section so as to provide more surface area. For its bulk, braided cable is almost pure surface.

Power Supply Distribution and Decoupling

The main consideration for power supply distribution lines is, as for signal lines, to minimize the areas of the current loops. But the power supply lines take on an importance that no signal line has when one considers the fact that these lines have access to every PC board in the system. The very extensiveness of the supply current loops makes it difficult to keep loop areas small. And, a noise glitch on a supply line is a glitch delivered to every board in the system.

The power supply provides low-frequency current to the load, but the inductance of the board-to-board and chip-to-chip distribution network makes it difficult for the power supply to maintain VCC specs on the chip while providing the current spikes that a digital system requires. In addition, the power supply current loop is a very large one, which means there will be a lot of noise pick-up. Figure 19a shows a load circuit trying to draw current spikes from a supply voltage through the line impedance. To the VCC waveform shown in that figure should be added the inductive pick-up associated with a large loop area.

Adding a decoupling capacitor solves two problems: The capacitor acts as a nearby source of charge to supply the current spikes through a smaller line impedance, and it defines a much smaller loop area for the higher frequency components of EMI. This is illustrated in Figure 19b, which shows the capacitor supplying the current spike, during which VCC drops from 5V by the amount indicated in the figure. Between current spikes the capacitor recovers through the line impedance.

One should resist the temptation to add a resistor or an inductor to the decoupler so as to form a genuine RC or LC low-pass filter because that slows down the speed with which the decoupler cap can be refreshed. Good filtering and good decoupling are not necessarily the same thing.

The current loop for the higher frequency currents, then, is defined by the decoupling cap and the load circuit, rather than by the power supply and the load circuit. For the decoupling cap to be able to provide the current spikes required by the load, the inductance of this current loop must be kept small, which is the same as saying the loop area must be kept small. This is also the requirement for minimizing inductive pick-up in the loop.

There are two kinds of decoupling caps: board decouplers and chip decouplers. A board decoupler will normally be a 10 to 100 μF electrolytic capacitor placed near to where the power supply enters the PC board, but its placement is relatively non-critical. The purpose of the board decoupler is to refresh the charge on the chip decouplers. The chip decouplers are what actually provide the current spikes to the chips. A chip decoupler will normally be a 0.1 to 1 μF ceramic capacitor placed near the chip and connected to the chip by traces that minimize the area of the loop formed by the cap and the chip. If a chip decoupler is not properly placed on the board, it will be ineffective as a decoupler

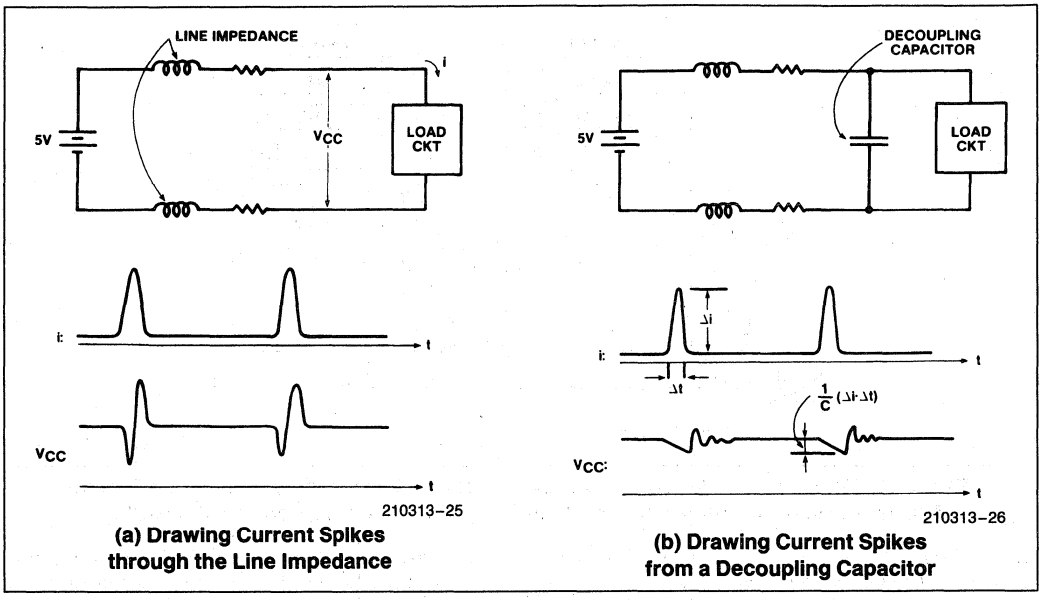


Figure 19. What a Decoupling Capacitor Does

and will serve only to increase the cost of the board. Good and bad placement of decoupling capacitors are illustrated in Figure 20.

Power distribution traces on the PC board need to be laid out so as to obtain minimal area (minimal inductance) in the loops formed by each chip and its decoupler, and by the chip decouplers and the board decoupler. One way to accomplish this goal is to use a power plane. A power plane is the same as a ground plane, but at VCC potential. More economically, a power grid similar to the ground grid previously discussed (Figure 8) can be used. Actually, if the chip decoupling loops are small, other aspects of the power layout are less critical. In other words, power planes and power gridding aren't needed, but power traces *should* be laid in the closest possible proximity to ground traces, preferably so that each power trace is on the direct opposite side of the board from a ground trace.

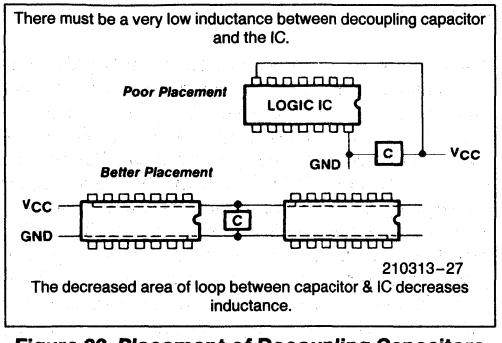


Figure 20. Placement of Decoupling Capacitors

Special-purpose power supply distribution buses which mount on the PCB are available. The buses use a parallel flat conductor configuration, one conductor being a VCC line and the other a ground line. Used in conjunction with a gridded ground layout, they not only provide a low-inductance distribution system, but can themselves form part of the ground grid, thus facilitating the PCB layout. The buses are available with and without enhanced bus capacitance, under the names Mini/Bus® and Q/PAC® from Rogers Corp. (5750 E. McKellips, Mesa, AZ 85205).

SELECTING THE VALUE OF THE DECOUPLING CAP

The effectiveness of the decoupling cap has a lot to do with the way the power and ground traces connect this capacitor to the chip. In fact, the area formed by this loop is more important than the value of the capacitance. Then, given that the area of this loop is indeed minimal, it can generally be said that the larger the value of the decoupling cap, the more effective it is, if the cap has a mica, ceramic, glass, or polystyrene dielectric.

It's often said, and not altogether accurately, that the chip decoupler shouldn't have too large a value. There are two reasons for this statement. One is that some capacitors, because of the nature of their dielectrics, tend to become inductive or lossy at higher frequencies. This is true of electrolytic capacitors, but mica, glass,

ceramic, and polystyrene dielectrics work well to several hundred MHz. The other reason cited for not using too large a capacitance has to do with lead inductance.

The capacitor with its lead inductance forms a series LC circuit. Below the frequency of series resonance, the net impedance of the combination is capacitive. Above that frequency, the net impedance is inductive. Thus a decoupling capacitor is capacitive only below the frequency of series resonance. The frequency is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

where C is the decoupling capacitance and L is the lead inductance between the capacitor and the chip. On a PC board this inductance is determined by the layout, and is the same whether the capacitor dropped into the PCB holes is 0.001 μF or 1 μF. Thus, increasing the capacitance lowers the series resonant frequency. In fact, according to the resonant frequency formula, increasing C by a factor of 100 lowers the resonant frequency by a factor of 10.

Figures quoted on the series resonant frequency of a 0.01 μF capacitor run from 10 to 15 MHz, depending on the lead length. If these numbers were accurate, a 1 μF capacitor in the same position on the board would have a resonant frequency of 1.0 to 1.5 MHz, and as a decoupler would do more harm than good. However, the numbers are based on a presumed inductance of a given length of wire (the lead length). It should be noted that a "length of wire" has no inductance at all, strictly speaking. Only a complete current loop has inductance, and the inductance depends on the geometry of the loop. Figures quoted on the inductance of a length of wire are based on a presumably "very large" loop area, such that the magnetic field produced by the return current has no cancellation effect on the field produced by the current in the given length of wire. Such a loop geometry is not and should not be the case with the decoupling loop.

Figure 21 shows VCC waveforms, measured between pins 40 and 20 (VCC and VSS) of an 8751 CPU, for several conditions of decoupling on a PC board that has a decoupling loop area slightly larger than necessary. These photographs show the effects of increasing the decoupling capacitance and decreasing the area of the decoupling loop. The indications are that a 1 μF capacitor is better than a 0.1 μF capacitor, which in turn is better than nothing, and that the board should have been laid out with more attention paid to the area of the decoupling loop.

Figure 21e was obtained using a special-purpose experimental capacitor designed by Rogers Corp. (Q-Pac Division, Mesa, AZ) for use as a decoupler. It consists of two parallel plates, the length of a 40-pin DIP, separated by a ceramic dielectric. Sandwiched between the CPU chip and the PCB (or between the CPU socket and the PCB), it makes connection to pins 40 and 20, forming a leadless decoupling capacitor. It is obviously a configuration of minimal inductance. Unfortunately, the particular sample tested had only 0.07 μF of capacitance and so was unable to prevent the 1 MHz ripple as effectively as the configuration of Figure 21d. It seems apparent, though, that with more capacitance this part will alleviate a lot of decoupling problems.

THE CASE FOR ON-BOARD VOLTAGE REGULATION

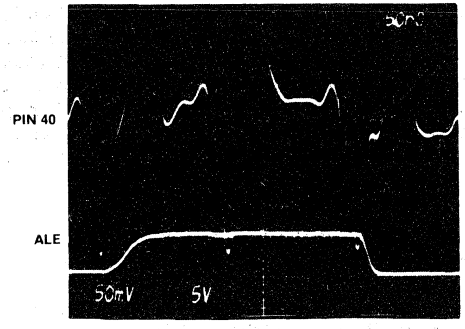
To complicate matters, supply line glitches aren't always picked up in the distribution networks, but can come from the power supply circuit itself. In that case, a well-designed distribution network faithfully delivers the glitch throughout the system. The VCC glitch in Figure 22 was found to be coming from within a bench power supply in response to the EMP produced by an induction coil spark generator that was being used at Intel during a study of noise sensitivity. The VCC glitch is about 400 mV high and some 20 μs in duration. Normal board decoupling techniques were ineffective in removing it, but adding an on-board voltage regulator chip did the job.

Thus, a good case can be made in favor of using a voltage regulator chip on each PCB, instead of doing all the voltage regulation at the supply circuit. This eases requirements on the heat-sinking at the supply circuit, and alleviates much of the distribution and board decoupling headaches. However, it also brings in the possibility that different boards would be operating at slightly different VCC levels due to tolerance in the regulator chips; this then leads to slightly different logic levels from board to board. The implications of that may vary from nothing to latch-up, depending on what kinds of chips are on the boards, and how they react to an input "high" that is perhaps 0.4V higher than local VCC.

Recovering Gracefully from a Software Upset

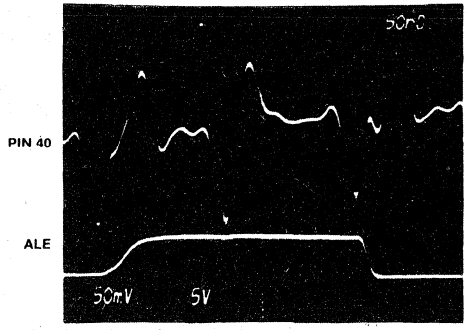
Even when one follows all the best guidelines for designing for a noisy environment, it's always possible for a noise transient to occur which exceeds the circuit's immunity level. In that case, one can strive at least for a graceful recovery.

Graceful recovery schemes involve additional hardware and/or software which is supposed to return the system to a normal operating mode after a software upset has occurred. Two decisions have to be made: How to recognize when an upset has occurred, and what to do about it.



210313-28

(a) No Decoupling Cap



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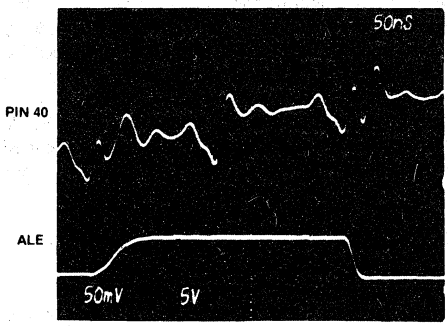
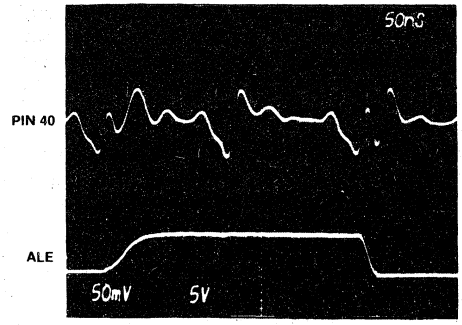
(b) 0.1 μF Decoupler in Place on the PCB



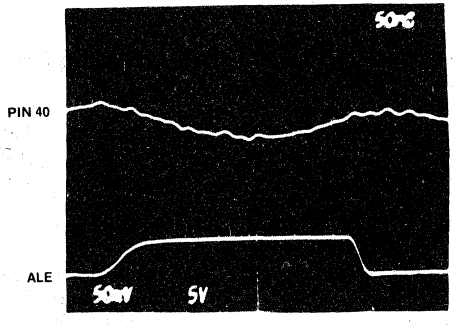
210313-30

(c) 0.1 μF Decoupler Stretched Directly from Pin 40 to Pin 20, under the Socket. (The difference between this and 21b is due only to the change in loop geometry. Also shown is the upward slope of a ripple in VCC. The ripple frequency is 1 MHz, the same as ALE.)



210313-31

(d) 1.0 μF Decoupler Stretched Directly from Pin 40 to Pin 20, under the Socket. (This prevents the 1 MHz ripple, but there's no reduction in higher frequency components. Further increases in capacitance effected no further improvement.)



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(e) Special-Purpose Decoupling Cap under Development by Rogers Corp. (Further discussion in text.)

Figure 21. Noise on VCC Line

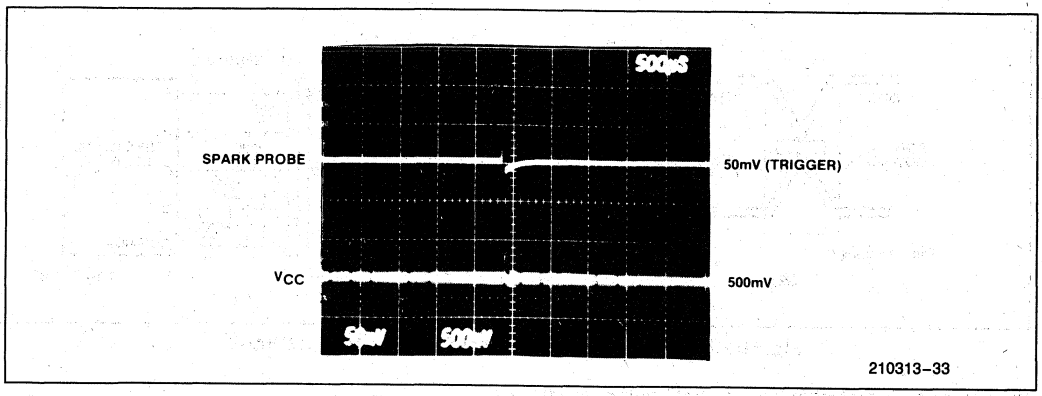

Figure 22. EMP-Induced Glitch

If the designer knows what kinds and combinations of outputs can legally be generated by the system, he can use gates to recognize and flag the occurrence of an illegal state of affairs. The flag can then trigger a jump to a recovery routine which then may check or re-initialize data, perhaps output an error message, or generate a simple reset.

The most reliable scheme is to use a so-called watchdog circuit. Here the CPU is programmed to generate a periodic signal as long as the system is executing instructions in an expected manner. The periodic signal is then used to hold off a circuit that will trigger a jump to a recovery routine. The periodic signal needs to be AC-coupled to the trigger circuit so that a "stuck-at" fault won't continue to hold off the trigger. Then, if the processor locks up someplace, the periodic signal is lost and the watchdog triggers a reset.

In practice, it may be convenient to drive the watchdog circuit with a signal which is being generated anyway by the system. One needs to be careful, however, that an upset does in fact discontinue that signal. Specifically, for example, one could use one of the digit drive signals going to a multiplexed display. But display scanning is often handled in response to a timer-interrupt, which may continue operating even though the main program is in a failure mode. Even so, with a little extra software, the signal can be used to control the watchdog (see Reference 8 on this).

Simpler schemes can work well for simpler systems. For example, if a CPU isn't doing anything but scanning and decoding a keyboard, there's little to lose and much to gain by simply resetting it periodically with an astable multivibrator. It only takes about 13 μs (at 6 MHz) to reset an 8048 if the clock oscillator is already running.

A zero-cost measure is simply to fill all unused program memory with NOPs and JMPs to a recovery routine. The effectiveness of this method is increased by writing the program in segments that are separated by NOPs and JMPs. It's still possible, of course, to get hung up in a data table or something. But you get a lot of protection, for the cost.

Further discussion of graceful recovery schemes can be found in Reference 13.

Special Problem Areas

ESD

MOS chips have some built-in protection against a static charge build-up on the pins, as would occur during normal handling, but there's no protection against the kinds of current levels and rise times that occur in a genuine electrostatic spark. These kinds of discharges can blow a crater in the silicon.

It must be recognized that connecting CPU pins unprotected to a keyboard or to anything else that is subject to electrostatic discharges makes an extremely fragile configuration. Buffering them is the very least one can do. But buffering doesn't completely solve the problem, because then the buffer chips will sustain the damage (even TTL); therefore, one might consider mounting the buffer chips in sockets for ease of replacement.

Transient suppressors, such as the TranZorbs® made by General Semiconductor Industries (Tempe, AZ), may in the long run provide the cheapest protection if their "zero inductance" structure is used. The structure and circuit application are shown in Figure 23.

