b) Lowest and Highest values can be captured during long term testing.

c) Using LAH and the % function allows the user to quickly determine the maximum, minimum and average % deviation for a quantity of electronic components.

3.4.9 NULL Function.

3.4.9.1 The NULL Function is an ESC feature of the DMM that can be enabled manually from the keyboard or through the GPIB remote system.

3.4.9.2 The NULL Function calculates and displays the difference between each measurement value and a Null constant. When NULL is enabled from the keyboard, *the number in the numerical input buffer, (see Fig. 3.7),* is stored as a NULL constant and subtracted from all future readings until changed or the NULL function is disabled by depressing the NULL key again. The NULL constant can be either the measurement value at the time NULL is enabled or a numerical value entered via the keyboard. A NULL constant can be entered from the keyboard when enabling Null operation or entered after the function is enabled. The operator can observe the Null constant in memory at any time by recalling it to the display.

3.4.9.3 To subtract the present reading from future measurements, simply depress the NULL key. The reading in the numerical input buffer, when the NULL key is depressed is stored as the Null constant.

3.4.9.4 To subtract a constant entered via the keyboard from each measurement value, execute the following keystrokes:

a) Depress the SHIFT key.

b) Key-in the numerics to be subtracted from each measurement value. This numeric will appear on the display as each key is depressed. If the Null constant is a resistance, enter the value in KΩ.

c) Depress the NULL key to store the numerical value as the Null Constant and simultaneously enable the Null Function.

3.4.9.5 To enter or modify the Null Constant after the Null Function is enabled, perform the following procedure:

a) If a measurement value is to be stored as the Null Constant, verify that a reading is presently in the display; if not, press the SINGLE or TRACK Key to take a measurement. Go to Step (c).

b) If a numerical constant is to be stored as the Null Constant, press the SHIFT Key and key-in the Null Constant with the numerical entry keys (these numerics will appear on the display). If the Null Constant is a resistance, enter the value in KΩ.

c) Depress the STORE key.

d) Depress the NULL key to enter the Null Constant into memory.

3.4.9.6 The NULL constant stored in memory can be recalled to the display anytime, with the two keystroke sequence RECALL and NULL.

3.4.9.7 The Null Function Applications are numerous but a few are listed as examples:

a) The measurement of line or load regulation of a DC power supply. The nominal DC output from the supply is substracted from its output under modified line or load conditions and the deviation displayed directly.

b) Cancellation of lead resistance in the measurement of low resistance values with a two-wire connection to the unknown resistance.

c) Addition or subtraction of a constant from the measured value. Addition is accomplished by entering the Null constant with a minus sign.

3.4.10 Percent Function.

3.4.10.1 The Percent Function complements the DMM's Extended Software Capability (ESC) features with the additions of percentage calculations when operating in the Volts and Ohms Functions. The Percent Function can be enabled manually from the keyboard or through the GPIB system.

3.4.10.2 The Percent Function calculates and displays the percentage deviation of each measurement and from a reference value (Percent Constant). The deviation calculation formula is:

PERCENT DEVIATION =

$$\frac{\text{Measurement Value - Percent Constant}}{\text{Percent Constant}} \text{ X } 100$$

The Percent Function is enabled or disabled, by pressing the Percent (%) key when not preceded by the STORE or RECALL key. However, a non-zero percent constant must be stored to obtain meaningful results. The "%" annunciator indicates when the function is enabled.

3.4.10.3 The Percent Constant can be either a measurement reading or a numerical value entered via the keyboard. Note that an "ERROR 0" message is displayed, when a Percent Constant is not stored in memory prior to enabling the Percent Function. The operator can check the Percent Constant in memory by recalling it to the display, following the instructions listed in Table 3.4 and paragraph 3.4.7.

3.4.10.4 To store a measurement value or numerical constant as the percent constant, perform the following procedure:

a) If a measurement value is to be stored as the Percent Constant, verify that a reading is presently in the display; if not, press the SINGLE or TRACK key to take a measurement. Go to step (c).

b) If a numerical constant is to be stored as the Percent Constant, press the SHIFT key and key-in the Percent constant with the numerical entry keys (these numerics will appear on the display).

c) Depress the STORE key.

d) Depress the % key to store the displayed number into memory. Note that pressing the % key did not enable or disable the Percent Function because it was preceded by the STORE key. If this procedure is performed while the Percent Function is enabled, the calculation and display of Percent Deviation will begin with the next reading.

3.4.10.5 Percentage Deviations too large to display normally will be displayed in Scientific Notation, (e.g., 1,000,000% displayed as 1.00E6). However, percent deviations equal to or greater than 10^{10}% will result in an "ERROR 6" message. Other conditions related to the number of significant digits in the calculated value will also cause the percentage to be displayed in scientific notation.

3.4.11 Time Function.

3.4.11.1 The Time function adds another dimension to the capabilities of the DMM by bringing measurement and computation features under the control of the DMM's built-in digital clock. It also gives the user a very useful 96 hour clock which can be used when the DMM is not otherwise employed. The Time function can be configured to provide timed measurements with selectable Start time, Stop time, Interval, Subinterval, Number of Readings (N), and Present Time. Most applications will require only a subset of the Time function's full capabilities.

3.4.11.2 The Time function when used in conjunction with other Extended Software Capability Features, increases the DMM's applications. The following list describes typical applications:

a) Monitor an input signal at programmed intervals up to 96 hours and beyond.

b) Store all readings into the Data Buffer for later recall.

c) The sync output can sequence a scanner (such as Racal-Dana's Model 1200) to scan up to 99 inputs at controlled intervals and store the readings to the Data Buffer as well as output them to a GPIB printer.

d) When used in conjunction with LAH function, it can be used to average up to 10,000 readings taken at controlled intervals.

3.4.11.3 The TIME function key on the keyboard is a toggle switch which is depressed to toggle "ON" and depressed again to toggle "OFF". When the Time key is toggled ON, it puts the DMM into hold. When the Time key is toggled OFF, it puts the DMM in the continuous reading mode. The Time annunciator will indicate the status of the Time key. When programmed from the GPIB, the trigger status is not affected by enabling or disabling the Time function. Further GPIB programming details are presented in paragraph 3.5.23.

3.4.11.4 There are six memory locations that control the various ways the TIME function operates. These memory locations, referred to in Table 3.5, have the indicated designators and limitations.

Table 3.5 - Time Register Codes

Name	Designator	Power-Up Initialization	Largest Value That The User Can Store	Comments
Start Time	Time 1	00.0000	99.5959	
Stop Time	Time 2	99.0000	99.5959	
Interval	Time 3	00.0000	99.5959	0 defaults to 1 second.
Subinterval	Time 4	00.0000	99.5959	
N (Number of Readings per interval)	Time 5	1	99	
Present Time	Time 6	00.0000	99.5959	Begins counting at power-up. Increments to 00.0000 at 96 hrs.
Note: The format for Time numbers is XX.YYZZ where XX = hours, YY = minutes, ZZ = seconds.				

3.4.11.5 The Present Time Register is the most important of the six Time Function registers. At power-up the present time begins incrementing at one-second intervals until it reaches 95.5959 (95 hours, 59 minutes, 59 seconds.). One second later it resets to 00.0000 and begins incrementing again. Figure 3.8 shows the path taken by the Present Timer register as it approaches 96 hours on the time axis and then resets to zero. Note that the Present Time register always increments whether or not the Time function is enabled.

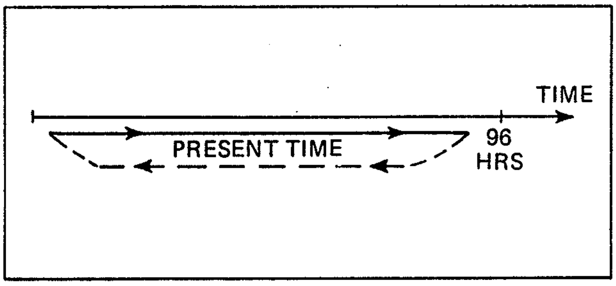


Figure 3.8 - Cycling of Present Time Register

3.4.11.6 The Start Time and Stop Time registers form a "window" during which readings can take place. As an example, Figure 3.9 shows the Start Time set to 20.0000 hours and the Stop Time set to 50.0000 hours. The example also shows how the Present Time has incremented past the Start Time, causing a reading to take place. Other readings may be triggered between start and stop times under control of the Interval, Subinterval, and N registers, which will be covered later.

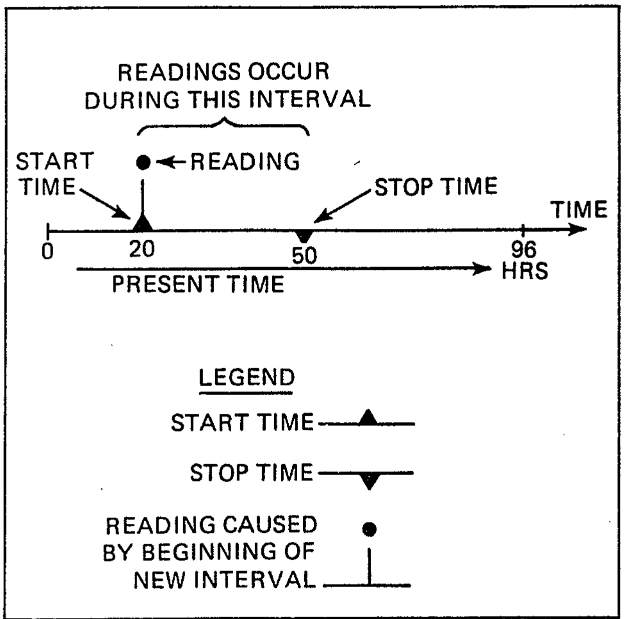


Figure 3.9 - Use of Start and Stop Time Register

3.4.11.7 Since the Present Time resets to zero at 96 hours, it is possible to set the Stop Time (or any other time register) at "infinity" on the time scale by storing a number greater than 95.5959 to the register in question. An example is shown in Figure 3.10, where the start time has been set to 30 hours and the stop time has been set to 99 hours, placing it "out of range" of the present time register. With these start/stop settings, reading(s) would begin at 30 hours and continue forever under control of the Interval, Subinterval and N registers.

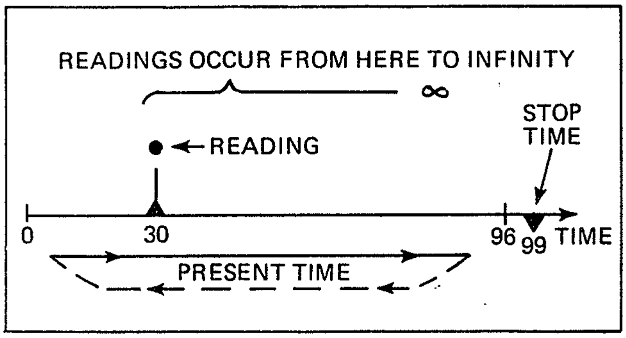
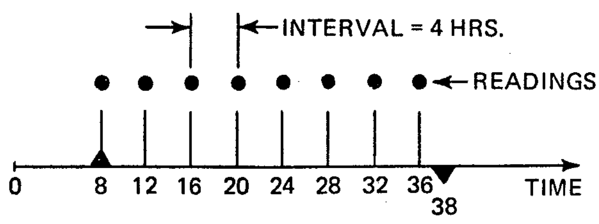


Figure 3.10 - Setting Stop Time at Infinity

3.4.11.8 Interval, Subinterval and N Registers: Once inside the Start-Time/Stop-Time window, the Interval, Subinterval and N registers control the triggering of readings. An example is shown in Figure 3.11, where the subinterval and N registers have been set to their power-up value and the Interval register is controlling the time between readings. Notice that once the Start Time is reached, the DMM's Interval register triggers a reading every Interval time until the Stop Time is reached.



REGISTER CONTENTS

START TIME	8.0000
STOP TIME	38.0000
INTERVAL	4.0000
SUBINTERVAL	0
N	1

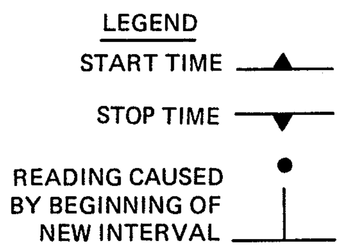
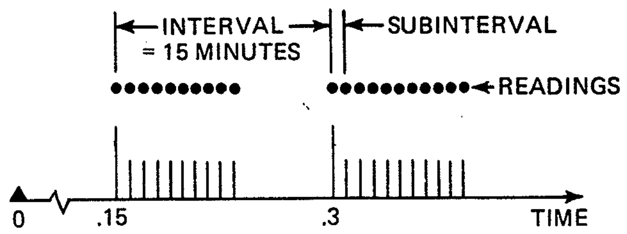


Figure 3.11 - Example of Start, Stop, and Interval Registers

3.4.11.9 Some applications require a read timing pattern similar to that shown in Figure 3.12. This read timing pattern is commonly used whenever a group of signals must be monitored within seconds of one-another periodically, as is the case when simultaneous temperature measurements must be made throughout a unit-under-test. Notice in this example that the Subinterval and N Registers are used to cause tight groups of 10 readings to occur every Interval time.