The suppressor element is a pn junction that operates like a Zener diode. Back-to-back units are available for AC operation. The element is more or less an open circuit at normal system voltage (the standoff voltage rating for the device), and conducts like a Zener diode at the clamping voltage.

The lead inductance in the conventional transient suppressor package makes the conventional package essen-

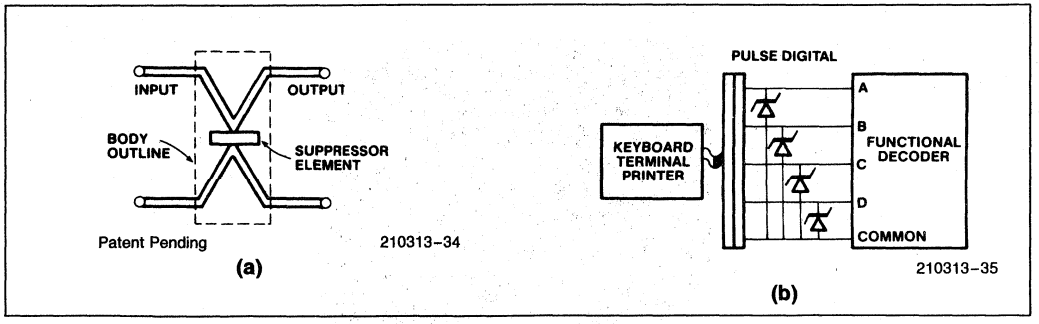

Figure 23. "Zero-Inductance" Structure and Use in Circuit

tially useless for protection against ESD pulses, owing to the fast rise of these pulses. The "zero inductance" units are available singly in a 4-pin DIP, and in arrays of four to a 16-pin DIP for PCB level protection. In that application they should be mounted in close proximity to the chips they protect.

In addition, metal enclosures or frames or parts that can receive an ESD spark should be connected by braided cable to the green-wire ground. Because of the ground impedance, ESD current shouldn't be allowed to flow through any signal ground, even if the chips are protected by transient suppressors. A 35 kV ESD spark can always spare a few hundred volts to drive a fast current pulse down a signal ground line if it can't find a braided cable to follow. Think how delighted your 8048 will be to find its VSS pin 250V higher than VCC for a few 10s of nanoseconds.

THE AUTOMOTIVE ENVIRONMENT

The automobile presents an extremely hostile environment for electronic systems. There are several parts to it:

1. Temperature extremes from −40°C to +125°C (under the hood) or +85°C (in the passenger compartment)
2. Electromagnetic pulses from the ignition system
3. Supply line transients that will knock your socks off

One needs to take a long, careful look at the temperature extremes. The allowable storage temperature range for most Intel MOS chips is −65°C to +150°C, although some chips have a maximum storage temperature rating of +125°C. In operation (or "under bias," as the data sheets say) the allowable ambient temperature range depends on the product grade, as follows:

Grade	Ambient Temperature	
	Min	Max
Commercial	0	70
Industrial	−40	+85
Automotive	−40	+110
Military	−55	+125

The different product grades are actually the same chip, but tested according to different standards. Thus, a given commercial-grade chip might actually pass military temperature requirements, but not have been tested for it. (Of course, there are other differences in grading requirements having to do with packaging, burn-in, traceability, etc.)

In any case, it's apparent that commercial-grade chips can't be used safely in automotive applications, not even in the passenger compartment. Industrial-grade chips can be used in the passenger compartment, and automotive or military chips are required in under-the-hood applications.

Ignition noise, CB radios, and that sort of thing are probably the least of your worries. In a poorly designed system, or in one that has not been adequately tested for the automotive environment, this type of EMI might cause a few software upsets, but not destroy chips.

The major problem, and the one that seems to come as the biggest surprise to most people, is the line transients. Regrettably, the 12V battery is not actually the source of power when the car is running. The charging system is, and it's not very clean. The only time the battery is the real source of power is when the car is first being started, and in that condition the battery terminals may be delivering about 5V or 6V. As follows is a brief description of the major idiosyncracies of the "12V" automotive power line.

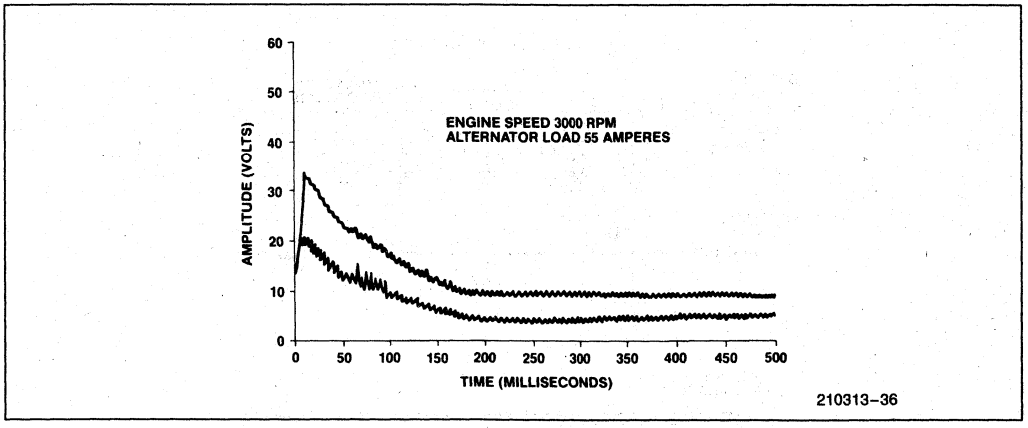

Figure 24. Typical Load Dump Transients

- An abrupt reduction in the alternator load causes a positive voltage transient called "load dump." In a load dump transient the line voltage rises to 20V or 30V in a few μs, then decays exponentially with a time constant of about 100 μs, as shown in Figure 24. Much higher peak voltages and longer decay times have also been reported. The worst case load dump is caused by disconnecting a low battery from the alternator circuit while the alternator is running. Normally this would happen intermittently when the battery terminal connections are defective.
- When the ignition is turned off, as the field excitation decays, the line voltage can go to between −40V and −100V for 100 μs or more.
- Miscellaneous solenoid switching transients, such as the one shown in Figure 25, can drive the line to + or −200V to 400V for several μs.
- Mutual coupling between unshielded wires in long harnesses can induce 100V and 200V transients in unprotected circuits.

What all this adds up to is that people in the business of building systems for automotive applications need a comprehensive testing program. An SAE guideline which describes the automotive environment is available to designers: SAE J1211, "Recommended Environmental Practices for Electronic Equipment Design," *1980 SAE Handbook,* Part 1, pp. 22.80–22.96.

Some suggestions for protecting circuitry are shown in Figure 26. A transient suppressor is placed in front of the regulator chip to protect it. Since the rise times in these transients are not like those in ESD pulses, lead inductance is less critical and conventional devices can be used. The regulator itself is pretty much of a necessity, since a load dump transient is simply not going to be removed by any conventional LC or RC filter.

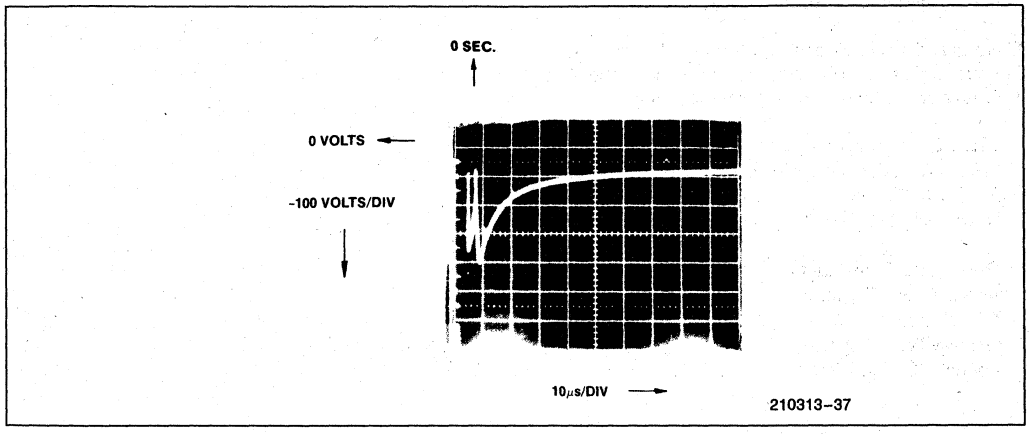

Figure 25. Transient Created by De-energizing an Air Conditioning Clutch Solenoid

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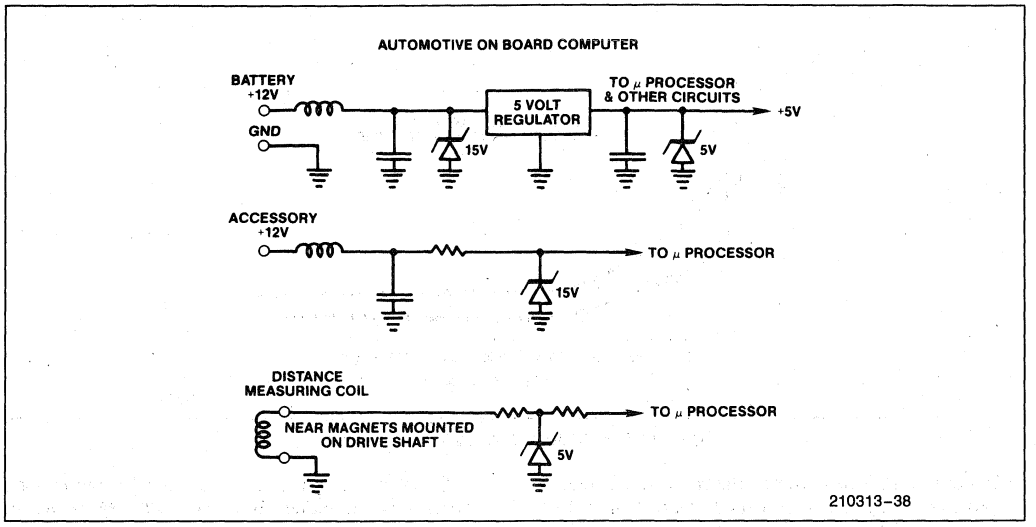

Figure 26. Use of Transient Suppressors in Automotive Applications

Special I/O interfacing is also required, because of the need for high tolerance to voltage transients, input noise, input/output isolation, etc. In addition, switches that are being monitored or driven by these buffers are usually referenced to chassis ground instead of signal ground, and in a car there can be many volts difference between the two. I/O interfacing is discussed in Reference 2.

Parting Thoughts

The main sources of information for this Application Note were the references by Ott and by White. Reference 5 is probably the finest treatment currently available on the subject. The other references provided specific information as cited in the text.

Courses and seminars on the subject of electromagnetic interference are given regularly throughout the year. Information on these can be obtained from:

IEEE Electromagnetic Compatibility Society
EMC Education Committee
345 East 47th Street
New York, NY 10017

Don White Consultants, Inc.
International Training Centre
P.O. Box D
Gainesville, VA 22065
Phone: (703) 347-0030

The EMC Education committee has available a video tape: "Introduction to EMC—A Video Training Tape," by Henry Ott. Don White Consultants offers a series of training courses on many different aspects of electromagnetic compatibility. Most organizations that sponsor EMC courses also offer in-plant presentations.

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APPLICATION NOTE

AP-155

June 1983

Oscillators for Microcontrollers

TOM WILLIAMSON
MICROCONTROLLER
TECHNICAL MARKETING

Order Number: 230659-001

OSCILLATORS FOR MICROCONTROLLERS

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INTRODUCTION

Intel's microcontroller families (MCS®-48, MCS®-51, and iACX-96) contain a circuit that is commonly referred to as the "on-chip oscillator". The on-chip circuitry is not itself an oscillator, of course, but an amplifier that is suitable for use as the amplifier part of a feedback oscillator. The data sheets and Microcontoller Handbook show how the on-chip amplifier and several off-chip components can be used to design a working oscillator. With proper selection of off-chip components, these oscillator circuits will perform better than almost any other type of clock oscillator, and by almost any criterion of excellence. The suggested circuits are simple, economical, stable, and reliable.

We offer assistance to our customers in selecting suitable off-chip components to work with the on-chip oscillator circuitry. It should be noted, however, that Intel cannot assume the responsibility of writing specifications for the off-chip components of the complete oscillator circuit, nor of guaranteeing the performance of the finished design in production, anymore than a transistor manufacturer, whose data sheets show a number of suggested amplifier circuits, can assume responsibility for the operation, in production, of any of them.

We are often asked why we don't publish a list of required crystal or ceramic resonator specifications, and recommend values for the other off-chip components. This has been done in the past, but sometimes with consequences that were not intended.

Suppose we suggest a maximum crystal resistance of 30 ohms for some given frequency. Then your crystal supplier tells you the 30-ohm crystals are going to cost twice as much as 50-ohm crystals. Fearing that Intel will not "guarantee operation" with 50-ohm crsytals, you order the expensive ones. In fact, Intel guarantees only what is embodied within an Intel product. Besides, there is no reason why 50-ohm crystals couldn't be used, if the other off-chip components are suitably adjusted.

Should we recommend values for the other off-chip components? Should we do it for 50-ohm crystals or 30-ohm crystals? With respect to what should we optimize their selection? Should we minimize start-up time or maximize frequency stability? In many applications, neither start-up time nor frequency stability are particularly critical, and our "recommendations" are only restricting your system to unnecessary tolerances. It all depends on the application.

Although we will neither "specify" nor "recommend" specific off-chip components, we do offer assistance in these tasks. Intel application engineers are available to provide whatever technical assistance may be needed or desired by our customers in designing with Intel products.

This Application Note is intended to provide such assistance in the design of oscillator circuits for microcontroller systems. Its purpose is to describe in a practical manner how oscillators work, how crystals and ceramic resonators work (and thus how to spec them), and what the on-chip amplifier looks like electronically and what its operating characteristics are. A BASIC program is provided in Appendix II to assist the designer in determining the effects of changing individual parameters. Suggestions are provided for establishing a pre-production test program.

FEEDBACK OSCILLATORS

Loop Gain

Figure 1 shows an amplifier whose output line goes into some passive network. If the input signal to the amplifier is v_1, then the output signal from the amplifer is $v_2 = Av_1$ and the output signal from the passive network is $v_3 = \beta v_2 = \beta A v_1$. Thus βA is the overall gain from terminal 1 to terminal 3.

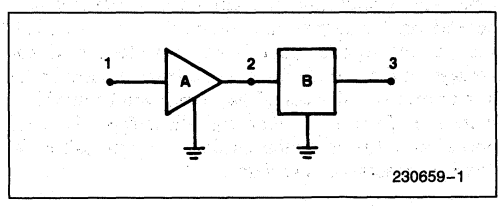

Figure 1. Factors in Loop Gain

Now connect terminal 1 to terminal 3, so that the signal path forms a loop: 1 to 2 to 3, which is also 1. Now we have a feedback loop, and the gain factor βA is called the *loop gain.*

Gain factors are complex numbers. That means they have a magnitude and a phase angle, both of which vary with frequency. When writing a complex number, one must specify both quantities, magnitude and angle. A number whose magnitude is 3, and whose angle is 45 degrees is commonly written this way: $3\angle 45°$. The number 1 is, in complex number notation, $1\angle 0°$, while -1 is $1\angle 180°$.

By closing the feedback loop in Figure 1, we force the equality

$$v_1 = \beta A v_1$$

This equation has two solutions:

1) $v_1 = 0$;

2) $\beta A = 1\angle 0°$.

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In a given circuit, either or both of the solutions may be in effect. In the first solution the circuit is quiescent (no output signal). If you're trying to make an oscillator, a no-signal condition is unacceptable. There are ways to guarantee that the second solution is the one that will be in effect, and that the quiescent condition will be excluded.

How Feedback Oscillators Work

A feedback oscillator amplifies its own noise and feeds it back to itself in exactly the right phase, at the oscillation frequency, to build up and reinforce the desired oscillations. Its ability to do that depends on its loop gain. First, oscillations can occur only at the frequency for which the loop gain has a phase angle of 0 degrees. Second build-up of oscillations will occur only if the loop gain exceeds 1 at the frequency. Build-up continues until nonlinearities in the circuit reduce the average value of the loop gain to exactly 1.

Start-up characteristics depend on the small-signal properties of the circuit, specifically, the small-signal loop gain. Steady-state characteristics of the oscillator depend on the large-signal properties of the circuit, such as the transfer curve (output voltage vs. input voltage) of the amplifier, and the clamping effect of the input protection devices. These things will be discussed more fully further on. First we will look at the basic operation of the particular oscillator circuit, called the "positive reactance" oscillator.

The Positive Reactance Oscillator

Figure 2 shows the configuration of the positive reactance oscillator. The inverting amplifier, working into the impedance of the feedback network, produces an output signal that is nominally 180 degrees out of phase with its input. The feedback network must provide an additional 180 degrees phase shift, such that the overall loop gain has zero (or 360) degrees phase shift at the oscillation frequency.

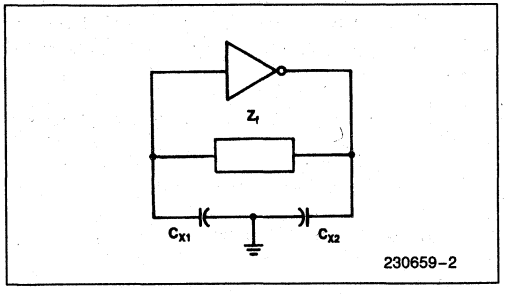

Figure 2. Positive Reactance Oscillator

In order for the loop gain to have zero phase angle it is necessary that the feedback element Z_f have a positive reactance. That is, it must be inductive. Then, the frequency at which the phase angle is zero is approximately the frequency at which

$$X_f = \frac{+1}{\omega C}$$

where X_f is the reactance of Z_f (the total Z_f being $R_f + jX_f$, and C is the series combination of C_{X1} and C_{X2}.

$$C = \frac{C_{X1}\,C_{X2}}{C_{X1} + C_{X2}}$$

In other words, Z_f and C form a parallel resonant circuit.

If Z_f is an inductor, then $X_f = \omega L$, and the frequency at which the loop gain has zero phase is the frequency at which

$$\omega L = \frac{1}{\omega C}$$

or

$$\omega = \frac{1}{\sqrt{LC}}$$

Normally, Z_f is not an inductor, but it must still have a positive reactance in order for the circuit to oscillate. There are some piezoelectric devices on the market that show a positive reactance, and provide a more stable oscillation frequency than an inductor will. Quartz crystals can be used where the oscillation frequency is critical, and lower cost ceramic resonators can be used where the frequency is less critical.