REGISTER CONTENTS

START TIME	0
STOP TIME	∞
INTERVAL	0.15 (15 MINUTES)
SUBINTERVAL	.0002 (2 SECONDS)
N	10 (10 RDGS/ INTERVAL)

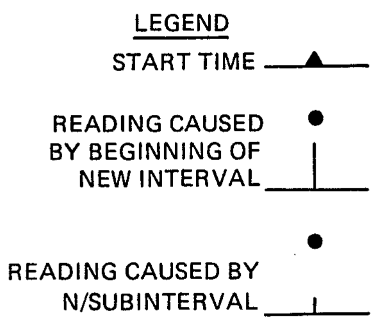


Figure 3.12 - Example of Interval, Subinterval and "N" Registers

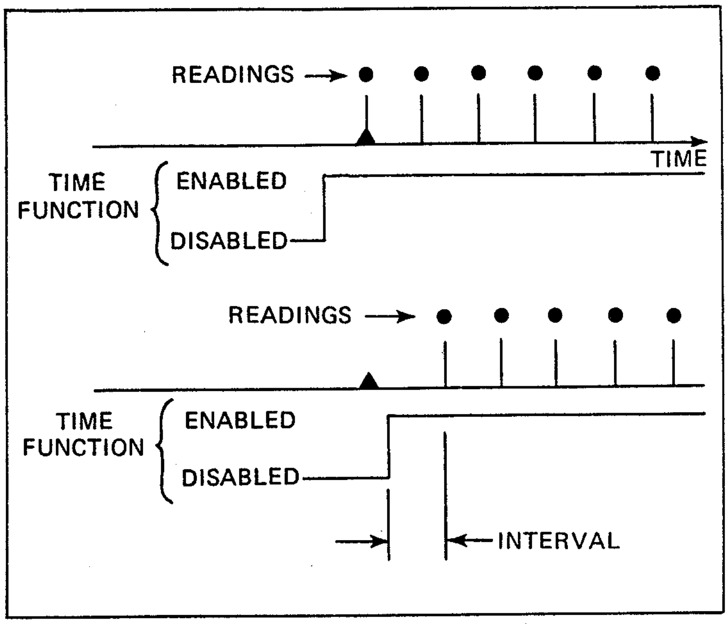


Figure 3.13 - Effect of Enabling Time Function After Start Time

3.4.11.10 Before the Time function is enabled, all 6 Time registers should be set to their proper values. Section 3.4.7 details the procedure for entering and storing all 6 Time constants. Keep in mind that hours are entered before the decimal point, minutes and seconds after the decimal point. Any Time constant can be examined by using the key procedure listed in Table 3.3. Recalling the Present Time allows the DMM's front panel display to be used as a 96 hour clock.

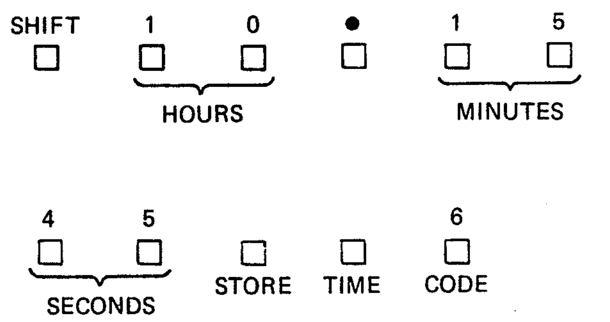
3.4.11.11 Some further points should be kept in mind when using the Time function:

a) If the Time function is disabled when the Present Time crosses the Start Time, readings will take place starting (1) Interval Time beyond the point when the Time function is enabled and continuing at Interval times from thereon. This is shown in Figure 3.13 where 2 identical Time function setups yield different results because of differences when the Time function is enabled. In order to avoid problems in critical applications, make sure that the Time function is enabled before the Present time encounters the Start time.

b) The accuracy of the Time function is ± [(2 seconds/hour) + 1 second].

c) Many front panel keyboard operations can disrupt the Time function. Therefore, the DMM should be completely set up before enabling the Time function.

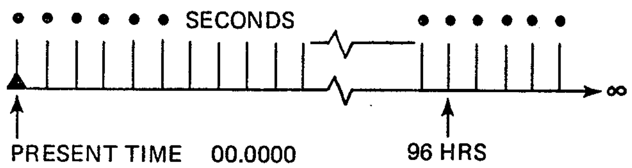
3.4.11.12 The following example lists the key strokes required to alter the Present Time (TIME6) to 10 hours, 15 minutes, and 45 seconds:



The SHIFT key enables the numeric key settings of 10 hours, 15 minutes and 45 seconds, this is followed by the STORE key, TIME key, and the last numeric entered sets the "N" register to be altered.

3.4.11.13 The following text represents a group of TIME Function examples and applications:

a) Pressing the TIME key without storing times in Time Registers will result in processing one reading per second (Time Registers are in their Power-up state). Note that TIME 3 (Interval) defaults to 1.0 second when no other value is stored.

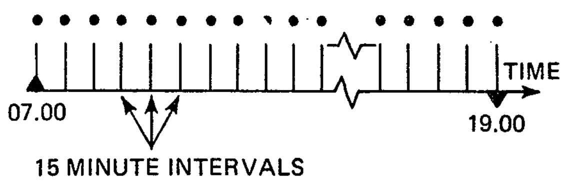


PRESENT TIME	00.0000
START TIME	00.0000
STOP TIME	99.0000
INTERVAL	00.0000
SUBINTERVAL	00.0000
N	1

b) For most applications the N and Subinterval will be left at their power-up values. As an example, suppose we wish to measure the AC line voltage every 15 minutes from 7:00 AM to 7:00 PM. The registers would be loaded as follows:

Start Time	(Time 1)	07.0000
Stop Time	(Time 2)	19.0000
Interval	(Time 3)	00.1500
Present Time	(Time 6)	Some real-time before 07.000.

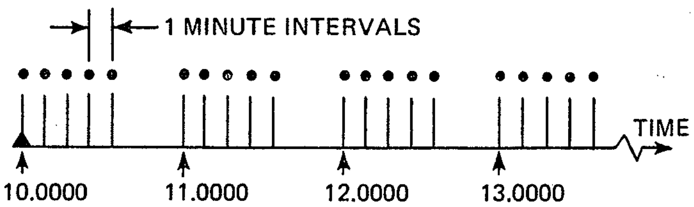
Graphic example:



c) To process 5 readings taken one minute apart, every hour, on the hour, starting at 10:000; the registers are set up as follows:

Present Time	(Time 6)	Some real-time before 10:00.
Start Time	(Time 1)	10.0000
Stop Time	(Time 2)	99.0000
Interval	(Time 3)	01.0000
N	(Time 5)	05.0
Subinterval	(Time 4)	00.0100

Graphic example:



3.4.12 External Reference (Software Ratio) Measurements

3.4.12.1 The External Reference, software ratio measurements are an ESC feature of the DMM that configures the DMM to function as a ratiometer. Ratio measurements are made by applying a DC or AC external reference voltage to the DMM's EXT REF input terminals located on the rear panel, and selecting the appropriate external reference function and external reference range. Section 3.5.29 and Table 3.12 give descriptions of the GPIB program codes required to enable the software ratios. Upon selecting the Software Ratio mode, the DMM reads the measurement signal, the external reference signal, then calculates:

$$\text{RATIO} = \frac{\text{Measurement Signal}}{\text{External Reference Signal}}$$

3.4.12.2 The selection of the Reference Function/Range is completely independent of the Measurement Function/Range, therefore, over 100 types of Software Ratios can be programmed. A few examples are:

$$\frac{\text{AC-10V Range}}{\text{DC-1000V Range}},\ \frac{\text{AC 1V Range}}{\text{AC 1V Range}}\ \text{and}\ \frac{\text{Ohms .1 Range}}{\text{DC-100V Range}}$$

3.4.12.3 To select the External Reference Function/Range, the REF key is depressed to enable or disable the external reference mode. When enabled, "REF" is displayed on the DMM's front panel and the annunciator LED's display the present reference function and range in the REF mode, if all the function LED's remain blank, then this indicates that the DMM's internal reference was selected, that is, the DMM is in its "normal" measurement mode.

3.4.12.4 While in the REF mode, an external reference function or range can be selected. This is done by pressing a function or range key. The following keys will modify the reference function or range setting:

FUNCTION ☐ =V ☐ ~V

RANGE ☐ .1 ☐ 1 ☐ 10 ☐ 100 ☐ 1K ☐ 10K ☐ AUTO

The annunciatorLED's will then indicate the new reference setting.

3.4.12.5 Once the reference function and range are selected, the REF key is pressed to exit the REF mode, also the DMM begins taking readings. The EXT REF LED will be ON if an external reference function was selected. When the LED is OFF, then the DMM is using its internal reference

3.4.12. The user can return to Internal Reference by pressing a Function key when not in the REF mode or by pressing the RESET key at any time. To examine the Reference settings without distributing it, press the REF key to enter the REF mode, examine the Function and Range annunciators, and then press the REF key again to exit the REF mode.

3.4.13 Program and Data Buffers.

3.4.13.1 The DMM 5004 contains a large area of Random Access Memory (RAMS U22 and U31) which is dedicated to the storage of instrument settings and readings. The instrument settings which refer to the position of all controls are stored in the Program Buffer and the readings which the DMM generates are stored in the Data Buffer.

3.4.13.2 THE PROGRAM BUFFER.

3.4.14.2.1 The Program Buffer allows the user to:

a) STORE ten complete instrument settings either as keyboard inputs or as GPIB inputs. The stored instrument settings can include Function, Range, Trigger, NULL, LAH, Percent, Time and numeric constants associated with the above mentioned ESC features.

b) In any sequence, RECALL the settings which were previously stored into the Program Buffer.

3.4.13.2.2 The ten Program Buffer registers will power-up in an 'empty' or initialized state, therefore instrument settings must be stored into the buffer before attempting to recall "program settings" from the buffer. To store a setting into the program buffer from the keyboard, (GPIB procedure is described in paragraph 3.5.9) the following procedure is used:

a) Keyboard Input: Program the DMM to the setting that will be stored in the buffer. For example, if Buffer program No. 9 will be DC, Auto-range and LAH function, depress the DC, AUTO and LAH keys, and continue with (b) next.

b) Press ☐ STORE Key.

c) Press SHIFT ☐ Key.

d) Press 0 ☐ .. 9 ☐ key as required.

During step d, the 7-segment display will display the message "ProGX" where X is the selected storage location (0-9).

3.4.13.2.3 There are some points to consider when "storing" programs to the Program Buffer:

a) Whenever a program is stored to the program buffer, the Data Buffer is cleared.

b) Programs can be redefined at any time. For example, the Program No. 9 contents can be changed to some other setting by first selecting the appropriate functions (using keyboard or GPIB) and then storing to program No. 9 again.

c) Once a program location is stored, it remains defined until the power is switched OFF to the DMM.

d) If the operator plans to use the Data Buffer, he should avoid storing programs to more program locations than necessary, otherwise the Data Buffer will become restricted in size. For further details, refer to paragraph 3.4.12.4, the Buffer Organization.

3.4.13.2.4 The following procedure is used to RECALL a program stored in the Program Buffer:

a) Press ☐ RECALL key.

b) Press SHIFT ☐ key.

c) Press 0 ☐ .. 9 ☐ key as required.

During step "C" the 7-segment display will show the message "ProGX" where X is the selected program location (0-9). When the RECALL procedure is completed, the DMM will immediately assume the settings which have been recalled from the program buffer.

3.4.13.2.5 Consider the following points when "recalling" programs from the Program Buffer.

a) Whenever a program is recalled, the LAH function is cleared. This is done so that if the recalled program makes use of LAH, the LAH constants which are generated will not be affected by the previous instrument settings.

b) All of the Time Function registers will be affected by a program recall with the exception of T6, the present time.

3.4.13.3 THE DATA BUFFER.

3.4.13.3.1 The Data Buffer allows the user to:

a) Store over 130 readings for later use.

b) Recall these readings to the display or over the GPIB.

c) The Data Buffer can store over 130 readings when the Program Buffer is not in use and over 45 readings can be stored when all 10 Program Buffers are used. This is described in Section 3.4.12.4 which discusses Buffer Organization.

d) The Data Buffer is a first-in-first-out (FIFO) register; therefore during recall location Ø contains the first stored reading, location 1 contains the second, etc.

3.4 .3.2 Unlike most ESC features of the DMM, the Data Buffer cannot be disabled or "turned-off"; therefore it is always either in the storing process or the register capacity is completely filled. The two operations which can be performed on the buffer are clearing (CE) and recalling (RECALL). Everytime that a reading is taken, it is first processed by other ESC functions such as NULL, %, and LAH. Then the Data Buffer is checked for space availability. If available, a copy of the processed reading is stored into the buffer. The buffer will remain filled until cleared and the readings from the buffer can be recalled any number of times to the display or the GPIB.

3.4.13.3.3 The Data Buffer will power-up in the cleared or empty state. Therefore data readings must be taken or accumulated in the buffer before attempting to recall the data readings from the Data buffer otherwise the DMM will either show mostly a blank display to a bench operator or send an SRQ to the controller if in remote. In order to prevent the Data Buffer from being accidentally cleared from the keyboard (GPIB procedure is described in paragraph 3.5.28) a time delay is inserted in the Keyboard Buffer Clear routine. To clear the Data Buffer, the BUFF key must be depressed until the seven-segment display shows the entire word "ClrbuF". This should take about five seconds.

3.4.13.3.4 The recalling of readings from the Data Buffer to the display (GPIB procedure is described in paragraph 3.5.9) can be accessed sequentially and displayed on the DMM's front panel by following the procedure listed below:

a) Press the RECALL key. The display will show "rCL".

b) Press the BUFF key. A number will appear at the right edge of the display, assuming that the buffer is not completely emptied or cleared. This number is the buffer address that will be recalled when the BUFF key is released. Depressing the BUFF key for two seconds enables the displayed address to increment and will eventually reach the point where the last reading was stored. The displayed address will then return to zero and begin incrementing up again. If the user wishes to initialize the recall process to address the first constant, the procedure listed next should be followed.

1) DO NOT DEPRESS THE RECALL KEY.

2) Depress the BUFF key and monitor the display.