When the feedback element is a piezoelectric device, this circuit configuration is called a Pierce oscillator. The advantage of piezoelectric resonators lies in their property of providing a wide range of positive reactance values over a very narrow range of frequencies. The reactance will equal $1/\omega C$ at some frequency within this range, so the oscillation frequency will be within the same range. Typically, the width of this range is

only 0.3% of the nominal frequency of a quartz crystal, and about 3% of the nominal frequency of a ceramic resonator. With relatively little design effort, frequency accuracies of 0.03% or better can be obtained with quartz crystals, and 0.3% or better with ceramic resonators.

QUARTZ CRYSTALS

The crystal resonator is a thin slice of quartz sandwiched between two electrodes. Electrically, the device looks pretty much like a 5 or 6 pF capacitor, except that over certain ranges of frequencies the crystal has a positive (i.e., inductive) reactance.

The ranges of positive reactance originate in the piezoelectric property of quartz: Squeezing the crystal generates an internal E-field. The effect is reversible: Applying an *AC* E-field causes the crystal to vibrate. At certain vibrational frequencies there is a mechanical resonance. As the E-field frequency approaches a frequency of mechanical resonance, the measured reactance of the crystal becomes positive, as shown in Figure 3.

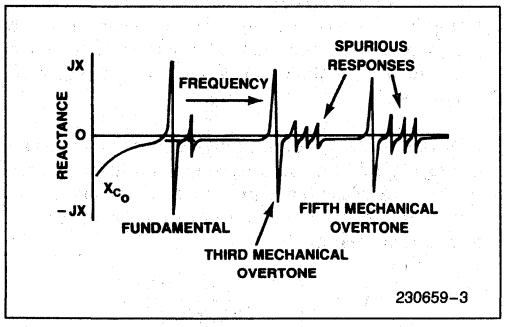

Figure 3. Crystal Reactance vs. Frequency

Typically there are several ranges of frequencies wherein the reactance of the crystal is positive. Each range corresponds to a different mode of vibration in the crystal. The main resonsances are the so-called fundamental response and the third and fifth overtone responses.

The overtone responses shouldn't be confused with the harmonics of the fundamental. They're not harmonics, but different vibrational modes. They're not in general at exact integer multiples of the fundamental frequency. There will also be "spurious" responses, occurring typically a few hundred KHz above each main response.

To assure that an oscillator starts in the desired mode on power-up, something must be done to suppress the loop gain in the undesired frequency ranges. The crystal itself provides some protection against unwanted modes of oscillation; too much resistance in that mode, for example. Additionally, junction capacitances in the amplifying devices tend to reduce the gain at higher frequencies, and thus may discriminate against unwanted modes. In some cases a circuit fix is necessary, such as inserting a trap, a phase shifter, or ferrite beads to kill oscillations in unwanted modes.

Crystal Parameters

Equivalent Circuit

Figure 4 shows an equivalent circuit that is used to represent the crystal for circuit analysis.

The R_1-L_1-C_1 branch is called the motivational arm of the crystal. The values of these parameters derive from the mechanical properties of the crystal and are constant for a given mode of vibration. Typical values for various nominal frequencies are shown in Table 1.

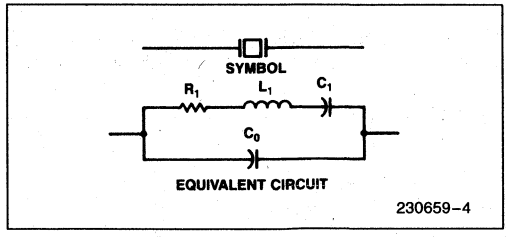

Figure 4. Quartz Crystal: Symbol and Equivalent Circuit

C_0 is called the shunt capacitance of the crystal. This is the capacitance of the crystal's electrodes and the mechanical holder. If one were to measure the reactance of the crystal at a freuqency far removed from a resonance frequency, it is the reactance of this capacitance that would be measured. It's normally 3 to 7 pF.

Table 1. Typical Crystal Parameters

Frequency MHz	R_1 ohms	L_1 mH	C_1 pF	C_0 pF
2	100	520	0.012	4
4.608	36	117	0.010	2.9
11.25	19	8.38	0.024	5.4

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The series resonant frequency of the crystal is the frequency at which L_1 and C_1 are in resonance. This frequency is given by

$$f_s = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

At this frequency the impedance of the crystal is R_1 in parallel with the reactance of C_0. For most purposes, this impedance is taken to be just R_1, since the reactance of C_0 is so much larger than R_1.

Load Capacitance

A crystal oscillator circuit such as the one shown in Figure 2 (redrawn in Figure 5) operates at the frequency for which the crystal is antiresonant (ie, parallel-resonant) with the total capacitance across the crystal terminals external to the crystal. This total capacitance external to the crystal is called the load capacitance.

As shown in Figure 5, the load capacitance is given by

$$C_L = \frac{C_{X1}\,C_{X2}}{C_{X1} + C_{X2}} + C_{stray}$$

The crystal manufacturer needs to know the value of C_L in order to adjust the crystal to the specified frequency.

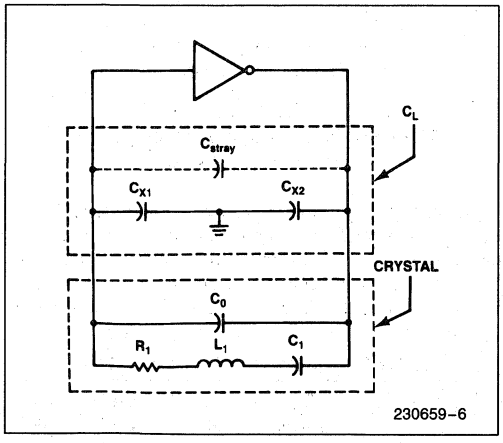


Figure 5. Load Capacitance

The adjustment involves putting the crystal in *series* with the specified C_L, and then "trimming" the crystal to obtain resonance of the series combination of the crystal and C_L at the specified frequency. Because of the high Q of the crystal, the resonant frequency of the series combination of the crystal and C_L is the same as the antiresonant frequency of the *parallel* combination of the crystal and C_L. This frequency is given by

$$f_a = \frac{1}{2\pi\sqrt{L_1 C_1 (C_L + C_0)/(C_1 + C_L + C_0)}}$$

These frequency formulas are derived (in Appendix A) from the equivalent circuit of the crystal, using the assumptions that the Q of the crystal is extremely high, and that the circuit external to the crystal has no effect on the frequency other than to provide the load capacitance C_L. The latter assumption is not precisely true, but it is close enough for present purposes.

"Series" vs. "Parallel" Crystals

There is no such thing as a "series cut" crystal as opposed to a "parallel cut" crystal. There are different cuts of crystal, having to do with the parameters of its motional arm in various frequency ranges, but there is no special cut for series or parallel operation.

An oscillator is series resonant if the oscillation frequency is f_s of the crystal. To operate the crystal at f_s, the amplifier has to be noninverting. When buying a crystal for such an oscillator, one does not specify a load capacitance. Rather, one specifies the loading condition as "series."

If a "series" crystal is put into an oscillator that has an inverting amplifier, it will oscillate in parallel resonance with the load capacitance presented to the crystal by the oscillator circuit, at a frequency slightly above f_s. In fact, at approximately

$$f_a = f_s\left(1 + \frac{C_1}{2(C_L + C_0)}\right)$$

This frequency would typically be about 0.02% above f_s.

Equivalent Series Resistance

The "series resistance" often listed on quartz crystal data sheets is the real part of the crystal impedance at the crystal's calibration frequency. This will be R1 if the calibration frequency is the series resonant frequency of the crystal. If the crystal is calibrated for parallel resonance with a load capacitance CL, the equivalent series resistance will be

$$ESR = R_1\left(1 + \frac{C_0}{C_L}\right)^2$$

The crystal manufacturer measures this resistance at the calibration frequency during the same operation in which the crystal is adjusted to the calibration frequency.

Frequency Tolerance

Frequency tolerance as discussed here is not a requirement on the crystal, but on the complete oscillator. There are two types of frequency tolerances on oscillators: frequency *acccuracy* and frequency *stability*. Frequency accuracy refers to the oscillator's ability to run at an exact specified frequency. Frequency stability refers to the constancy of the oscillation frequency.

Frequency accuracy requires mainly that the oscillator circuit present to the crystal the same load capacitance that it was adjusted for. Frequency stability requires mainly that the load capacitance be constant.

In most digital applications the accuracy and stability requirements on the oscillator are so wide that it makes very little difference what load capacitance the crystal was adjusted to, or what load capacitance the circuit actually presents to the crystal. For example, if a crystal was calibrated to a load capacitance of 25 pF, and is used in a circuit whose actual load capacitance is 50 pF, the frequency error on that account would be less than 0.01%.

In a positive reactance oscillator, the crystal only needs to be in the intended response mode for the oscillator to satisfy a 0.5% or better frequency tolerance. That's because for any load capacitance the oscillation frequency is certain to be between the crystal's resonant and antiresonant frequencies.

Phase shifts that take place within the amplifier part of the oscillator will also affect frequency accuracy and stability. These phase shifts can normally be modeled as an "output capacitance" that, in the positive reactance oscillator, parallels C_{X2}. The predictability and constancy of this output capacitance over temperature and device sample will be the limiting factor in determining the tolerances that the circuit is capable of holding.

Drive Level

Drive level refers to the power dissipation in the crystal. There are two reasons for specifying it. One is that the parameters in the equivalent circuit are somewhat dependent on the drive level at which the crystal is calibrated. The other is that if the application circuit exceeds the test drive level by too much, the crystal may be damaged. Note that the terms "test drive level" and "rated drive level" both refer to the drive level at which the crystal is calibrated. Normally, in a microcontroller system, neither the frequency tolerances nor the power levels justify much concern for this specification. Some crystal manufacturers don't even require it for microprocessor crystals.

In a positive reactance oscillator, if one assumes the peak voltage across the crystal to be something in the neighborhood of V_{CC}, the power dissipation can be approximated as

$$P = 2R_1 [\pi f (C_L + C_0) V_{CC}]^2$$

This formula is derived in Appendix A. In a 5V system, P rarely evaluates to more than a milliwatt. Crystals with a standard 1 or 2 mW drive level rating can be used in most digital systems.

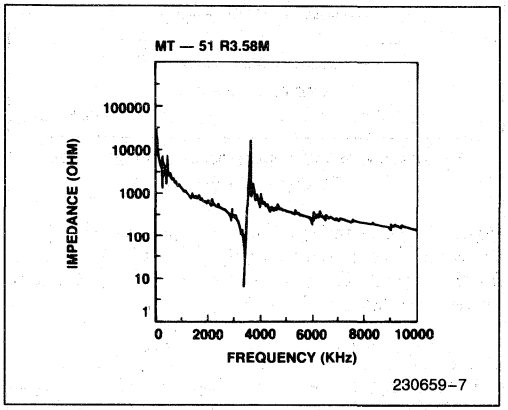


Figure 6. Ceramic Resonator Impedance vs. Frequency (Test Data Supplied by NTK Technical Ceramics)

CERAMIC RESONATORS

Ceramic resonators operate on the same basic principles as a quartz crsytal. Like quartz crsytals, they are piezoelectric, have a reactance versus frequency curve similar to a crystal's, and an equivalent circuit that looks just like a crystal's (with different parameter values, however).

The frequency tolerance of a ceramic resonator is about two orders of magnitude wider than a crystal's, but the ceramic is somewhat cheaper than a crystal. It may be noted for comparison that quartz crystals with relaxed tolerances cost about twice as much as ceramic resonators. For purposes of clocking a microcontroller, the frequency tolerance is often relatively noncritical, and the economic consideration becomes the dominant factor.

Figure 6 shows a graph of impedance magnitude versus frequency for a 3.58 MHz ceramic resonator. (Note that Figure 6 is a graph of $|Z_f|$ versus frequency, where

as Figure 3 is a graph of X_f versus frequency.) A number of spurious responses are apparent in Figure 6. The manufacturers state that spurious responses are more prevalent in the lower frequency resonators (kHz range) than in the higher frequency units (MHz range). For our purposes only the MHz range ceramics need to be considered.

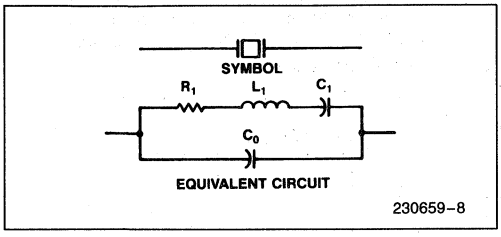


Figure 7. Ceramic Resonator: Symbol and Equivalent Circuit

Figure 7 shows the symbol and equivalent circuit for the ceramic resonator, both of which are the same as for the crystal. The parameters have different values, however, as listed in Table 2.

Table 2. Typical Ceramic Parameters

Frequency MHz	R_1 ohms	L_1 mH	C_1 pF	C_0 pF
3.58	7	0.113	19.6	140
6.0	8	0.094	8.3	60
8.0	7	0.092	4.6	40
11.0	10	0.057	3.9	30

Note that the motional arm of the ceramic resonator tends to have less resistance than the quartz crystal and also a vastly reduced L_1/C_1 ratio. This results in the motional arm having a Q (given by $(1/R_1)\sqrt{L_1/C_1}$) that is typically two orders of magnitude lower than that of a quartz crystal. The lower Q makes for a faster startup of the oscilaltor and for a less closely controlled frequency (meaning that circuitry external to the resonator will have more influence on the frequency than with a quartz crystal).

Another major difference is that the shunt capacitance of the ceramic resonator is an order of magnitude higher than C_0 of the quartz crystal and more dependent on the frequency of the resonator.

The implications of these differences are not all obvious, but some will be indicated in the section on Oscillator Calculations.

Specifications for Ceramic Resonators

Ceramic resonators are easier to specify than quartz crystals. All the vendor wants to know is the desired frequency and the chip you want it to work with. They'll supply the resonators, a circuit diagram showing the positions and values of other external components that may be required and a guarantee that the circuit will work properly at the specified frequency.

OSCILLATOR DESIGN CONSIDERATIONS

Designers of microcontroller systems have a number of options to choose from for clocking the system. The main decision is whether to use the "on-chip" oscillator or an external oscillator. If the choice is to use the on-chip oscillator, what kinds of external components are needed to make it operate as advertised? If the choice is to use an external oscillator, what type of oscillator should it be?

The decisions have to be based on both economic and technical requirements. In this section we'll discuss some of the factors that should be considered.

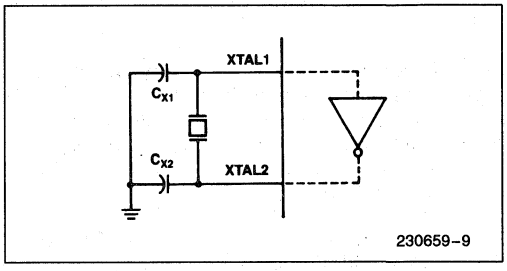


Figure 8. Using the "On-Chip" Oscillator

On-Chip Oscillators

In most cases, the on-chip amplifier with the appropriate external components provides the most economical solution to the clocking problem. Exceptions may arise in severe environments when frequency tolerances are tighter than about 0.01%.

The external components that need to be added are a positive reactance (normally a crystal or ceramic resonator) and the two capacitors C_{X1} and C_{X2}, as shown in Figure 8.

Crystal Specifications

Specifications for an appropriate crystal are not very critical, unless the frequency is. *Any* fundamental-mode crystal of medium or better quality can be used.

We are often asked what maximum crystal resistance should be specified. The best answer to this question is the lower the better, but use what's available. The crystal resistance will have some effect on start-up time and steady-state amplitude, but not so much that it can't be compensated for by appropriate selection of the capacitances C_{X1} and C_{X2}.

Similar questions are asked about specifications of load capacitance and shunt capacitance. The best advice we can give is to understand what these parameters mean and how they affect the operation of the circuit (that being the purpose of this Application Note), and then decide for yourself if such specifications are meaningful in your application or not. Normally, they're not, unless your frequency tolerances are tighter than about 0.1%.

Part of the problem is that crystal manufacturers are accustomed to talking "ppm" tolerances with radio engineers and simply won't take your order until you've filled out their list of specifications. It will help if you define your actual frequency tolerance requirements, both for yourself and to the crystal manufacturer. Don't pay for 0.003% crystals if your actual frequency tolerance is 1%.

Oscillation Frequency

The oscillation frequency is determined 99.5% by the crystal and up to about 0.5% by the circuit external to the crystal. The on-chip amplifier has little effect on the frequency, which is as it should be, since the amplifier parameters are temperature and process dependent.

The influence of the on-chip amplifier on the frequency is by means of its input and output (pin-to-ground) capacitances, which parallel C_{X1} and C_{X2}, and the XTAL1-to-XTAL2 (pin-to-pin) capacitance, which parallels the crystal. The input and pin-to-pin capacitances are about 7 pF each. Internal phase deviations from the nominal 180° can be modeled as an output capacitance of 25 to 30 pF. These deviations from the ideal have less effect in the positive reactance oscillator (with the inverting amplifer) than in a comparable series resonant oscillator (with the noninverting amplifier) for two reasons: first, the effect of the output capacitance is lessened, if not swamped, by the off-chip capacitor; secondly, the positive reactance oscillator is less sensitive, frequency-wise, to such phase errors.

Selection of C_{X1} and C_{X2}

Optimal values for the capacitors C_{X1} and C_{X2} depend on whether a quartz crystal or ceramic resonator is being used, and also on application-specific requirements on start-up time and frequency tolerance.

Start-up time is sometimes more critical in microcontroller systems than frequency stability, because of various reset and initialization requirements.

Less commonly, accuracy of the oscillator frequency is also critical, for example, when the oscillator is being used as a time base. As a general rule, fast start-up and stable frequency tend to pull the oscillator design in opposite directions.

Considerations of both start-up time and frequency stability over temperature suggest that C_{X1} and C_{X2} should be about equal and at least 20 pF. (But they don't *have* to be either.) Increasing the value of these capacitances above some 40 or 50 pF improves frequency stability. It also tends to increase the start-up time. There is a maximum value (several hundred pF, depending on the value of R_1 of the quartz or ceramic resonator) above which the oscillator won't start up at all.