3) The display will show "Clr" as the BUFF key is depressed. Release the key after appearance of the r in "Clr".

4) This will initialize the recall address to 00.

3.4.13.4 BUFFER ORGANIZATION.

3.4.13.4.1 By allowing the two buffers to share the same memory, more readings can be stored into the data buffer (over 130) when the program buffer is not in use. This is best described by reviewing Figure 3.14A and Figure 3.14B which show the relation between Program and Data buffers.

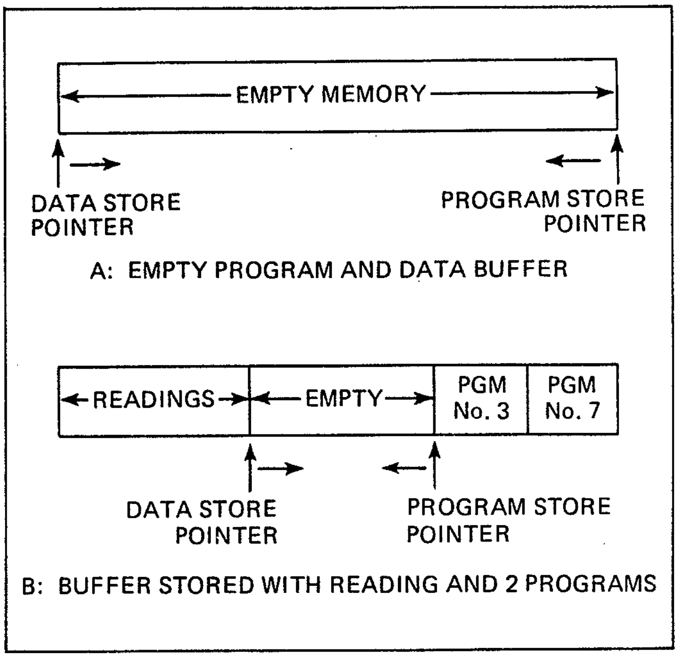


Figure 3.14 - Program and Data Buffer Storage

3.4.13.4.2 There are two pointers associated with the buffer operation as shown in Figure 3.14. The Program Store pointer points to the next available program storage location, moving right to left as programs are stored. The Data Store pointer points to the next available data storage, moving left to right as readings are stored. The Data Store pointer bumps into the Program Store pointer when the memory block is full. Hence, no more readings are stored until the data buffer is cleared.

3.4.14.4.3 When the Program and Data Buffers are used simultaneously, the Data Buffer must operate with a smaller memory space, as shown in Figure 3.14B. From the figure, it is noted that program No. 7 and program No. 3 have been stored in the buffer. This has reduced the number of readings which can be stored.

3.4.13.4.4 Data Buffer size can be determined when Data and Program Buffers are used simultaneously. The following equation can be used to determine the number of readings which can be stored:

No. of Readings = 130 – (7·N)

where N is the number of programs which were stored (N = 2 in Figure 3.14B).

3.4.14 Error Messages.

3.4.14.1 Error messages are classified in two categories, General Error Messages and GPIB Error Messages. The general error messages with numerics 0 through 9 apply to local and remote operations. GPIB error messages with numerics 10 through 13 apply only to remote operation.

3.4.14.2 For local operation, the DMM employs the 7-segment display to exhibit the error message code numbers. The error message numbers and explanations are listed in Table 3.6; General and Remote Error Messages.

3.4.14.3 For remote GPIB operation, the DMM transmits an SRQ to the controller; the controller replies with the "Y" program code to the DMM to request the error message number. The remote error message numbers and explanations are listed in Table 3.6. Refer to Section 3.5.20 for further explanation of the "Y" program code.

Table 3.6 - General and Remote Error Messages

Error Message No.	Error Message
	GENERAL ERROR MESSAGES
0	Percent Constant: 0 during Percent calculations.
1	Not in the DC function, 0.1 range when executing DIGITAL ZERO command.
2	Attempting to execute DIGITAL ZERO command with an input voltage applied or the input open-circuited. Connect a short across input terminals and repeat DIGITAL ZERO command.
3	The microprocessor's on-board RAM is defective (U35 on the motherboard).
4	The contents of the non-volatile memory have been disrupted, therefore the instrument's calibration should be verified.
5	A digitizer offset greater than 1000 digits was measured during execution of DIGITAL ZERO command.
6	Percent Deviation of $\geq 10^{10}$% while in the Percent Function.
7	The RAM is defective, U22 and/or U31 on the motherboard.
8	An attempt was made to store a overload reading to a register inside the DMM or an attempt was made to store > 99.5959 hours into a Time function register.
9	At attempt was made to recall a program setting from the program buffer before setting was stored to the program buffer.
	GPIB ERROR MESSAGES
10	Recall of a constant whose value is empty set, for example - sending an "L7" command to a DMM will cause this error if the LOW, AVERAGE, and HIGH constants are the empty set (no readings taken yet.)
11	Triggered too fast or too often.
12	Syntax error during GPIB programming.
13	Option not installed.

3.4.15 DMM Pulse Level/Timing Characteristics.

3.4.15.1 EXTERNAL TRIGGER.

3.4.15.1.1 The signal level and timing requirements for the external trigger are presented in Figure 3.16A. These timing requirements are not critical when in local control as the DMM interprets a tight group of external triggers as a single trigger command and the rise and fall time specifications stated in Figure 3.16A do not apply, due to this internal debouncing. This allows the use of mechanical foot switches and other "noisy" signal sources with good results. When in remote, all external triggers are treated individually and two or more closely spaced triggers will cause the DMM to issue an SRQ to the bus and make an error message available to the controller.

3.4.15.2 SYNC OUTPUT.

3.4.15.2.1 The DMM provides a synchronizing output pulse from a BNC connector on the rear panel. Refer to Figure 3.2. This pulse, timing shown in Figure 3.16B, indicates when the DMM has finished a reading or a sequence of readings. This output pulse can be used to sequence a signal scanner or other device as shown in Figure 3.16C.

3.4.15.2.2 When Autorange is selected, the sync output will not appear until the DMM has completed autoranging, and has taken the reading on the proper range.

3.5 SYSTEM OPERATION.

3.5.1 This subsection presents information on the operation of the DMM in a system.

3.5.2 General Purpose Interface Bus.

3.5.2.1 The IEEE-488-1978 (GPIB) Interface provides remote programming for all controls and the output of data from the DMM. Inputs and outputs are made via a 24 pin connector, (see Figure 3.15), located on the rear panel. The pin location, line identification, and operation of the GPIB are in compliance with IEEE-STD-488-1978. The GPIB provides interface capability with other instruments and with a controller also utilizing the "interface bus" structure. Connector pin assignments are shown in Figure 3.17. The IEEE-488-1978 subsets available are listed in Table 3.7.

3.5.2.2 By assigning a unique address to the DMM, it can be "called up" by the controller or another device on the bus without interfering with other units on the bus. Switches located on the rear panel of the DMM permit the programming of the instrument address. The coding used for the address is binary. Any one of 31 codes can be used for the address of an instrument, but a total of 15 is the maximum number of devices that can be used on one bus.

Table 3.7 - IEEE-488-1978 Standard Interface Subset Capability

GPIB Subset	Description	Applicable Capability
SH1	Source Handshake	Complete Capability
AH1	Acceptor Handshake	Complete Capability
T5	Talker	Complete Capability (1) Basic Talker (2) Serial Poll (3) Talk only Mode (4) Unaddress if MLA
TE0	Extended Talker	None
L4	Listener	Complete except Listen Only (1) Basic Listener (2) Unaddress if MTA
LE0	Extended Listener	None
SR1	Service Request	Complete Capability
RL1	Remote/Local	Complete Capability (1) REN - Remote Enable (2) LLO - Local Lockout (3) GTL - Go to Local
PP0	Parallel Poll	No Capability
DC1	Device Clear	Complete Capability (1) DCL - Device Clear (2) SDC - Selected Device Clear
DT1	Device Trigger	Complete Capability GET - Group Execute Trigger
C0	Controller	No Capability
E1	Open Collector Bus Drivers	

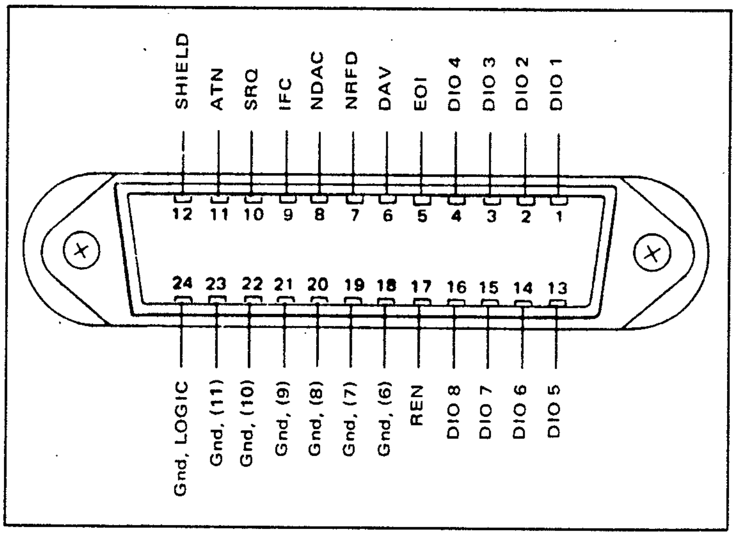


Figure 3.15 - GPIB Connector (Rear Panel)