If the on-chip amplifier is a simple inverter, such as in the 8051, the user can select values for C_{X1} and C_{X2} between some 20 and 100 pF, depending on whether start-up time or frequency stability is the more critical parameter in a specific application. If the on-chip amplifier is a Schmitt Trigger, such as in the 8048, smaller values of C_{X1} must be used (5 to 30 pF), in order to prevent the oscillator from running in a relaxation mode.

Later sections in this Application Note will discuss the effects of varying C_{X1} and C_{X2} (as well as other parameters), and will have more to say on their selection.

Placement of Components

Noise glitches arriving at XTAL1 or XTAL2 pins at the wrong time can cause a miscount in the internal clock-generating circuitry. These kinds of glitches can be produced through capacitive coupling between the oscillator components and PCB traces carrying digital signals with fast rise and fall times. For this reason, the oscillator components should be mounted close to the chip and have short, direct traces to the XTAL1, XTAL2, and VSS pins.

Clocking Other Chips

There are times when it would be desirable to use the on-chip oscillator to clock other chips in the system.

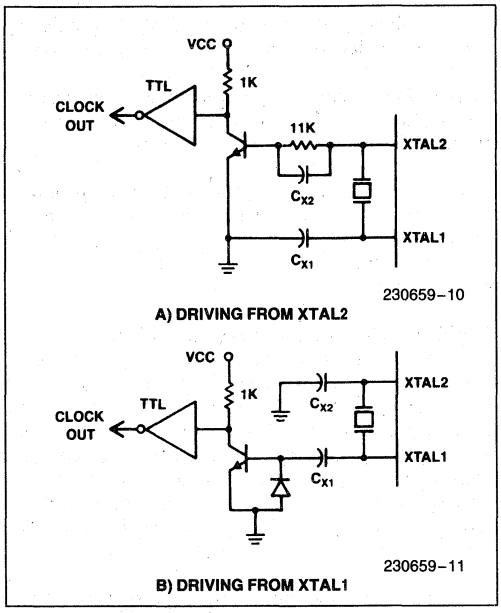


Figure 9. Using the On-Chip Oscillator to Drive Other Chips

This can be done if an appropriate buffer is used. A TTL buffer puts too much load on the on-chip amplifier for reliable start-up. A CMOS buffer (such as the 74HC04) can be used, if it's fast enough and if its VIH and VIL specs are compatible with the available signal amplitudes. Circuits such as shown in Figure 9 might also be considered for these types of applications.

Clock-related signals are available at the TO pin in the MCS-48 products, at ALE in the MCS-48 and MCS-51 lines, and the iACX-96 controllers provide a CLKOUT signal.

External Oscillators

When technical requirements dictate the use of an external oscillator, the external drive requirements for the microcontroller, as published in the data sheet, must be carefully noted. The logic levels are not in general TTL-compatible. And each controller has its idiosyncracies in this regard. The 8048, for example, requires that both XTAL1 and XTAL2 be driven. The 8051 *can* be driven that way, but the data sheet suggest the simpler method of grounding XTAL1 and driving XTAL2. For this method, the driving source must be capable of sinking some current when XTAL2 is being driven low.

For the external oscillator itself, there are basically two choices: ready-made and home-grown.

TTL Crystal Clock Oscillator

The HS-100, HS-200, & HS-500 all-metal package series of oscillators are TTL compatible & fit a DIP layout. Standard electrical specifications are shown below. Variations are available for special applications.

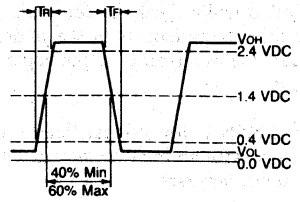
Frequency Range: HS-100—3.5 MHz to 30 MHz
HS-200—225 KHz to 3.5 MHz
HS-500—25 MHz to 60 MHz

Frequency Tolerance: ±0.1% Overall 0°C–70°C

Hermetically Sealed Package

Mass spectrometer leak rate max.
1×10^{-8} atmos. cc/sec. of helium

Output Waveform



230659-12

INPUT				
	HS-100		HS-200	HS-500
	3.5 MHz–20 MHz	20+ MHz–30 MHz	225 KHz–4.0 MHz	25 MHz–60 MHz
Supply Voltage (V_{CC})	5V ±10%	5V ±10%	5V ±10%	5V ±10%
Supply Current (I_{CC}) max.	30 mA	40 mA	85 mA	50 mA

OUTPUT				
	HS-100		HS-200	HS-500
	3.5 MHz–20 MHz	20+ MHz–30 MHz	225 KHz–4.0 MHz	25 MHz–60 MHz
V_{OH} (Logic "1")	+2.4V min.[1]	+2.7V min.[2]	+2.4V min.[1]	+2.7V min.[2]
V_{OL} (Logic "0")	+0.4V max.[3]	+0.5V max.[4]	+0.4V max.[3]	+0.5V max.[4]
Symmetry	60/40%[5]	60/40%[5]	55/45%[5]	60/40%[5]
T_R, T_F (Rise & Fall Time)	< 10 ns[6]	< 5 ns[6]	< 15 ns[6]	< 5 ns[6]
Output Short Circuit Current	18 mA min.	40 mA min.	18 mA min.	40 mA min.
Output Load	1 to 10 TTL Loads[7]	1 to 10 TTL Loads[8]	1 to 10 TTL Loads[7]	1 to 10 TTL Loads[8]

CONDITIONS

[1] I_O source = −400 μA max.
[2] I_O source = −1.0 mA max.
[3] I_O sink = 16.0 mA max.
[4] I_O sink = 20.00 mA max.
[5] V_O = 1.4V
[6] (0.4V to 2.4V)
[7] 1.6 mA per load
[8] 2.0 mA per load

Figure 10. Pre-Packaged Oscillator Data*

9

*Reprinted with the permission of © Midland-Ross Corporation 1982.

Prepackaged oscillators are available from most crystal manufacturers, and have the advantage that the system designer can treat the oscillator as a black box whose performance is guaranteed by people who carry many years of experience in designing and building oscillators. Figure 10 shows a typical data sheet for some prepackaged oscillators. Oscillators are also available with complementary outputs.

If the oscillator is to drive the microcontroller directly, one will want to make a careful comparison between the external drive requirements in the microcontroller data sheet and the oscillator's output logic levels and test conditions.

If oscillator stability is less critical than cost, the user may prefer to go with an in-house design. Not without some precautions, however.

It's easy to design oscillators that work. Almost all of them do work, even if the designer isn't too clear on why. The key point here is that *almost* all of them work. The problems begin when the system goes into production, and marginal units commence malfunctioning in the field. Most digital designers, after all, are not very adept at designing oscillators *for production.*

Oscillator design is somewhat of a black art, with the quality of the finished product being *very* dependent on the designer's experience and intuition. For that reason the most important consideration in any design is to have an adequate preproduction test program. Preproduction tests are discussed later in this Application Note. Here we will discuss some of the design options and take a look at some commonly used configurations.

Gate Oscillators versus Discrete Devices

Digital systems designers are understandably reluctant to get involved with discrete devices and their peculiarities (biasing techniques, etc.). Besides, the component count for these circuits tends to be quite a bit higher than what a digital designer is used to seeing for that amount of functionality. Nevertheless, if there are unusual requirements on the accuracy and stability of the clock frequency, it should be noted that discrete device oscillators can be tailored to suit the exact needs of the application and perfected to a level that would be difficult for a gate oscillator to approach.

In most cases, when an external oscillator is needed, the designer tends to rely on some form of a gate oscillator. A TTL inverter with a resistor connecting the output to the input makes a suitable inverting amplifier. The resistor holds the inverter in the transition region between logical high and low, so that at least for start-up purposes the inverter is a linear amplifier.

The feedback resistance has to be quite low, however, since it must conduct current sourced by the input pin without allowing the DC input voltage to get too far above the DC output voltage. For biasing purposes, the feedback resistance should not exceed a few k-ohms. But shunting the crystal with such a low resistance does not encourage start-up.

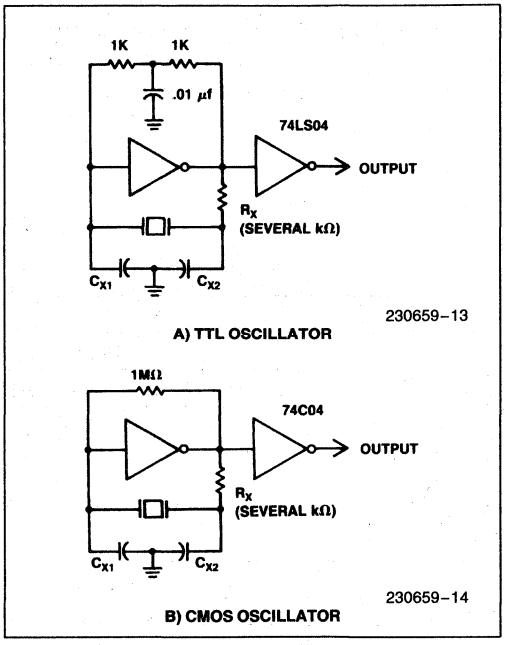


Figure 11. Commonly Used Gate Oscillators

Consequently, the configuration in Figure 11A might be suggested. By breaking R_f into two parts and AC-grounding the midpoint, one achieves the DC feedback required to hold the inverter in its active region, but without the negative signal feedback that is in effect telling the circuit *not* to oscillate. However, this biasing scheme will increase the start-up time, and relaxation-type oscillations are also possible.

A CMOS inverter, such as the 74HC04, might work better in this application, since a larger R_f can be used to hold the inverter in its linear region.

Logic gates tend to have a fairly low output resistance, which destabilizes the oscillator. For that reason a resistor Rx is often added to the feedback network, as shown in Figures 11A and B. At higher frequencies a 20 or 30 pF capacitor is sometimes used in the Rx position, to compensate for some of the internal propagation delay.

Reference 1 contains an excellent discussion of gate oscillators, and a number of design examples.

Fundamental versus Overtone Operation

It's easier to design an oscillator circuit to operate in the resonator's fundamental response mode than to design one for overtone operation. A quartz crystal whose fundamental response mode covers the desired frequency can be obtained up to some 30 MHz. For frequencies above that, the crystal might be used in an overtone mode.

Several problems arise in the design of an overtone oscillator. One is to stop the circuit from oscillating in the fundamental mode, which is what it would really rather do, for a number of reasons, involving both the amplifying device and the crystal. An additional problem with overtone operation is an increased tendency to spurious oscillations. That is because the R_1 of various spurious modes is likely to be about the same as R_1 of the intended overtone response. It may be necessary, as suggested in Reference 1, to specify a "spurious-to-main-response" resistance ratio to avoid the possibility of trouble.

Overtone oscillators are not to be taken lightly. One would be well advised to consult with an engineer who is knowledgeable in the subject during the design phase of such a circuit.

Series versus Parallel Operation

Series resonant oscillators use noninverting amplifiers. To make a noninverting amplifier out of logic gates requires that two inverters be used, as shown in Figure 12.

This type of circuit tends to be inaccurate and unstable in frequency over variations in temperature and V_{CC}. It has a tendency to oscillate at overtones, and to oscillate through C_0 of the crystal or some stray capacitance rather than as controlled by the mechanical resonance of the crystal.

The demon in series resonant oscillators is the phase shift in the amplifier. The series resonant oscillator wants more than just a "noninverting" amplifier—it wants a *zero phase-shift* amplifier. Multistage noninverting amplifiers tend to have a considerably lagging phase shift, such that the crystal reactance must be capacitive in order to bring the total phase shift around the feedback loop back up to 0. In this mode, a "12 MHz" crystal may be running at 8 or 9 MHz. One can put a capacitor in series with the crystal to relieve the crystal of having to produce all of the required phase shift, and bring the oscillation frequency closer to fs. However, to further complicate the situation, the amplifier's phase shift is strongly dependent on frequency, temperature, VCC, and device sample.

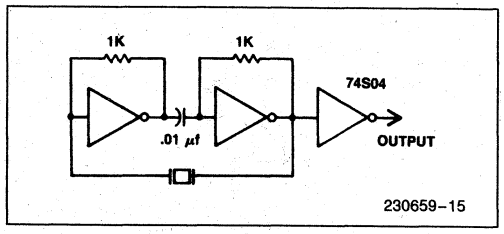


Figure 12. "Series Resonant" Gate Oscillator

Positive reactance oscillators ("parallel resonant") use inverting amplifiers. A single logic inverter can be used for the amplifier, as in Figure 11. The amplifier's phase shift is less critical, compared to a series resonant circuit, and since only one inverter is involved there's less phase error anyway. The oscillation frequency is effectively bounded by the resonant and antiresonant frequencies of the crystal itself. In addition, the feedback network includes capacitors that parallel the input and output terminals of the amplifier, thus reducing the effect of unpredictable capacitances at these points.

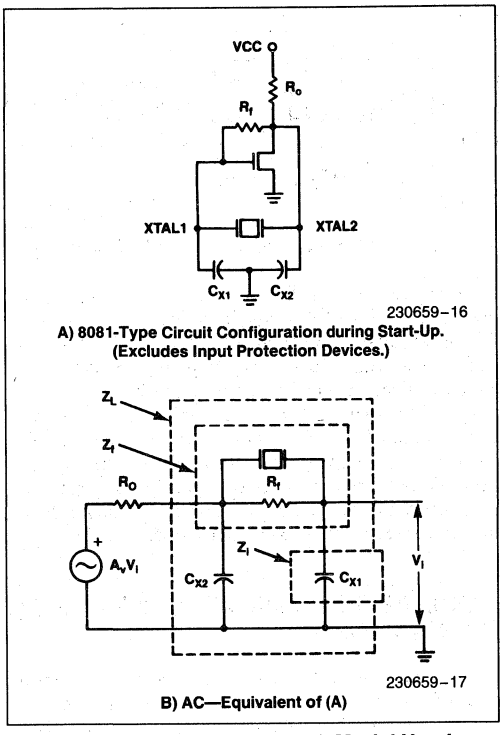
MORE ABOUT USING THE "ON-CHIP" OSCILLATORS

In this section we will describe the on-chip inverters on selected microcontrollers in some detail, and discuss criteria for selecting components to work with them. Future data sheets will supplement this discussion with updates and information pertinent to the use of each chip's oscillator circuitry.

Oscillator Calculations

Oscillator design, though aided by theory, is still largely an empirical exercise. The circuit is inherently nonlinear, and the normal analysis parameters vary with instantaneous voltage. In addition, when dealing with the on-chip circuitry, we have FETs being used as resistors, resistors being used as interconnects, distributed delays, input protection devices, parasitic junctions, and processing variations.

Consequently, oscillator calculations are never very precise. They can be useful, however, if they will at least indicate the effects of *variations* in the circuit parameters on start-up time, oscillation frequency, and steady-state amplitude. Start-up time, for example, can be taken as an indication of start-up reliability. If preproduction tests indicate a possible start-up problem, a relatively inexperienced designer can at least be made aware of what parameter may be causing the marginality, and what direction to go in to fix it.



A) 8081-Type Circuit Configuration during Start-Up. (Excludes Input Protection Devices.)

B) AC—Equivalent of (A)

Figure 13. Oscillator Circuit Model Used in Start-Up Calculations

The analysis used here is mathematically straightforward but algebraically intractable. That means it's relatively easy to understand and program into a computer, but it will not yield a neat formula that gives, say, steady-state amplitude as a function of this or that list of parameters. A listing of a BASIC program that implements the analysis will be found in Appendix II.

When the circuit is first powered up, and before the oscillations have commenced (and if the oscillations *fail* to commence), the oscillator can be treated as a small signal linear amplifier with feedback. In that case, standard small-signal analysis techniques can be used to determine start-up characteristics. The circuit model used in this analysis is shown in Figure 13.

The circuit approximates that there are no high-frequency effects within the amplifier itslef, such that its high-frequency behavior is dominated by the load impedance Z_L. This is a reasonable approximation for single-stage amplifiers of the type used in 8051-type devices. Then the gain of the amplifier as a function of frequency is

$$A = \frac{A_V Z_L}{Z_L + R_0}$$

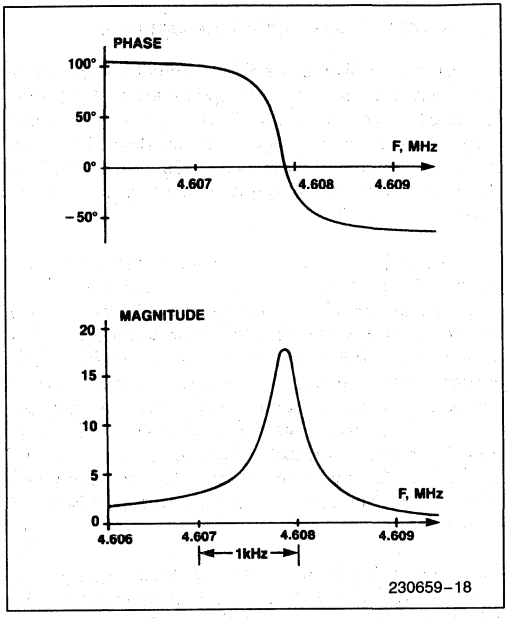


Figure 14. Loop Gain versus Frequency (4.608 MHz Crystal)

The gain of the feedback network is

$$\beta = \frac{Z_i}{Z_i + Z_f}$$

And the loop gain is

$$\beta A = \frac{Z_i}{Z_i + Z_f} \times \frac{A_V Z_L}{Z_L + R_0}$$

The impedances Z_L, Z_f, and Z_i are defined in Figure 13B.

Figure 14 shows the way the loop gain thus calculated (using typical 8051-type parameters and a 4.608 MHz crystal) varies with frequency. The frequency of interest is the one for which the phase of the loop gain is zero. The accepted criterion for start-up is that the magnitude of the loop gain must exceed unity at this frequency. This is the frequency at which the circuit is in resonance. It corresponds very closely with the antiresonant frequency of the motional arm of the crystal in parallel with C_L.

Figure 15 shows the way the loop gain varies with frequency when the parameters of a 3.58 MHz ceramic resonator are used in place of a crystal (the amplifier parameters being typical 8051, as in Figure 14). Note the different frequency scales.