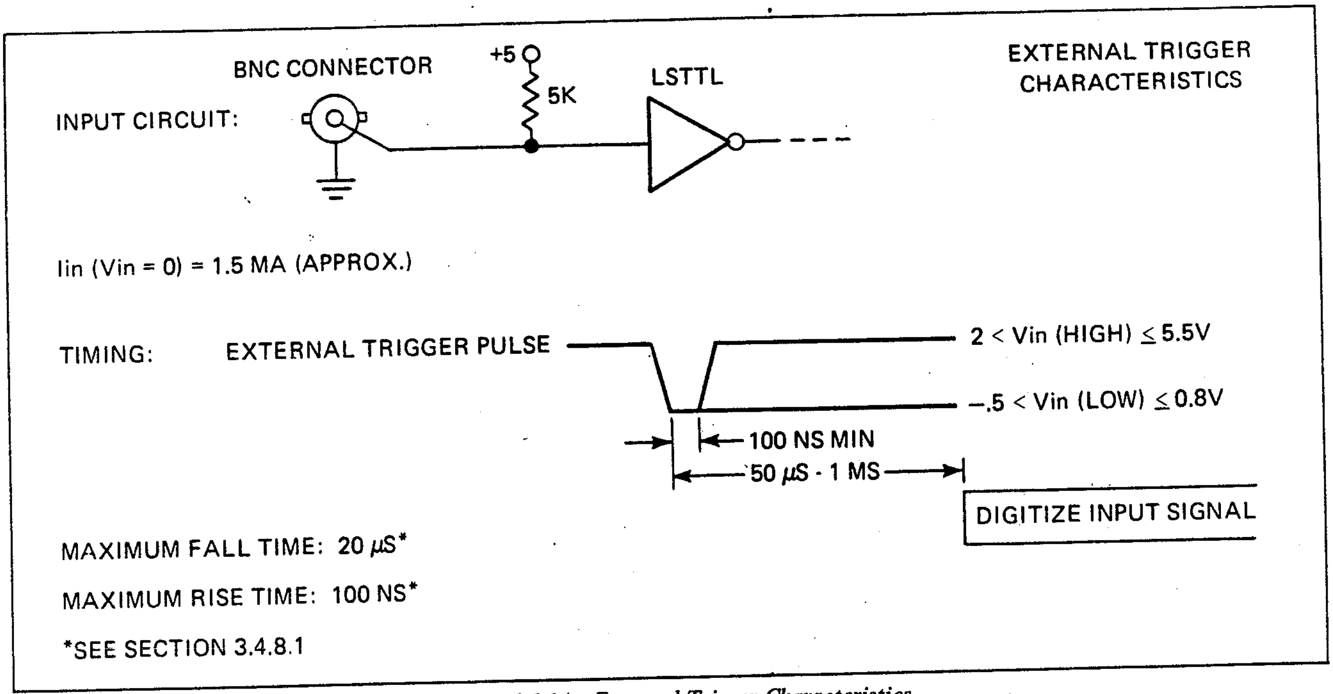


Figure 3.16A - External Trigger Characteristics

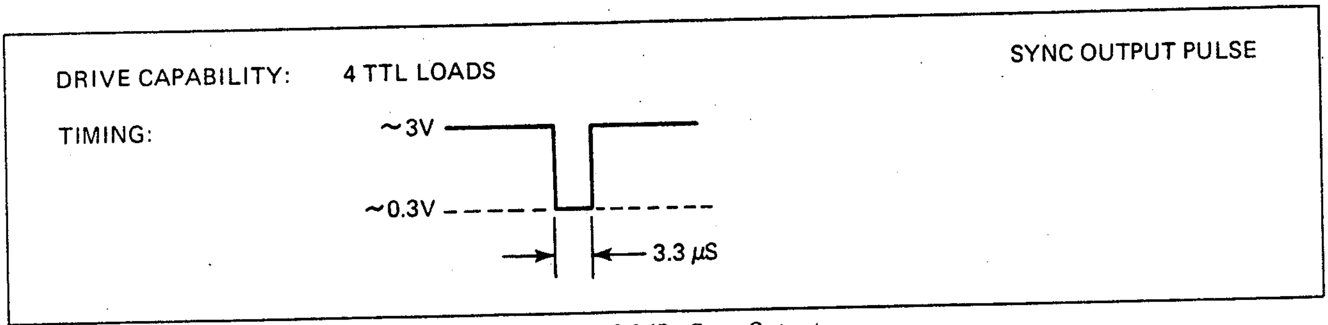


Figure 3.16B - Sync Output

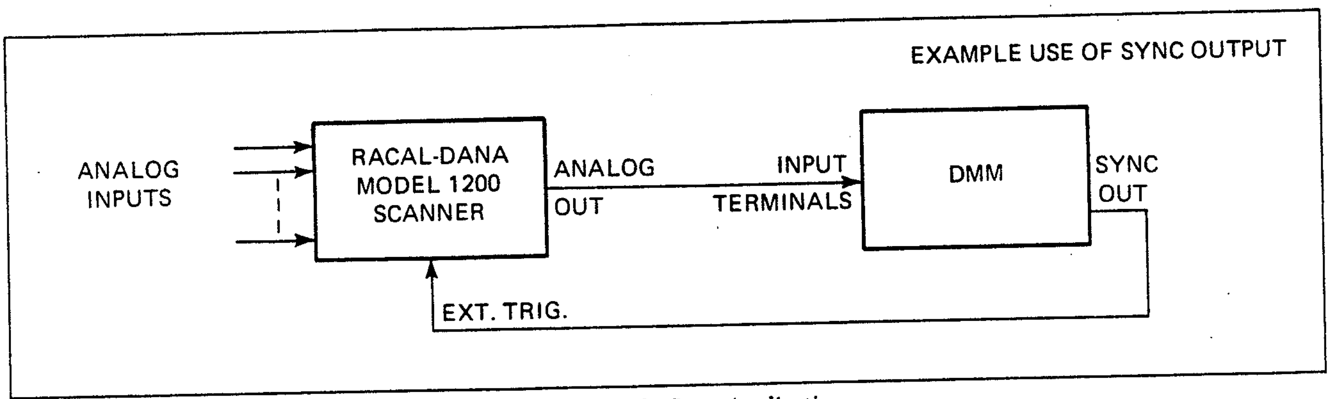


Figure 3.16C - Sync Application

3.5.3 GPIB Description.

3.5.3.1 Of the twenty-four lines available at the connector (shown in Figure 3.15) seven are grounds, one is a shield, and the remaining 16 lines are the signal lines. All of the signal lines are either input or output lines and have the following characteristics:

Logic Levels:	(1 = Low = ≤ .8V) (0 = Hi = ≥ 2.0V)
Input Loading:	Each input ∿ two TTL loads
Output:	The output is capable of driving 15 interface bus loads. It consists of an open collector driver and is capable of sinking 48 mA with a maximum voltage drop of 0.5 volts. See IEEE-488 Electrical Specifications.

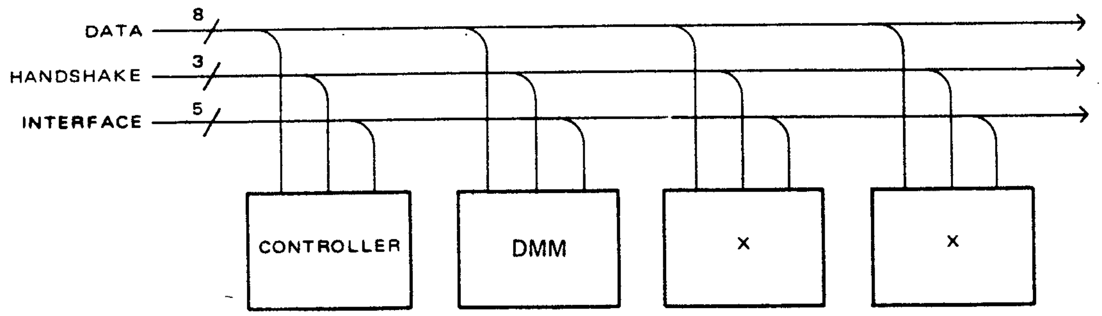
3.5.3.2 The signal lines, as shown in Figure 3.17 consist of three functionally separate sets: Data, Handshake and Interface.

3.5.3.3 DATA.

3.5.3.3.1 The data lines consist of lines DI0-1 through DI0-8. These lines are the lines over which data flows between all instruments on the bus in bit parallel, byte serial form.

3.5.3.4 HANDSHAKE.

3.5.3.4.1 The transfer lines consist of: DAV (data valid), NDAC (not data accepted), and NRFD (not ready for data). These lines provide communication (between the instrument that is talking and the instruments that are listening) to



PIN			PIN	
1	DIO-1 Data In/Out Bit 1 (LSB)	DATA LINES ARE USED TO TRANSFER DATA FROM ONE INSTRUMENT TO ANOTHER	12	SHIELD
2	DIO-2 Data In/Out Bit 2		18	GND
3	DIO-3 Data In/Out Bit 3		19	GND
4	DIO-4 Data In/Out Bit 4		20	GND
13	DIO-5 Data In/Out Bit 5		21	GND
14	DIO-6 Date In/Out Bit 6		22	GND
15	DIO-7 Data In/Out Bit 7		23	GND
16	DIO-8 Data In/Out Bit 8		24	LOGIC GND
6	DAV (DATA VALID)	HANDSHAKE LINES OPERATE IN A PROPER TIME SEQUENCE FOR COMPLETE COMMUNICATION BETWEEN INSTRUMENTS	25	NOT USED
7	NRFD (NOT READY FOR DATA)			
8	NDAC (NOT DATA ACCEPTED)			
5	EOI (END OR IDENTIFY)	INTERFACE LINES ARE USED TO PROVIDE AN ORDERLY FLOW OF INFORMATION BETWEEN UNITS		
9	IFC (INTERFACE CLEAR)			
10	SRQ (SERVICE REQUEST)			
11	ATN (ATTENTION)			
17	REN (REMOTE ENABLE)			

Figure 3.17 - Interface Signal Pin Assignments

synchronize the flow of information across the eight data lines. These lines derive their nomenclature from their meaning in the low or one state (eg: when NRFD is low the device is Not Ready For Data).

a. DAV. Signifies that valid information is available on the data lines.

b. NRFD. Signifies that the instrument is not ready to accept information.

c. NDAC. Signifies that the information is not accepted by the acceptor.

3.5.3.5 INTERFACE.

3.5.3.5.1 The five interface lines coordinate the flow of information on the bus.

a. Interface Clear
'IFC'. Places the DMM interface in the IDLE state. (Untalk, Unlisten).

b. Attention
'ATN'. Indicates the nature of information on data lines during a handshake transfer sequence. Low indicates data lines carry interface commands; high indicates that the data lines carry data.

c. Remote Enable
'REN'. Arms instrument to select Remote Operation. (Low for Remote)

d. Service Request
'SRQ'. Service request signal line. Signals the controller that a peripheral or bus member wants attention for such purposes as transmitting measurement, status or condition information to the bus controller.

e. End or Identify
'EOI'. End or Identify signal. Used for two purposes: (1) to signify the end of a message and (2) to signal bus peripherals to set the I/O bit assigned for parallel poll identification process.