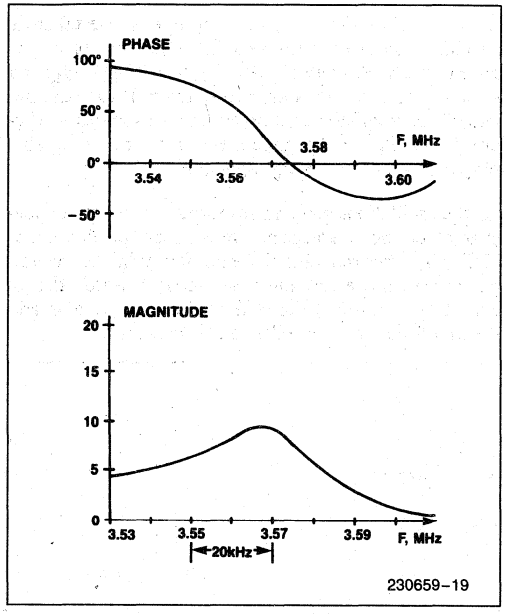


Figure 15. Loop Gain versus Frequency (3.58 MHz Ceramic)

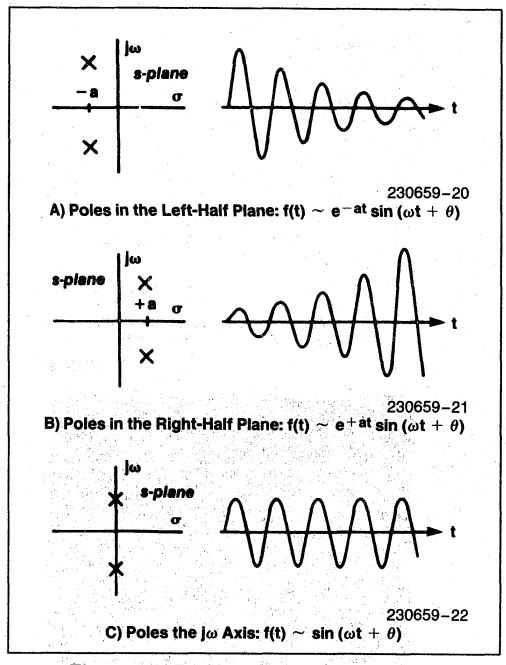


Figure 16. Do You Know Where Your Poles Are Tonight?

Start-Up Characteristics

It is common, in studies of feedback systems, to examine the behavior of the closed loop gain as a function of complex frequency $s = \sigma + j\omega$; specifically, to determine the location of its poles in the complex plane. A pole is a point on the complex plane where the gain function goes to infinity. Knowledge of its location can be used to predict the response of the system to an input disturbance.

The way that the response function depends on the location of the poles is shown in Figure 16. Poles in the left-half plane cause the response function to take the form of a damped sinusoid. Poles in the right-half plane cause the response function to take the form of an exponentially growing sinusoid. In general,

$$v(t) \sim e^{at} \sin(\omega t + \theta)$$

where a is the real part of the pole frequency. Thus if the pole is in the right-half plane, a is positive and the sinusoid grows. If the pole is in the left-half plane, a is negative and the sinusoid is damped.

The same type of analysis can usefully be applied to oscillators. In this case, however, rather than trying to ensure that the poles are in the left-half plane, we would seek to ensure that they're in the *right*-half plane. An exponentially growing sinusoid is exactly what is wanted from an oscillator that has just been powered up.

The gain function of interest in oscillators is $1/(1 - \beta A)$. Its poles are at the complex frequencies where $\beta A = 1\angle 0°$, because that value of βA causes the gain function to go to infinity. The oscillator will start up if the real part of the pole frequency is positive. More importantly, the *rate* at which it starts up is indicated by how *much* greater than 0 the real part of the pole frequency is.

The circuit in Figure 13B can be used to find the pole frequencies of the oscillator gain function. All that needs to be done is evaluate the impedances at complex frequencies $\sigma + j\omega$ rather than just at ω, and find the value of $\sigma + j\omega$ for which $\beta A = 1\angle 0°$. The larger that value of σ is, the faster the oscillator will start up.

Of course, other things besides pole frequencies, things like the VCC rise time, are at work in determining the start-up time. But to the extend that the pole frequencies *do* affect start-up time, we can obtain results like those in Figures 17 and 18.

To obtain these figures the pole frequencies were computed for various values of capacitance C_X from XTAL1 and XTAL2 to ground (thus $C_{X1} = C_{X2} = C_X$). Then a "time constant" for start-up was calculated as $T_s = \frac{1}{\sigma}$ where σ is the real part of the pole frequency (rad/sec), and this time constant is plotted versus C_X.

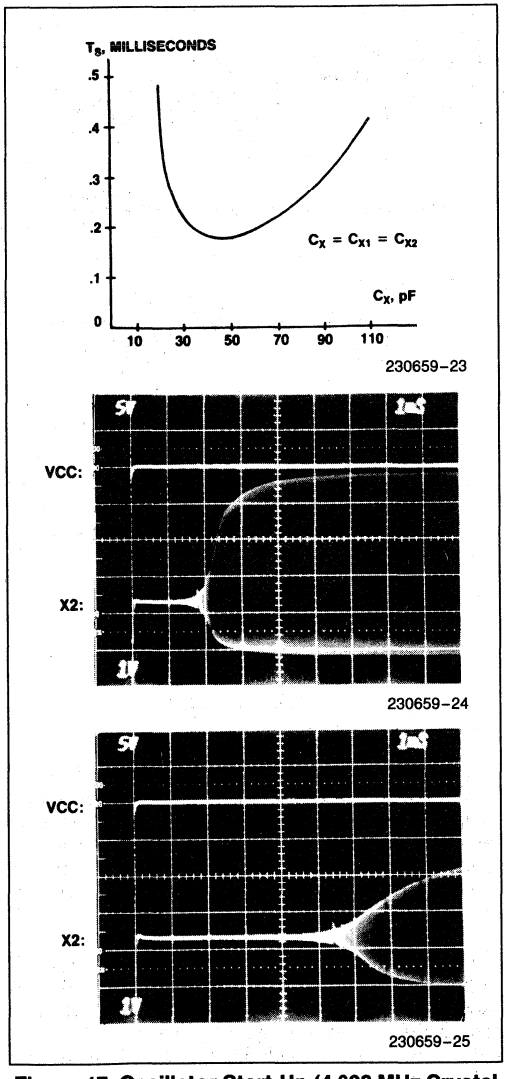


Figure 17. Oscillator Start-Up (4.608 MHz Crystal from Standard Crystal Corp.)

A short time constant means faster start-up. A long time constant means slow start-up. Observations of actual start-ups are shown in the figures. Figure 17 is for a typical 8051 with a 4.608 MHz crystal supplied by Standard Crystal Corp., and Figure 18 is for a typical 8051 with a 3.58 MHz ceramic resonator supplied by NTK Technical Ceramics, Ltd.

It can be seen in Figure 17 that, for this crystal, values of C_X between 30 and 50 pF minimize start-up time, but that the exact value in this range is not particularly important, even if the start-up time itself is critical.

As previously mentioned, start-up time can be taken as an indication of start-up reliability. Start-up problems are normally associated with C_{X1} and C_{X2} being too small or too large for a given resonator. If the parameters of the resonator are known, curves such as in Figure 17 or 18 can be generated to define acceptable ranges of values for these capacitors.

As the oscillations grow in amplitude, they reach a level at which they undergo severe clipping within the amplifier, in effect reducing the amplifier gain. As the amplifier gain decreases, the poles move towards the jω axis. In steady-state, the poles are on the jω axis and the amplitude of the oscillations is constant.

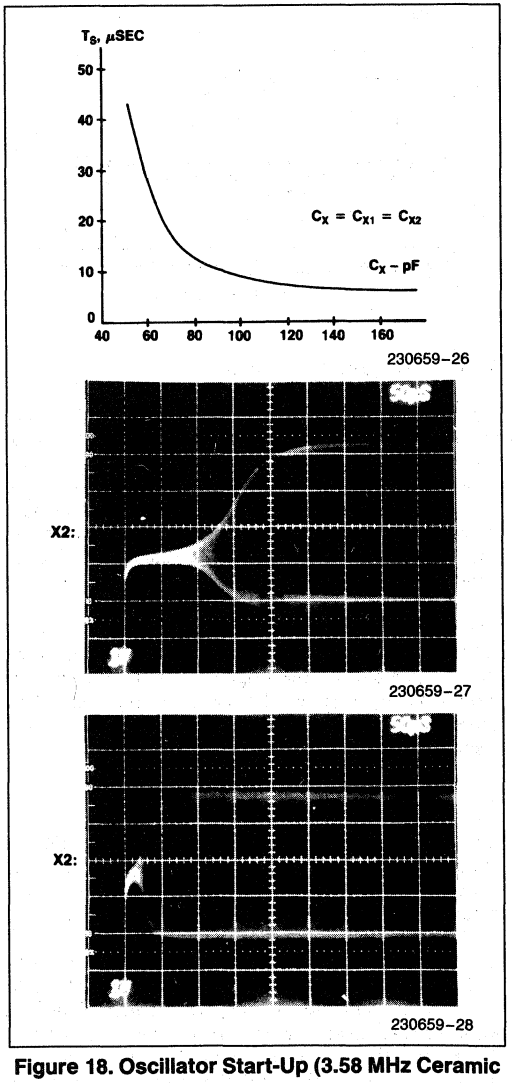
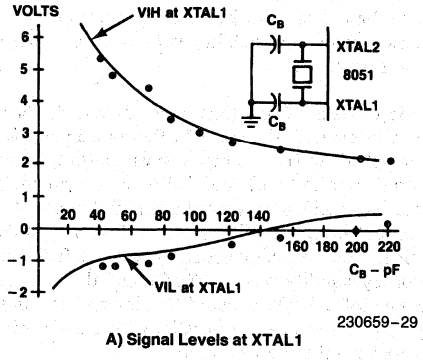
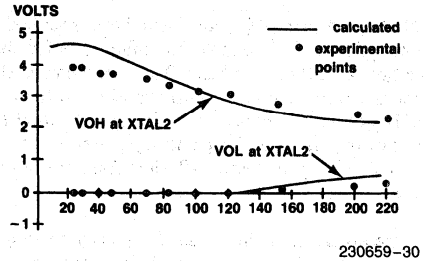


Figure 18. Oscillator Start-Up (3.58 MHz Ceramic Resonator from NTK Technical Ceramics)



A) Signal Levels at XTAL1



B) Signal Levels at XTAL2

Figure 19. Calculated and Experimental Steady-State Amplitudes vs. Bulk Capacitance from XTAL1 and XTAL2 to Ground

Steady-State Characteristics

Steady-state analysis is greatly complicated by the fact that we are dealing with large signals and nonlinear circuit response. The circuit parameters vary with instantaneous voltage, and a number of clamping and clipping mechanisms come into play. Analyses that take all these things into account are too complicated to be of general use, and analyses that don't take them into account are too inaccurate to justify the effort.

There is a steady-state analysis in Appendix B that takes some of the complications into account and ignores others. Figure 19 shows the way the steady-state amplitudes thus calculated (using typical 8051 parameters and a 4.608 MHz crystal) vary with equal bulk capacitance placed from XTAL1 and XTAL2 to ground. Experimental results are shown for comparison.

The waveform at XTAL1 is a fairly clean sinusoid. Its negative peak is normally somewhat below zero, at a level which is determined mainly by the input protection circuitry at XTAL1.

The input protection circuitry consists of an ohmic resistor and an enhancement-mode FET with the gate and source connected to ground (VSS), as shown in Figure 20 for the 8051, and in Figure 21 for the 8048. Its function is to limit the positive voltage at the gate of the input FET to the avalanche voltage of the drain junction. If the input pin is driven below VSS, the drain and source of the protection FET interchange roles, so its gate is connected to what is now the drain. In this condition the device resembles a diode with the anode connected to VSS.

There is a parasitic pn junction between the ohmic resistor and the substrate. In the ROM parts (8015, 8048, etc.) the substrate is held at approximately −3V by the on-chip back-bias generator. In the EPROM parts (8751, 8748, etc.) the substrate is connected to VSS.

The effect of the input protection circuitry on the oscillator is that if the XTAL1 signal goes negative, its negative peak is clamped to $-V_{DS}$ of the protection FET in the ROM parts, and to about −0.5V in the EPROM parts. These negative voltages on XTAL1 are in this application self-limiting and nondestructive.

The clamping action does, however, raise the DC level at XTAL1, which in turn tends to reduce the positive peak at XTAL2. The waveform at XTAL2 resembles a sinusoid riding on a DC level, and whose negative peaks are clipped off at zero.

Since it's normally the XTAL2 signal that drives the internal clocking circuitry, the question naturally arises as to how large this signal must be to reliably do its job. In fact, the XTAL2 signal doesn't have to meet the same VIH and VIL specifications that an external driver would have to. That's because as long as the oscillator is working, the on-chip amplifier is driving itself through its own 0-to-1 transition region, which is very nearly the same as the 0-to-1 transition region in the internal buffer that follows the oscillator. If some processing variations move the transition level higher or lower, the on-chip amplifier tends to compensate for it by the fact that its own transition level is correspondingly higher or lower. (In the 8096, it's the XTAL1 signal that drives the internal clocking circuitry, but the same concept applies.)

The main concern about the XTAL2 signal amplitude is an indication of the general health of the oscillator. An amplitude of less than about 2.5V peak-to-peak indicates that start-up problems could develop in some units (with low gain) with some crystals (with high R_1). The remedy is to either adjust the values of C_{X1} and/or C_{X2} or use a crystal with a lower R_1.

The amplitudes at XTAL1 and XTAL2 can be adjusted by changing the ratio of the capacitors from XTAL1 and XTAL2 to ground. Increasing the XTAL2 capacitance, for example, decreases the amplitude at XTAL2 and increases the amplitude at XTAL1 by about the same amount. Decreasing both caps increases both amplitudes.

Pin Capacitance

Internal pin-to-ground and pin-to-pin capacitances at XTAL1 and XTAL2 will have some effect on the oscillator. These capacitances are normally taken to be in the range of 5 to 10 pF, but they are extremely difficult to evaluate. Any measurement of one such capacitance will necessarily include effects from the others. One advantage of the positive reactance oscillator is that the pin-to-ground capacitances are paralleled by external bulk capacitors, so a precise determination of their value is unnecessary. We would suggest that there is little justification for more precision than to assign them a value of 7 pF (XTAL1-to-ground and XTAL1-to-XTAL2). This value is probably not in error by more than 3 or 4 pF.

The XTAL2-to-ground capacitance is not entirely "pin capacitance," but more like an "equivalent output capacitance" of some 25 to 30 pF, having to include the effect of internal phase delays. This value will vary to some extent with temperature, processing, and frequency.

MCS®-51 Oscillator

The on-chip amplifier on the HMOS MCS-51 family is shown in Figure 20. The drain load and feedback "resistors" are seen to be field-effect transistors. The drain load FET, R_D, is typically equivalent to about 1K to 3 K-ohms. As an amplifier, the low frequency voltage gain is normally between -10 and -20, and the output resistance is effectively R_D.

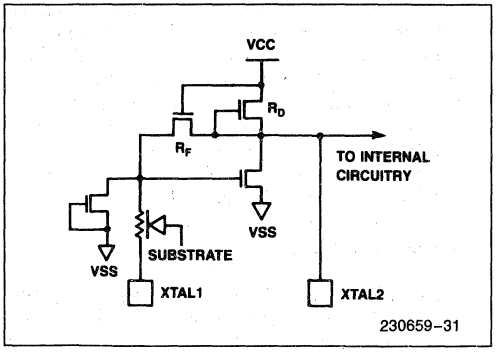


Figure 20. MCS®-51 Oscillator Amplifier

The 80151 oscillator is normally used with equal bulk capacitors placed externally from XTAL1 to ground and from XTAL2 to ground. To determine a reasonable value of capacitance to use in these positions, given a crystal of ceramic resonator of known parameters, one can use the BASIC analysis in Appendix II to generate curves such as in Figures 17 and 18. This procedure will define a range of values that will minimize start-up time. We don't suggest that smaller values be used than those which minimize start-up time. Larger values than those can be used in applications where increased frequency stability is desired, at some sacrifice in start-up time.

Standard Crystal Corp. (Reference 8) studied the use of their crystals with the MCS-51 family using skew sample supplied by Intel. They suggest putting 30 pF capacitors from XTAL1 and XTAL2 to ground, if the crystal is specified as described in Reference 8. They noted that in that configuration and with crystals thus specified, the frequency accuracy was $\pm 0.01\%$ and the frequency stability was $\pm 0.005\%$, and that a frequency accuracy of $\pm 0.005\%$ could be obtained by substituting a 25 pF fixed cap in parallel with a 5–20 pF trimmer for one of the 30 pF caps.

MCS-51 skew samples have also been supplied to a number of ceramic resonator manufacturers for characterization with their products. These companies should be contacted for application information on their products. In general, however, ceramics tend to want somewhat larger values for C_{X1} and C_{X2} than quartz crystals do. As shown in Figure 18, they start up a lot faster that way.

In some application the actual frequency tolerance required is only 1% or so, the user being concerned mainly that the circuit *will* oscillate. In that case, C_{X1} and C_{X2} can be selected rather freely in the range of 20 to 80 pF.

As you can see, "best" values for these components and their tolerances are strongly dependent on the application and its requirements. In any case, their suitability should be verified by environmental testing before the design is submitted to production.

MCS®-48 Oscillator

The NMOS and HMOS MCS-48 oscillator is shown in Figure 21. It differs from the 8051 in that its inverting

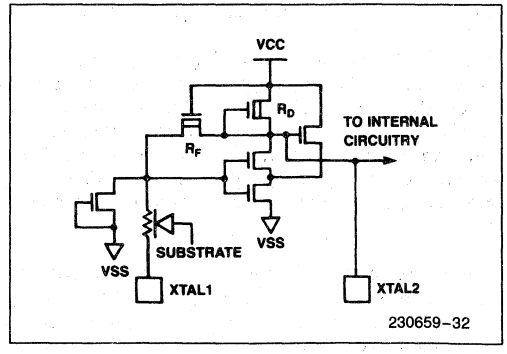


Figure 21. MCS®-48 Oscillator Amplifier

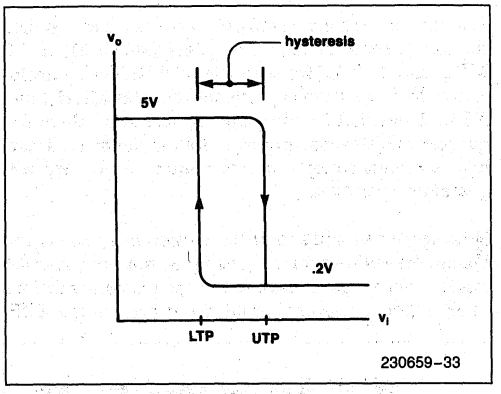


Figure 22. Schmitt Trigger Characteristic

amplifier is a Schmitt Trigger. This configuration was chosen to prevent crosstalk from the TO pin, which is adjacent to the XTAL1 pin.

All Schmitt Trigger circuits exhibit a hysteresis effect, as shown in Figure 22. The hysteresis is what makes it less sensitive to noise. The same hysteresis allows any Schmitt Trigger to be used as a relaxation oscillator. All you have to do is connect a resistor from output to input, and a capacitor from input to ground, and the circuit oscillates in a relaxation mode as follows.

If the Schmitt Trigger output is at a logic high, the capacitor commences charging through the feedback resistor. When the capacitor voltage reaches the upper trigger point (UTP), the Schmitt Trigger output switches to a logic low and the capacitor commences discharging through the same resistor. When the capacitor voltage reaches the lower trigger point (LTP), the Schmitt Trigger output switches to a logic high again, and the sequence repeats. The oscillation frequency is determined by the RC time constant and the hysteresis voltage, UTP-LTP.

The 8048 can oscillate in this mode. It has an internal feedback resistor. All that's needed is an external capacitor from XTAL1 to ground. In fact, if a smaller external feedback resistor is added, an 8048 system could be designed to run in this mode. *Do it at your own risk!* This mode of operation is not tested, specified, documented, or encouraged in any way by Intel for the 8048. Future steppings of the device might have a different type of inverting amplifier (one more like the 8051). The CHMOS members of the MCS-48 family do not use a Schmitt Trigger as the inverting amplifier.

Relaxation oscillations in the 8048 must be avoided, and this is the major objective in selecting the off-chip components needed to complete the oscillator circuit.

When an 8048 is powered up, if VCC has a short rise time, the relaxation mode starts first. The frequency is normally about 50 KHz. The resonator mode builds more slowly, but it eventually takes over and dominates the operation of the cirucit. This is shown in Figure 23A.

Due to processing variations, some units seem to have a harder time coming out of the relaxation mode, particularly at low temperatures. In some cases the resonator oscillations may fail entirely, and leave the device in the relaxation mode. Most units will stick in the relaxation mode at any temperature if C_{X1} is larger than about 50 pF. Therefore, C_{X1} should be chosen with some care, particularly if the system must operate at lower temperatures.

One method that has proven effective in all units to $-40°C$ is to put 5 pF from XTAL1 to ground and 20 pF from XTAL2 to ground. Unfortunately, while this method does discourage the relaxation mode, it is not an optimal choice for the resonator mode. For one thing, it does not swamp the pin capacitance. Also, it makes for a rather high signal level at XTAL1 (8 or 9 volts peak-to-peak).

The question arises as to whether that level of signal at XTLA1 might damage the chip. Not to worry. The negative peaks are self-limiting and nondestructive. The positive peaks could conceivably damage the oxide, but in fact, NMOS chips (eg, 8048) and HMOS chips (eg, 8048H) are tested to a much higher voltage than that. The technology trend, of course, is to thinner oxides, as the devices shrink in size. For an extra margin of safety, the HMOS II chips (eg, 8048AH) have an internal diode clamp at XTAL1 to VCC.

In reality, C_{X1} doesn't have to be quite so small to avoid relaxation oscillations, if the minimum operating temperature is not $-40°C$. For less severe temperature requirements, values of capacitance selected in much the same way as for an 8051 can be used. The circuit should be tested, however, at the system's lowest temperature limit.

Additional security against relaxation oscillations can be obtained by putting a 1M-ohm (or larger) resistor from XTAL1 to VCC. Pulling up the XTAL1 pin this way seems to discourage relaxation oscillations as effectively as any other method (Figure 23B).

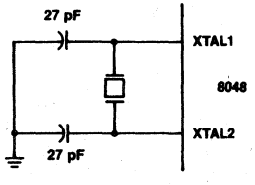
Another thing that discourages relaxation oscillations is low VCC. The resonator mode, on the other hand is much less sensitive to VCC. Thus if VCC comes up relatively slowly (several milliseconds rise time), the resonator mode is normally up and running before the relaxation mode starts (in fact, before VCC has even reached operating specs). This is shown in Figure 23C.

A secondary effect of the hysteresis is a shift in the oscillation frequency. At low frequencies, the output signal from an inverter without hysteresis leads (or lags) the input by 180 degrees. The hysteresis in a Schmitt Trigger, however, causes the output to lead the

input by less than 180 degrees (or lag by more than 180 degrees), by an amount that depends on the signal amplitude, as shown in Figure 24. At higher frequencies, there are additional phase shifts due to the various reactances in the circuit, but the phase shift due to the hysteresis is still present. Since the total phase shift in the oscillator's loop gain is necessarily 0 or 360 degrees, it is apparent that as the oscillations build up, the frequency has to change to allow the reactances to compensate for the hysteresis. In normal operation, this additional phase shift due to hysteresis does not exceed a few degrees, and the resulting frequency shift is negligible.

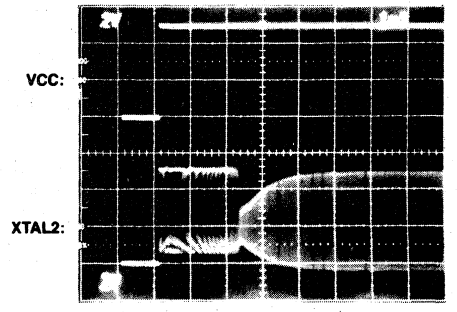
Kyocera, a ceramic resonator manufacturer, studied the use of some of their resonators (at 6.0 MHz, 8.0 MHz, and 11.0 MHz) with the 8049H. Their conclusion as to the value of capacitance to use at XTAL1 and XTAL2 was that 33 pF is appropriate at all three frequencies. One should probably follow the manufacturer's recommendations in this matter, since they will guarantee operation.

Whether one should accept these recommendations and guarantees without further testing is, however, another matter. Not all users have found the recommendations to be without occasional problems. If you run into diffi-



230659-34

A) When VCC Comes Up Fast, Relaxation Oscillations Start First. But Then the Crystal Takes Over.



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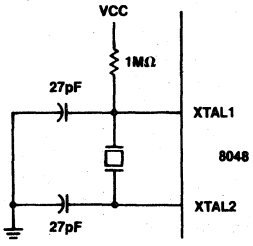

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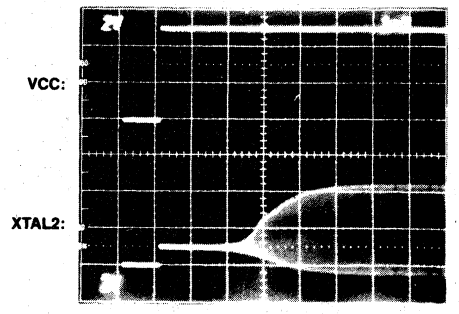
B) Weak Pullup (1 MΩ or More) on XTAL1 Discourages Relaxation Mode.



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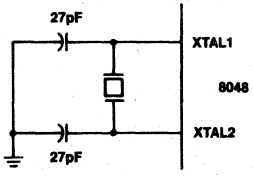

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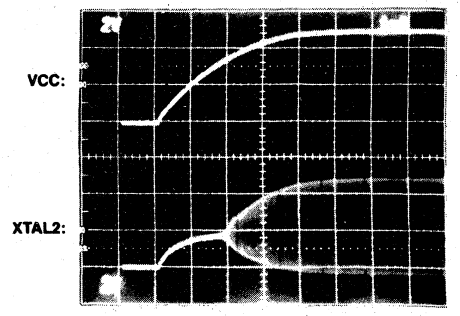
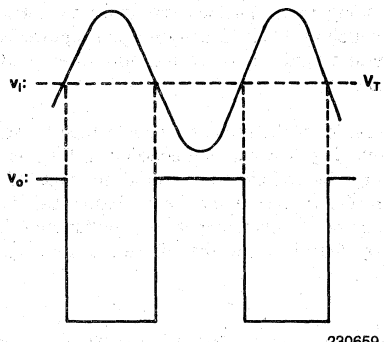
C) No Relaxation Oscillations When VCC Comes Up More Slowly.



230659-39

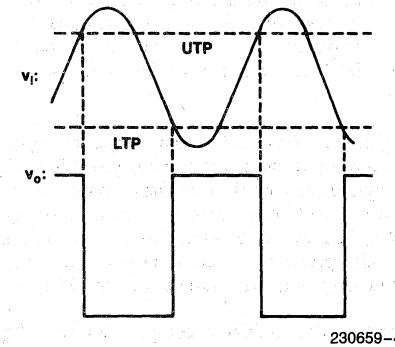
Figure 23. Relaxation Oscillations in the 8048

culties using their recommendations, both Intel and the ceramic resonator manufacturer want to know about it. It is to their interest, and ours, that such problems be resolved.



230659-40

A) Inverter Without Hysteresis: Output Leads Input by 180°.



230659-41

B) Inverter With Hysteresis: Output Leads Input by Less than 180°.

Figure 24. Amplitude—Dependent Phase Shift in Schmitt Trigger

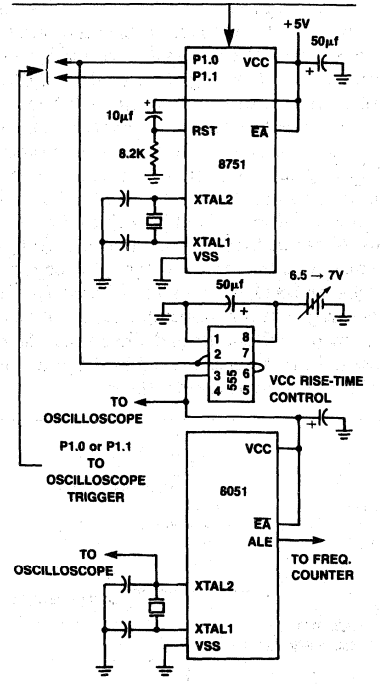
Preproduction Tests

An oscillator design should never be considered ready for production until it has proven its ability to function acceptably well under worst-case environmental conditions and with parameters at their worst-case tolerance limits. Unexpected temperature effects in parts that may already be near their tolerance limits can prevent start-up of an oscillator that works perfectly well on the bench. For example, designers often overlook temperature effects in ceramic capacitors. (Some ceramics are down to 50% of their room-temperature values at −20°C and +60°C). The problem here isn't just one of frequency stability, but also involves start-up time and steady-state amplitude. There may also be temperature effects in the resonator and amplifier.

It will be helpful to build a test jig that will allow the oscillator circuit to be tested independently of the rest of the system. Both start-up and steady-state characteristics should be tested. Figure 25 shows the circuit that

A) Software for Oscillator Test

```
SOURCE
ORG 0000 H
        JMP   START
ORG 000B H                ;TIMER 0 INTERRUPT:
        CPL   T1          ;  TOGGLE T1
        RETI
ORG 001BH                 ;TIMER 1 INTERRUPT:
        CPL   P1.1        ;  TOGGLE CRO TRIGGER
        DJNZ  P2,$        ;  DELAY
        CPL   P1.0        ;  TOGGLE VCC CONTROL
        RETI
START:  MOV   TH1,#0FAH ;TIMER 1 RELOAD VALUE
        MOV   TL1,#0FAH ;START TL1 AT RELOAD VALUE
        MOV   TMOD,#61H ;TIMER 1 TO COUNTER, AUTO
                        ;RELOAD
                        ;TIMER 0 TO TIMER, 16-BIT
        MOV   IE,#BAH   ;ENABLE TIMER INTERRUPTS
                        ;ONLY
        MOV   TCON,#50H ;TURN ON BOTH TIMERS
        JMP   $         ;IDLE
END
```



230659-42

B) Oscillator Test Circuit (Shown for 8051 Test)

Figure 25. Oscillator Test Circuit and Software

9

was used to obtain the oscillator start-up photographs in this Application Note. This circuit or a modified version of it would make a convenient test vehicle. The oscillator and its relevant components can be physically separated from the control circuitry, and placed in a temperature chamber.

Start-up should be observed under a variety of conditions, including low VCC and using slow and fast VCC rise times. The oscillator should not be reluctant to start up even when VCC is below its spec value for the rest of the chip. (The rest of the chip may not function, but the oscillator should work.) It should also be verified that start-up occurs when the resonator has more than its upper tolerance limit of series resistance. (Put some resistance in series with the resonator for this test.) The bulk capacitors from XTAL1 and XTAL2 to ground should also be varied to their tolerance limits.

The same circuit, with appropriate changes in the software to lengthen the "on" time, can be used to test the steady-state characteristics of the oscillator, specifically the frequency, frequency stability, and amplitudes at XTAL1 and XTAL2.

As previously noted, the voltage swings at these pins are not critical, but they should be checked at the system's temperature limits to ensure that they are in good health. Observing these signals necessarily changes them somewhat. Observing the signal at XTAL2 requires that the capacitor at that pin be reduced to account for the oscilloscope probe capacitance. Observing the signal at XTAL1 requires the same consideration, plus a blocking capacitor (switch the oscilloscope input to AC), so as to not disturb the DC level at that pin. Alternatively, a MOSFET buffer such as the one shown in Figure 26 can be used. It should be verified by direct measurement that the ground clip on the scope probe is ohmically connected to the scope chassis (probes are incredibly fragile in this respect), and the observations should be made with the ground clip on the VSS pin, or very close to it. If the probe shield isn't operational and in use, the observations are worthless.

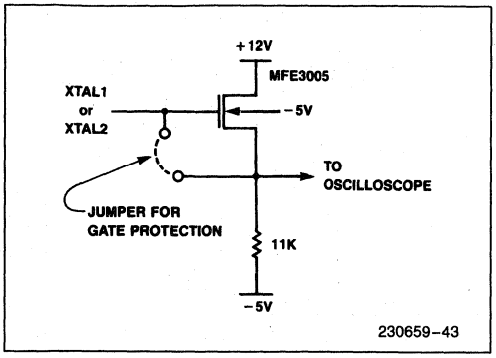


Figure 26. MOSFET Buffer for Observing Oscillator Signals

Frequency checks should be made with only the oscillator circuitry connected to XTAL1 and XTAL2. The ALE frequency can be counted, and the oscillator frequency derived from that. In systems where the frequency tolerance is only "nominal," the frequency should still be checked to ascertain that the oscillator isn't running in a spurious resonance or relaxation mode. Switching VCC off and on again repeatedly will help reveal a tendency to go into unwanted modes of oscillation.

The operation of the oscillator should then be verified under actual system running conditions. By this stage one will be able to have some confidence that the basic selection of components for the oscillator itself is suitable, so if the oscillator appears to malfunction in the system the fault is not in the selection of these components.

Troubleshooting Oscillator Problems

The first thing to consider in case of difficulty is that between the test jig and the actual application there may be significant differences in stray capacitances, particularly if the actual application is on a multi-layer board.

Noise glitches, that aren't present in the test jig but are in the application board, are another possibility. Capacitive coupling between the oscillator circuitry and other signal has already been mentioned as a source of miscounts in the internal clocking circuitry. Inductive coupling is also possible, if there are strong currents nearby. These problems are a function of the PCB layout.

Surrounding the oscillator components with "quiet" traces (VCC and ground, for example) will alleviate capacitive coupling to signals that have fast transition times. To minimize inductive coupling, the PCB layout should minimize the areas of the loops formed by the oscillator components. These are the loops that should be checked:

XTAL1 through the resonator to XTAL2;
XTAL1 through C_{X1} to the VSS pin;
XTAL2 through C_{X2} to the VSS pin.

It is not unusual to find that the grounded ends of C_{X1} and C_{X2} eventually connect up to the VSS pin only after looping around the farthest ends of the board. Not good.

Finally, it should not be overlooked that software problems sometimes imitate the symptoms of a slow-starting oscillator or incorrect frequency. Never underestimate the perversity of a software problem.

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APPENDIX A
QUARTZ AND CERAMIC RESONATOR FORMULAS

Based on the equivalent circuit of the crystal, the impedance of the crystal is

$$Z_{XTAL} = \frac{(R_1 + j\omega L_1 + 1/j\omega C_1)(1/j\omega C_0)}{R_1 + j\omega L_1 + 1/j\omega C_1 + 1/j\omega C_0}$$

After some algebraic manipulation, this calculation can be written in the form

$$Z_{XTAL} = \frac{1}{j\omega(C_1 + C_0)} \bullet \frac{1 - \omega^2 L_1 C_1 + j\omega R_1 C_1}{1 - \omega^2 L_1 C_T + j\omega R_1 C_T}$$

where C_T is the capacitance of C_1 in series with C_0:

$$C_T = \frac{C_1 C_0}{C_1 + C_0}$$

The impedance of the crystal in parallel with an external load capacitance C_L is the same expression, but with $C_0 + C_L$ substituted for C_0:

$$Z_{XTAL} \|_{CL} = \frac{1}{j\omega(C_1 + C_0 + C_L)} \bullet \frac{1 - \omega^2 L_1 C_1 + j\omega R_1 C_1}{1 - \omega^2 L_1 C'_T + j\omega R_1 C'_T}$$

where C'_T is the capacitance of C_1 in series with $(C_0 + C_L)$:

$$C'_T = \frac{C_1(C_0 + C_L)}{C_1 + C_0 + C_L}$$

The impedance of the crystal in *series* with the load capacitance is

$$Z_{XTAL + CL} = Z_{XTAL} + \frac{1}{j\omega C_L}$$

$$= \frac{C_L + C_1 + C_0}{j\omega C_L (C_1 + C_0)} \bullet \frac{1 - \omega^2 L_1 C'_T + j\omega R_1 C'_T}{1 - \omega^2 L_1 C_T + j\omega R_1 C_T}$$

where C_T and C'_T are as defined above.

The phase angles of these impedances are readily obtained from the impedance expressions themselves:

$$\theta_{XTAL} = \arctan \frac{\omega R_1 C_1}{1 - \omega^2 L_1 C_1}$$

$$- \arctan \frac{\omega R_1 C_T}{1 - \omega^2 L_1 C_T} - \frac{\pi}{2}$$

$$\theta_{XTAL \| C_L} = \arctan \frac{\omega R_1 C_1}{1 - \omega^2 L_1 C_1}$$

$$- \arctan \frac{\omega R_1 C'_T}{1 - \omega^2 L_1 C'_T} - \frac{\pi}{2}$$

$$\theta_{XTAL + C_L} = \arctan \frac{\omega R_1 C'_T}{1 - \omega^2 L_1 C'_T}$$

$$- \arctan \frac{\omega R_1 C_T}{1 - \omega^2 L_1 C_T} - \frac{\pi}{2}$$

The resonant ("series resonant") frequency is the frequency at which the phase angle is zero and the impedance is low. The antiresonant ("parallel resonant") frequency is the frequency at which the phase angle is zero and the impedance is high.

Each of the above θ-expressions contains two arctan functions. Setting the denominator of the argument of the first arctan function to zero gives (approximately) the "series resonant" frequency for that configuration. Setting the denominator of the argument of the second arctan function to zero gives (approximately) the "parallel resonant" frequency for that configuration.

For example, the resonant frequency of the crystal is the frequency at which

$$1 - \omega^2 L_1 C_1 = 0$$

Thus

$$\omega_s = \frac{1}{\sqrt{L_1 C_1}}$$

or

$$f_s = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

It will be noted that the series resonant frequency of the "XTAL + CL" configuration (crystal in series with CL) is the same as the parallel resonant frequency of the "XTAL‖CL" configuration (crystal in parallel with C_L). This is the frequency at which

$$1 - \omega^2 L_1 C'_T = 0$$

Thus

$$\omega_a = \frac{1}{\sqrt{L_1 C'_T}}$$

or

$$f_a = \frac{1}{2\pi\sqrt{L_1 C'_T}}$$

This fact is used by crystal manufacturers in the process of calibrating a crystal to a specified load capacitance.

By subtracting the resonant frequency of the crystal from its antiresonant frequency, one can calculate the range of frequencies over which the crystal reactance is positive:

$$f_a - f_s = f_s(\sqrt{1 + C_1/C_0} - 1$$

$$f_s\left(\frac{C_1}{2C_0}\right)$$

Given typical values for C_1 and C_0, this range can hardly exceed 0.5% of fs. Unless the inverting amplifier in the positive reactance oscillator is doing something very strange indeed, the oscillation frequency is bound to be accurate to that percentage whether the crystal was calibrated for series operation or to any unspecified load capacitance.

Equivalent Series Resistance

ESR is the real part of Z_{XTAL} at the oscillation frequency. The oscillation frequency is the parallel resonant frequency of the "XTAL‖CL" configuration (which is the same as the series resonant frequency of the "XTAL + CL" configuration). Substituting this frequency into the Z_{XTAL} expression yields, after some algebraic manipulation,

$$ESR = \frac{R_1\left(\frac{C_0 + C_L}{C_L}\right)^2}{1 + \omega^2 C_1^2\left(\frac{C_0 + C_L}{C_L}\right)^2}$$

$$\cong R_1\left(1 + \frac{C_0}{C_L}\right)^2$$

Drive Level

The power dissipated by the crystal is $I_1^2 R_1$, where I_1 is the RMS current in the motional arm of the crystal. This current is given by $V_x/|Z_1|$, where V_x is the RMS voltage across the crystal, and $|Z_1|$ is the magnitude of the impedance of the motional arm. At the oscillation frequency, the motional arm is a positive (inductive) reactance in parallel resonance with $(C_0 + C_L)$. Therefore $|Z_1|$ is approximately equal to the magnitude of the reactance of $(C_0 + C_L)$:

$$|Z_1| = \frac{1}{2\pi f(C_0 + C_L)}$$

where f is the oscillation frequency. Then,

$$P = I_1^2 R_1 = \left(\frac{V_x}{|Z_1|}\right)^2 R_1$$

$$= [2\pi f (C_0 + C_L) V_x]^2 R_1$$

The waveform of the voltage across the crystal (XTAL1 to XTAL2) is approximately sinusoidal. If its peak value is VCC, then V_x is $VCC/\sqrt{2}$. Therefore,

$$P = 2R_1 [\pi f (C_0 + C_L) VCC]^2$$

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APPENDIX B
OSCILLATOR ANALYSIS PROGRAM

The program is written in BASIC. BASIC is excruciatingly slow, but it has some advantages. For one thing, more people know BASIC than FORTRAN. In addition, a BASIC program is easy to develop, modify, and "fiddle around" with. Another important advantage is that a BASIC program can run on practically any small computer system.

Its slowness is a problem, however. For example, the routine which calculates the "start-up time constant" discussed in the text may take several hours to complete. A person who finds this program useful may prefer to convert it to FORTAN, if the facilities are available.

Limitations of the Program

The program was developed with specific reference to 8051-type oscillator circuitry. That means the on-chip amplifier is a simple inverter, and not a Schmitt Trigger. The 8096, the 80C51, the 80C48 and 80C49 all have simple inverters. The 8096 oscillator is almost identical to the 8051, differing mainly in the input protection circuitry. The CHMOS amplifiers have somewhat different parameters (higher gain, for example), and different transition levels than the 8051.

The MCS-48 family is specifically included in the program only to the extent that the input-output curve used in the steady-state analysis is that of a Schmitt Trigger, if the user identifies the device under analysis as an MCS-48 device. The analysis does not include the voltage dependent phase shift of the Schmitt Trigger.

The clamping action of the input protection circuitry is important in determining the steady-state amplitudes. The steady-state routine accounts for it by setting the negative peak of the XTAL1 signal at a level which depends on the amplitude of the XTAL1 signal in accordance with experimental observations. It's an exercise in curve-fitting. A user may find a different type of curve works better. Later steppings of the chips may behave differently in this respect, having somewhat different types of input protection circuitry.

It should be noted that the analysis ignores a number of important items, such as high-frequency effects in the on-chip circuitry. These effects are difficult to predict, and are no doubt dependent on temperature, frequency, and device sample. However, they can be simulated to a reasonable degree by adding an "output capacitance" of about 20 pF to the circuit model (i.e., in parallel with CX2) as described below.

Notes on Using the Program

The program asks the user to input values for various circuit parameters. First the crystal (or ceramic resonator) parameters are asked for. These are R1, L1, C1, and C0. The manufacturer can supply these values for selected samples. To obtain any kind of correlation between calculation and experiment, the values of these parameters must be known for the specific sample in the test circuit. The value that should be entered for C0 is the C0 of the crystal itself plus an estimated 7 pF to account for the XTAL1-to-XTAL2 pin capacitance, plus any other stray capacitance paralleling the crystal that the user may feel is significant enough to be included.

Then the program asks for the values of the XTAL1-to-ground and XTAL2-to-ground capacitances. For CXTAL1, enter the value of the externally connected bulk capacitor plus an estimated 7 pF for pin capacitance. For CXTAL2, enter the value of the externally connected bulk capacitor plus an estimated 7 pF for pin capacitance plus about 20 pF to simulate high-frequency roll-off and phase shifts in the on-chip circuitry.

Next the program asks for values for the small-signal parameters of the on-chip amplifier. Typically, for the 8051/8751,

Amplifier Gain Magnitude	= 15
Feedback Resistance	= 2300 KΩ
Output Resistance	= 2 KΩ

The same values can be used for MCS-48 (NMOS and HMOS) devices, but they are difficult to verify, because the Schmitt Trigger does not lend itself to small-signal measurements.

```
100 DEFDBL C,D,F,G,L,P,R,S,X
200 REM                                                              APRIL 8, 1983
300 REM ************************************************************************
400 REM
500 REM                          FUNCTIONS
600 REM
700 REM
800 REM FNZM(R,X) = MAGNITUDE OF A COMPLEX NUMBER, |R+jX|
900 DEF FNZM(R,X) = SQR(R^2+X^2)
1000 REM
1100 REM FNZP(R,X) = ANGLE OF A COMPLEX NUMBER
1200 REM           = 180/PI*ARCTAN(X/R)          IF R>0
1300 REM           = 180/PI*ARCTAN(X/R) + 180    IF R<0 AND X>0
1400 REM           = 180/PI*ARCTAN(X/R) - 180    IF R<0 AND X<0
1500 DEF FNZP(R,X) = 180/PI*ATN(X/R) - (SGN(R)-1)*SGN(X)*90
1600 REM
1700 REM     INDUCTIVE IMPEDANCE AT COMPLEX FREQUENCY S+jF (HZ)
1800 REM          Z = 2*PI*S*L  + j2*PI*F*L
1900 REM            = FNRL(S,L) + jFNXL(F,L)
2000 DEF FNRL(SL,LL) = 2#*PI*SL*LL
2100 DEF FNXL(FL,LL) = 2#*PI*FL*LL
2200 REM
2300 REM     CAPACITIVE IMPEDANCE AT COMPLEX FREQUENCY S+jF (HZ)
2400 REM          Z = 1/[2*PI*(S+jF)*C]
2500 REM            = S/[2*PI*(S^2+F^2)*C] + j(-F)/[2*PI*(S^2+F^2)C]
2600 REM            = FNRC(S,F,C) + jFNXC(S,F,C)
2700 DEF FNRC(SC,FC,CC) = SC/(2#*PI*(SC^2+FC^2)*CC)
2800 DEF FNXC(SC,FC,CC) = -FC/(2#*PI*(SC^2+FC^2)*CC)
2900 REM
3000 REM     RATIO OF TWO COMPLEX NUMBERS
3100 REM          RA+jXA      RA*RB+XA*XB       XA*RB-RA*XB
3200 REM          ------  =  -----------  + j  -----------
3300 REM          RB+jXB       RB^2+XB^2         RB^2+XB^2
3400 REM                   = FNRR(RA,XA,RB,XB) + jFNXR(RA,XA,RB,XB)
3500 DEF FNRR(RA,XA,RB,XB) = (RA*RB+XA*XB)/(RB^2+XB^2)
3600 DEF FNXR(RA,XA,RB,XB) = (XA*RB-XB*RA)/(RB^2+XB^2)
3700 REM
3800 REM     PRODUCT OF TWO COMPLEX NUMBERS
3900 REM         (RA+jXA)*(RB+jXB)  =  RA*RB-XA*XB + j(XA*RB+RA*XB)
4000 REM                            = FNRM(RA,XA,RB,XB) + jFNXM(RA,XA,RB,XB)
4100 DEF FNRM(RA,XA,RB,XB) = RA*RB - XA*XB
4200 DEF FNXM(RA,XA,RB,XB) = RA*XB + RB*XA
4300 REM
4400 REM
4500 REM     PARALLEL IMPEDANCES
4600 REM                                (RA+jXA)*(RB+jXB)
4700 REM     (RA+jXA)||(RB+jXB)  =  ------------------
4800 REM                             RA+RB +j(XA+XB)
4900 REM
5000 REM        RA*(RB^2+XB^2)+RB*(RA^2+XA^2)        XA*(RB^2+XB^2)+XB*(RA^2+XA^2)
5100 REM    =  ------------------------------  +  j ------------------------------
5200 REM          (RA+RB)^2 + (XA+XB)^2                (RA+RB)^2 + (XA+XB)^2
5300 REM
5400 REM    = FNRP(RA,XA,RB,XB) + jFNXP(RA,XA,RB,XB)
5500 DEF FNRP(RA,XA,RB,XB) = (RA*(RB^2+XB^2) + RB*(RA^2+XA^2))/((RA+RB)^2 + (XA+XB)^2)
5600 DEF FNXP(RA,XA,RB,XB) = (XA*(RB^2+XB^2) + XB*(RA^2+XA^2))/((RA+RB)^2 + (XA+XB)^2)
5700 REM
5800 REM ************************************************************************
5900 REM
6000 REM               BEGIN COMPUTATIONS
6100 REM
6200 LET PI = 3.141592654#
6300 REM
6400 REM            DEFINE CIRCUIT PARAMETERS
6500 GOSUB 14500
6600 REM
6700 REM  ESTABLISH NOMINAL RESONANT AND ANTIRESONANT CRYSTAL FREQUENCIES
6800 FS = FIX(1/(2*PI*SQR(L1*C1)))
6900 FA = FIX(1/(2*PI*SQR(L1*C1*C0/(C1+C0))))
7000 PRINT
7100 PRINT "XTAL IS SERIES RESONANT AT ";FS;" HZ"
7200 PRINT "      PARALLEL RESONANT AT ";FA;" HZ"
7300 PRINT
7400 PRINT "SELECT: 1. LIST PARAMETERS"
7500 PRINT "        2. CIRCUIT ANALYSIS"
7600 PRINT "        3. OSCILLATION FREQUENCY"
7700 PRINT "        4. START-UP TIME CONSTANT"
7800 PRINT "        5. STEADY-STATE ANALYSIS"
```

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```
7900 PRINT
8000 INPUT N
8100 IF N=1 THEN PRINT ELSE 8600
8200 REM
8300 REM ---------- LIST PARAMETERS ----------
8400 GOSUB 17100
8500 GOTO 6800
8600 IF N=2 THEN PRINT ELSE 9400
8700 REM
8800 REM ---------- CIRCUIT ANALYSIS ----------
8900 PRINT " FREQUENCY S+OF  TYPE (S),(F) "
9000 INPUT SQ,FQ
9100 GOSUB 20200
9200 GOSUB 26600
9300 GOTO 6800
9400 IF N=3 THEN 10300 ELSE 11000
9500 REM
9600 REM ---------- OSCILLATION FREQUENCY ----------
9700 CL = CX*CY/(CX+CY) + CO
9800 FQ = FIX(1/(2*PI*SQR(L1*C1*CL/(C1+CL))))
9900 SQ = 0
10000 DF = FIX(10^INT(LOG(FA-FS)/LOG(10)-2)+.5)
10100 DS = 0
10200 RETURN
10300 GOSUB 9700
10400 GOSUB 30300
10500 PRINT
10600 PRINT
10700 PRINT "FREQUENCY AT WHICH LOOP GAIN HAS ZERO PHASE ANGLE:"
10800 GOSUB 26600
10900 GOTO 6800
11000 IF N=4 THEN PRINT ELSE 12200
11100 REM
11200 REM ---------- START-UP TIME CONSTANT ----------
11300 PRINT "THIS WILL TAKE SOME TIME          "
11400 GOSUB 9700
11500 GOSUB 37700
11600 PRINT
11700 PRINT
11800 PRINT "FREQUENCY AT WHICH LOOP GAIN = 1 AT 0 DEGREES:"
11900 GOSUB 26600
12000 PRINT : PRINT "THIS YIELDS A START-UP TIME CONSTANT OF ";CSNG(1000000!/(2*PI*SQ));" MICROSECS"
12100 GOTO 6800
12200 IF N=5 THEN PRINT ELSE 7300
12300 REM
12400 REM ---------- STEADY-STATE ANALYSIS ----------
12500 PRINT "STEADY-STATE ANALYSIS"
12600 PRINT
12700 PRINT "SELECT:  1. 8031/8051"
12800 PRINT "         2. 8751"
12900 PRINT "         3. 8035/8039/8040/8048/8049"
13000 PRINT "         4. 8748/8749"
13100 INPUT IC%
13200 IF IC%<1 OR IC%>4 THEN 12600
13300 GOSUB 46900
13400 GOTO 7300
13500 REM   SUBROUTINE BELOW DEFINES INPUT-OUTPUT CURVE OF OSCILLATOR CKT
13600 IF IC%>2 AND VO=5 AND VI<2 THEN RETURN
13700 VO = -10*VI + 15
13800 IF VO>5 THEN VO = 5
13900 IF VO<.2 THEN VO = .2
14000 IF IC%>2 AND VO>2 THEN VO = 5
14100 RETURN
14200 REM
14300 REM ****************************************************************
14400 REM
14500 REM              DEFINE CIRCUIT PARAMETERS
14600 REM
14700 INPUT " R1 (OHMS)";R1
14800 INPUT " L1 (HENRY)";L1
14900 INPUT " C1 (PF)";X
15000 C1 = X*1E-12
15100 INPUT " CO (PF)";X
15200 CO = X*1E-12
15300 INPUT " CXTAL1 (PF)";X
15400 CX = X*1E-12
15500 INPUT " CXTAL2 (PF)";X
15600 CY = X*1E-12
```

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```
15700 INPUT " GAIN FACTOR MAGNITUDE";AV#
15800 INPUT " AMP FEEDBACK RESISTANCE (K-OHMS)";X
15900 RX = X*1000#
16000 INPUT " AMP OUTPUT RESISTANCE (K-OHMS)";X
16100 RO = X*1000#
16200 REM
16300 REM
16400 REM          LIST CURRENT PARAMETER VALUES
16500 GOSUB 17100
16600 RETURN
16700 REM
16800 REM
16900 REM ************************************************************
17000 REM
17100 REM              LIST CURRENT PARAMETER VALUES
17200 REM
17300 PRINT
17400 PRINT "CURRENT PARAMETER VALUES:  1. R1 = ";R1;" OHMS"
17500 PRINT "                           2. L1 = ";CSNG(L1);" HENRY"
17600 PRINT "                           3. C1 = ";CSNG(C1*1E+12);" PF"
17700 PRINT "                           4. CO = ";CSNG(CO*1E+12);" PF"
17800 PRINT "                           5. CXTAL1 = ";CSNG(CX*1E+12);" PF"
17900 PRINT "                           6. CXTAL2 = ";CSNG(CY*1E+12);" PF"
18000 PRINT "     7. AMPLIFIER GAIN MAGNITUDE = ";AV#
18100 PRINT "     8.       FEEDBACK RESISTANCE = ";CSNG(RX*.001);" K-OHMS"
18200 PRINT "     9.         OUTPUT RESISTANCE = ";CSNG(RO*.001);" K-OHMS"
18300 PRINT
18400 PRINT "TO CHANGE A PARAMETER VALUE, TYPE (PARAM NO.),(NEW VALUE)."
18500 PRINT "OTHERWISE, TYPE 0,0 "
18600 INPUT N%,X
18700 IF N%=0 THEN RETURN
18800 IF N%=1 THEN R1 = X
18900 IF N%=2 THEN L1 = X
19000 IF N%=3 THEN C1 = X*1E-12
19100 IF N%=4 THEN CO = X*1E-12
19200 IF N%=5 THEN CX = X*1E-12
19300 IF N%=6 THEN CY = X*1E-12
19400 IF N%=7 THEN AV# = X
19500 IF N%=8 THEN RX = X*1000!
19600 IF N%=9 THEN RO = X*1000!
19700 GOTO 17400
19800 REM
19900 REM
20000 REM ************************************************************
20100 REM
20200 REM                  CIRCUIT ANALYSIS
20300 REM
20400 REM  This routine calculates the loop gain at complex frequency SQ+jFQ.
20500 REM
20600 REM  1. Crystal impedance: RE + jXE
20700 REM
20800 X1 = FNXL(FQ,L1) + FNXC(SQ,FQ,C1)
20900 RE = FNRP((R1+FNRL(SQ,L1)+FNRC(SQ,FQ,C1)),X1,FNRC(SQ,FQ,CO),FNXC(SQ,FQ,CO))
21000 XE = FNXP((R1+FNRL(SQ,L1)+FNRC(SQ,FQ,C1)),X1,FNRC(SQ,FQ,CO),FNXC(SQ,FQ,CO))
21100 REM
21200 REM  2. RF + jXF  =  (RE+jXE)|||(amplifier feedback resistance)
21300 REM
21400 RF = FNRP(RX,0,RE,XE)
21500 XF = FNXP(RX,0,RE,XE)
21600 REM
21700 REM  3. Input impedance: Zi = RI + jXI = impedance of CXTAL1
21800 REM
21900 RI = FNRC(SQ,FQ,CX)
22000 XI = FNXC(SQ,FQ,CX)
22100 REM
22200 REM  4. Load impedance: ZL = (impedance of CXTAL2)|||[(RF+RI)+j(XF+XI)]
22300 REM
22400 RL = FNRP((RF+RI),(XF+XI),FNRC(SQ,FQ,CY),FNXC(SQ,FQ,CY))
22500 XL = FNXP((RF+RI),(XF+XI),FNRC(SQ,FQ,CY),FNXC(SQ,FQ,CY))
22600 REM
22700 REM  5. Amplifier gain  A = -AV*ZL/(ZL+RO)
22800 REM                       = A(real) + jA(imaginary)
22900 REM
23000 AR# = -AV#*FNRR(RL,XL,(RO+RL),XL)
23100 AI# = -AV#*FNXR(RL,XL,(RO+RL),XL)
23200 REM
23300 REM  6. Feedback ratio  (beta) = (RI+jXI)/[(RF+RI)+j(XF+XI)]
23400 REM                           = B(real) + jB(imaginary)
```

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```
23500 REM
23600 BR# = FNRR(RI,XI,(RI+RF),(XI+XF))
23700 BI# = FNXR(RI,XI,(RI+RF),(XI+XF))
23800 REM
23900 REM  7. Amplifier gain in magnitude/phase form:  AR+jAI = A at AP degrees
24000 REM
24100 A = FNZM(AR#,AI#)
24200 AP = FNZP(AR#,AI#)
24300 REM
24400 REM  8. (beta) in magnitude/phase form:  BR+jBI = B at BP degrees
24500 REM
24600 B = FNZM(BR#,BI#)
24700 BP = FNZP(BR#,BI#)
24800 REM
24900 REM  9. Loop gain:  G = (BR+jBI)*(AR+jAI)
25000 REM                   = G(real) + jG(imaginary)
25100 REM
25200 GR = FNRM(AR#,AI#,BR#,BI#)
25300 GI = FNXM(AR#,AI#,BR#,BI#)
25400 REM
25500 REM  10. Loop gain in magnitude/phase form:  GR+jGI = AL at AQ degrees
25600 REM
25700 AL = FNZM(GR,GI)
25800 AQ = FNZP(GR,GI)
25900 RETURN
26000 REM
26100 REM
26200 REM ************************************************************
26300 REM
26400 REM              PRINT CIRCUIT ANALYSIS RESULTS
26500 REM
26600 PRINT
26700 PRINT " FREQUENCY = ";SQ;" + J";FQ;" HZ"
26800 PRINT " XTAL IMPEDANCE = ";FNZM(RE,XE);" OHMS AT ";FNZP(RE,XE);" DEGREES"
26900 PRINT "         (RE = ";CSNG(RE);" OHMS)"
27000 PRINT "         (XE = ";CSNG(XE);" OHMS)"
27100 PRINT " LOAD IMPEDANCE = ";FNZM(RL,XL);" OHMS AT ";FNZP(RL,XL);" DEGREES"
27200 PRINT " AMPLIFIER GAIN = ";A;" AT ";AP;" DEGREES"
27300 PRINT " FEEDBACK RATIO = ";B;" AT ";BP;" DEGREES"
27400 PRINT " LOOP GAIN = ";AL;" AT ";AQ;" DEGREES"
27500 RETURN
27600 REM
27700 REM
27800 REM ************************************************************
27900 REM
28000 REM                  SEARCH FOR FREQUENCY (S+JF)
28100 REM          AT WHICH LOOP GAIN HAS ZERO PHASE ANGLE
28200 REM
28300 REM  This routine searches for the frequency at which the imaginary part
28400 REM  of the loop gain is zero.  The algorithm is as follows:
28500 REM    1. Calculate the sign of the imaginary part of the loop gain (GI).
28600 REM    2. Increment the frequency.
28700 REM    3. Calculate the sign of GI at the incremented frequency.
28800 REM    4. If the sign of GI has not changed, go back to 2.
28900 REM    5. If the sign of GI has changed, and this frequency is within
29000 REM       1Hz of the previous sign-change, exit the routine.
29100 REM    6. Otherwise, divide the frequency increment by -10.
29200 REM    7. Go back to 2.
29300 REM  The routine is entered with the starting frequency SQ+jFQ and
29400 REM  starting increment DS+jDF already defined by the calling program.
29500 REM  In actual use either DS or DF is zero, so the routine searches for
29600 REM  a GI=0 point by incrementing either SQ or FQ while holding the other
29700 REM  constant.  It returns control to the calling program with the
29800 REM  incremented part of the frequency being within 1Hz of the actual
29900 REM  GI=0 point.
30000 REM
30100 REM  1. CALCULATE THE SIGN OF THE IMAGINARY PART OF THE LOOP GAIN (GI).
30200 REM
30300 GOSUB 20200
30400 GOSUB 26600
30500 IF GI=0 THEN RETURN
30600 SX% = INT(SGN(GI))
30700 IF SX%=+1 THEN DS = -DS
30800 REM  (REVERSAL OF DS FOR GI=0 IS FOR THE POLE-SEARCH ROUTINE.)
30900 REM
31000 REM  2.  INCREMENT THE FREQUENCY.
31100 REM
31200 SP = SQ
```

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```
31300 FP = FQ
31400 SQ = SQ + DS
31500 FQ = FQ + DF
31600 REM
31700 REM  3.  CALCULATE THE SIGN OF GI AT THE INCREMENTED FREQUENCY.
31800 REM
31900 GOSUB 20200
32000 GOSUB 26600
32100 IF INT(SGN(GI))=0 THEN RETURN
32200 REM
32300 REM  4.  IF THE SIGN OF GI HAS NOT CHANGED, GO BACK TO 2.
32400 REM
32500 IF SX%+INT(SGN(GI))=0 THEN PRINT ELSE 31400
32600 SX% = -SX%
32700 REM
32800 REM  5.  IF THE SIGN OF GI HAS CHANGED, AND IF THIS FREQUENCY IS WITHIN
32900 REM      1HZ OF THE PREVIOUS SIGN-CHANGE, AND IF GI IS NEGATIVE, THEN
33000 REM      EXIT THE ROUTINE.  (THE ADDITIONAL REQUIREMENT FOR NEGATIVE GI
33100 REM      IS FOR THE POLE-SEARCH ROUTINE.)
33200 REM
33300 IF ABS(SP-SQ)<1 AND ABS(FP-FQ)<1 AND SX%=-1 THEN RETURN
33400 REM
33500 REM  6.  DIVIDE THE FREQUENCY INCREMENT BY -10.
33600 REM
33700 DS = -DS/10#
33800 DF = -DF/10#
33900 REM
34000 REM  7.  GO BACK TO 2.
34100 REM
34200 GOTO 31200
34300 REM
34400 REM
34500 REM ************************************************************
34600 REM
34700 REM                  SEARCH FOR POLE FREQUENCY
34800 REM
34900 REM  This routine searches for the frequency at which the loop gain = 1
35000 REM  at 0 degrees.  That frequency is the pole frequency of the closed-
35100 REM  loop gain function.  The pole frequency is a complex number, SQ+jFQ
35200 REM  (Hz).  Oscillator start-up ensues if SQ>0.  The algorithm is based on
35300 REM  the calculated behavior of the phase angle of the loop gain in the
35400 REM  region of interest on the complex plane.  The locus of points of zero
35500 REM  phase angle crosses the j-axis at the oscillation frequency and at
35600 REM  some higher frequency.  In between these two crossings of the j-axis,
35700 REM  the locus lies in Quadrant I of the complex plane, forming an
35800 REM  approximate parabola which opens to the left.  The basic plan is to
35900 REM  follow the locus from where it crosses the j-axis at the oscillation
36000 REM  frequency, into Quadrant I, and find the point on that locus where
36100 REM  the loop gain has a magnitude of 1.  The algorithm is as follows:
36200 REM    1.  Find the oscillation frequency, 0+jFQ.
36300 REM    2.  At this frequency calculate the sign of (AL-1).  (AL = magnitude
36400 REM        of loop gain.)
36500 REM    3.  Increment FQ.
36600 REM    4.  For this value of FQ, find the value of SQ for which the loop
36700 REM        gain has zero phase.
36800 REM    5.  For this value of SQ+jFQ, calculate the sign of (AL-1).
36900 REM    6.  If the sign of (AL-1) has not changed, go back to 3.
37000 REM    7.  If the sign of (AL-1) has changed, and this value of FQ is
37100 REM        within 1Hz of the previous sign-change, exit the routine.
37200 REM    8.  Otherwise, divide the FQ-increment by -10.
37300 REM    9.  Go back to 3.
37400 REM
37500 REM  1.  FIND THE OSCILLATION FREQUENCY, 0+jFQ.
37600 REM
37700 GOSUB 9700
37800 GOSUB 30300
37900 REM
38000 REM  2.  AT THIS FREQUENCY, CALCULATE THE SIGN OF (AL-1).
38100 REM
38200 SY% = INT(SGN(AL-1!))
38300 IF SY%=-1 THEN STOP
38400 REM  ESTABLISH INITIAL INCREMENTATION VALUE FOR FQ.
38500 F1 = FQ
38600 DF = (FA-F1)/10#
38700 GOSUB 30300
38800 DE = (FQ-F1)/10#
38900 DF = 0
39000 FQ = F1
```

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```
39100 REM
39200 REM  3. INCREMENT FQ.
39300 REM
39400 FQ = FQ + DE
39500 REM
39600 REM  4. FOR THIS VALUE OF FQ, FIND THE VALUE OF SQ FOR WHICH THE LOOP
39700 REM     GAIN HAS ZERO PHASE. (THE ROUTINE WHICH DOES THAT NEEDS DF = 0,
39800 REM     SO THAT IT CAN HOLD FQ CONSTANT, AND NEEDS AN INITIAL VALUE FOR
39900 REM     DS, WHICH IS ARBITRARILY SET TO DS = 1000.)
40000 REM
40100 DS = 1000#
40200 SQ = 0
40300 GOSUB 30300
40400 IF AL=1! THEN RETURN
40500 REM
40600 REM  5. FOR THIS VALUE OF SQ+jFQ, CALCULATE THE SIGN OF (AL-1).
40700 REM  6. IF THE SIGN OF (AL-1) HAS NOT CHANGED, GO BACK TO 3.
40800 REM
40900 IF SY%+INT(SGN(AL-1!))=0 THEN PRINT ELSE 39400
41000 REM
41100 REM  7. IF THE SIGN OF (AL-1) HAS CHANGED, AND THIS VALUE OF FQ IS WITHIN
41200 REM     1HZ OF THE PREVIOUS SIGN-CHANGE, EXIT THE ROUTINE.
41300 REM
41400 IF ABS(F1-FQ)<1 THEN RETURN
41500 REM
41600 REM  8. DIVIDE THE FQ-INCREMENT BY -10.
41700 REM
41800 DE = -DE/10#
41900 F1 = FQ
42000 SY% = -SY%
42100 REM
42200 REM  9. GO BACK TO 3.
42300 REM
42400 GOTO 39400
42500 REM
42600 REM
42700 REM ************************************************************
42800 REM
42900 REM                    STEADY-STATE ANALYSIS
43000 REM
43100 REM  The circuit model used in this analysis is similar to the one used
43200 REM  in the small-signal analysis, but differs from it in two respects.
43300 REM  First, it includes clamping and clipping effects described in the
43400 REM  text. Second, the voltage source in the Thevenin equivalent of the
43500 REM  amplifier is controlled by the input voltage in accordance with an
43600 REM  input-output curve defined elsewhere in the program.
43700 REM    The analysis applies a sinusoidal input signal of arbitrary
43800 REM  amplitude, at the oscillation frequency, to the XTAL1 pin, then
43900 REM  calculates the resulting waveform from the voltage source. Using
44000 REM  standard Fourier techniques, the fundamental frequency component of
44100 REM  this waveform is extracted. This frequency component is then
44200 REM  multiplied by the factor |ZL/(ZL+RO)|, and the result is taken to be
44300 REM  the signal appearing at the XTAL2 pin. This signal is then
44400 REM  multiplied by the feedback ratio (beta), and the result is taken to
44500 REM  be the signal appearing at the XTAL1 pin. The algorithm is now
44600 REM  repeated using this computed XTAL1 signal as the assumed input
44700 REM  sinusoid. Every time the algorithm is repeated, new values appear at
44800 REM  XTAL1 and XTAL2, but the values change less and less with each
44900 REM  repetition. Eventually they stop changing. This is the steady-state.
45000 REM    The algorithm is as follows:
45100 REM  1. Compute approximate oscillation frequency.
45200 REM  2. Call a circuit analysis at this frequency.
45300 REM  3. Find the quiescent levels at XTAL1 and XTAL2 (to establish the
45400 REM     beginning DC level at XTAL1).
45500 REM  4. Assume an initial amplitude for the XTAL1 signal.
45600 REM  5. Correct the DC level at XTAL1 for clamping effects, if necessary.
45700 REM  6. Using the appropriate input-output curve, extract a DC level and
45800 REM     the fundamental frequency component (multiplying the latter by
45900 REM     |ZL/(ZL+RO)|).
46000 REM  7. Clip off the negative portion of this output signal, if the
46100 REM     negative peak falls below zero.
46200 REM  8  If this signal, multiplied by (beta), differs from the input
46300 REM     amplitude by less than 1mV, or if the algorithm has been repeated
46400 REM     10 times, exit the routine
46500 REM  9. Otherwise, multiply the XTAL2 amplitude by (beta) and feed it
46600 REM     back to XTAL1, and go back to 5.
46700 REM
46800 REM     1. COMPUTE APPROXIMATE OSCILLATION FREQUENCY.
```

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```
46900 GOSUB 9700
47000 REM
47100 REM     2. CALL A CIRCUIT ANALYSIS AT THIS FREQUENCY.
47200 GOSUB 20800
47300 PRINT : PRINT   PRINT "ASSUMED OSCILLATION FREQUENCY: "
47400 GOSUB 26600
47500 PRINT : PRINT
47600 REM
47700 REM     3. FIND QUIESCENT POINT
47800 REM  (At quiescence the voltages at XTAL1 and XTAL2 are equal. This
47900 REM   voltage level is found by trial-and-error, based on the input-
48000 REM   output curve, so that a person can change the input-output curve
48100 REM   as desired without having to re-calculate the quiescent point.)
48200 VI = 0
48300 VB = 1
48400 K1 = 1
48500 VI = VI + VB
48600 GOSUB 13600
48700 IF ABS(VO-VI)<.001 THEN 49200
48800 IF K1+SGN(VO-VI)=0 THEN 48900 ELSE 48500
48900 K1 = SGN(VO-VI)
49000 VB = -VB/10
49100 GOTO 48500
49200 VB = VI
49300 PRINT "QUIESCENT POINT = ";VB
49400 REM
49500 REM     4. ASSUME AN INITIAL AMPLITUDE FOR THE XTAL1 SIGNAL.
49600 EI = .01
49700 NR% = 0
49800 REM
49900 REM     5. CORRECT FOR CLAMPING EFFECTS, IF NECESSARY.
50000 REM  (K1 and K2 are curve-fitting parameters for the ROM parts.)
50100 K1 = (2.5-VB)/(3-VB)
50200 K2 = (VB-1.25)/(3-VB)
50300 IF IC%=2 OR IC%=4 THEN IF EI<(VB+.5) THEN EO = VB ELSE EO = EI - .5
50400 IF IC%=1 OR IC%=3 THEN IF EI<(VB+.5) THEN EO = VB ELSE EO = K1*EI+K2
50500 NR% = NR% + 1
50600 REM
50700 REM     6. DERIVE XTAL2 AMPLITUDE.
50800 VO = 0
50900 VC = 0
51000 VS = 0
51100 FOR N% = -25 TO +24
51200 VI = EO - EI*COS(PI*N%/25)
51300 GOSUB 13600
51400 VO = VO + VO
51500 VC = VC + VO*COS(PI*N%/25)
51600 VS = VS + VO*SIN(PI*N%/25)
51700 NEXT N%
51800 VO = VO/50
51900 V1 = SQR(VC^2+VS^2)/25*FNZM(RL,XL)/FNZM((RL+RO),XL)
52000 REM
52100 REM     7. CLIP XTAL2 SIGNAL.
52200 IF VO-V1<0 THEN VL = 0 ELSE VL = VO-V1
52300 PRINT : PRINT "XTAL1 SWING = ";EO-EI;" TO ";EO+EI
52400 PRINT "XTAL2 SWING = ";VL;" TO ";VO+V1
52500 REM
52600 REM     8. TEST FOR TERMINATION.
52700 IF ABS(EI-V1*B)<.001 OR NR%=10 THEN RETURN
52800 REM
52900 REM     9. FEED BACK TO XTAL1 AND REPEAT
53000 EI = V1*B
53100 GOTO 50300
```

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ISBN# 1-55512-123-3