3.5.4 GPIB Bus Structure.

3.5.4.1 The bus structure, to maintain an orderly transfer of data between the controller and devices, requires eight signal lines. Three signal lines (DAV, NRFD, and NDAC) to regulate transfers control are referred to as handshaking. Five signal lines (EOI, IFC, SRQ, ATN, and REN) to handle interface management are necessary to maintain a bi-directional data follow. The data lines D101 through D108 carry the bit parallel byte serial information between the talker and listener. Figures 3.17 and 3.18 illustrate the sequential relationship between DAV, NRFD and NDAC lines.

3.5.5 Address Assignment.

3.5.5.1 When the DMM is used as a system instrument it must be assigned an address as a bus member. The instrument is equipped with an address switch located on the rear panel which enables the user to assign it one of 31 decimal addresses. The decimal addresses available are the numbers 00 through 30.

3.5.5.2 Table 3.8 contains all of the information required for setting the instrument address switch and for determining the talk and listen address codes used in programming the controller.

3.5.5.3 Refer to Table 3.8 and note that the right hand column shows the decimal addresses available for assignment to the DMM. The column titled Address Switch Setting illustrates the positions of the switches for each decimal address. To set the address on the instrument at the desired decimal address, refer to Table 3.8, and set the switches on the address switch to the pattern shown in the Address Switch column of the table.

3.5.5.4 As an aid in setting the address switches, the decimal address may be displayed on the DMM readout by holding the "Local" key down. The address switches may then be set until the desired address appears on the display. Turning on the "Talk Only" switch will cause the displayed address to be 64 or greater. This illegal address is displayed to alert the user that the DMM is in the "talk only mode".

3.5.5.5 Once the instrument has been assigned an address, and the address switch has been set, the controller may address the instrument as a talker or as a listener by transmitting the appropriate ASCII character on the data lines. The Data Lines column shows the 7 bit binary code required for each talk and listen address assigned to the instrument. These are the codes the controller must transmit to establish the talker/listener condition of the DMM. Note that there are two address codes used for each decimal address. Each of these address codes constitutes a different ASCII character. For example, if it is desired to use the decimal address 02, the address switch on the rear panel of the instrument is set to the pattern shown in Table 3.8. As shown in the table, the talk address is the ASCII character " and the listen address is the ASCII character B. Note that the only difference in the binary code in each case is the state of data lines D6 and D7.

3.5.5.6 Table 3.8 illustrates the data line code in binary form for each decimal address. Again, using the example for decimal address 02, note that bits D1 through D5 are the same for both talk and listen address and that the only difference is in bits D6 and D7.

3.5.6 Bus Operation Sequence.

3.5.6.1 The transmission of programming instructions to the DMM and the subsequent transmission of measurement data to the controller are accomplished by transmitting programming instructions as outlined in the bus operation sequence in Table 3.9. Table 3.9 and the accompanying timing chart (Figure 3.19) illustrate the sequence of the transmission of device dependent messages to the DMM which cause it to measure the voltage applied to the input and then transmit the resultant measurement data to the controller via the interface bus.

3.5.6.2 Note that the left hand column of Table 3.9 contains line numbers. These are used for reference purposes throughout the following description of the bus operation sequence. The column titled Handshake Lines indicates the high/low condition of the handshake lines at various points throughout the two-way transmission of information. In a similar fashion the columns titled Interface Lines and Data Lines contain entries reflecting the state of the interface lines and data lines during operation. The column titled Meaning or Function contains entries explaining the purpose of each operational step during the data transfer.

3.5.6.3 A timing chart is included to illustrate the condition of each individual bus line at each stage of the data transfer operation. Note that the timing chart includes numbers adjacent to each level change. These numbers refer to the individual line entries of the table.

3.5.6.4 The measurement operation used in Table 3.9 is a simple voltage measurement. The measurement parameters are as follows: Function DC volts, Range 10 volts, Trigger continuous. Note that the measurement parameters are shown in the meaning or function column of the table in lines 17 through 22 and that the program string required to perform this measurement is F1R5T1. The program string will include a carriage return and line feed, but in this case this command is automatically transmitted by the Hewlett Packard 9825.

3.5.6.5 For purposes of this example it is assumed that the DMM has been assigned the decimal address 02 and that the controller is a Hewlett Packard 9825 calculator with a talk address U. It is further assumed that both the controller and the DMM are system connected, turned on and operational.

3.5.6.6 Table 3.9 shows the sequence of bus operation. Lines 1 through 13 show the detailed operation of the bus for one handshake cycle (ie: the transmission of one ASCII character as a bus message). Lines 14 through 44 do not indicate the detail for each handshake cycle; they indicate only the transmission of the characters required for the programming commands and the subsequent transmission of the data by the DMM. Each transmission by the controller or the DMM, shown in lines 14 through 44, requires the handshake cycle illustrated by line entries 1 through 13 of the table.

3.5.6.7 Refer to Table 3.9, line 1, and note that the first operation performed is the setting of the Remote Enable (REN) line to the low state. As explained in the table, this operation arms the bus members to go to the remote mode. The controller then transmits the interface clear (IFC) signal which stops bus activity and the attention (ATN) line is set low indicating that the next data byte placed on the bus by the controller will be a Bus Message. Note in the timing chart that when the ATN line is set low (3) that the DMM responds by setting the NRFD line high (4). This response by the DMM indicates that it is now ready to accept data.

3.5.6.8 When the DMM transmits the ready for data signal by setting the NRFD line high (line 4 of Table 3.9) the controller puts the bus message UNL on the data lines. As shown in line 5 of the table this is the ASCII character ?. The unlisten message is a universal message understood by all bus members as the command "unlisten". Having placed the data character on the lines, the controller now says the data is valid by setting the DAV line low (6). The DMM then says "I'm going to accept the data now on the data lines; don't change the data lines". The DMM then reads the data lines (8) and acknowledges acceptance of the data by setting the NDAC line high (9). The controller then removes the data valid signal (10), removes or changes data (11) and the DMM removes the data accepted signal from the bus (12).

3.5.6.9 At this point, one ASCII character has been transmitted by the controller to the DMM and the DMM is now ready to accept a new data byte. It indicates this (13) by setting the NRFD line high. The controller now puts the next character on the data line and the handshake cycle for the transfer of the character is repeated. The next character transmitted by the controller is the ASCII character U which is the talk address of the Hewlett-Packard 9825 calculator. As indicated in Table 3.9, by transmitting this character the calculator is making itself a talker. The next character transmitted is the quotation mark which is the listen address of the DMM when it has been assigned the decimal address 02.

3.5.6.10 Lines 16 through 24 of the table illustrate the sequence of transmission of the program string which instructs the DMM to make the DC voltage measurement. Lines 26 and 29 of the table indicate the end of transmission with the characters CR (carriage return) and LF (line feed). Note that at line 16 of the table the controller sets the ATN line high indicating that the program string to follow in lines 17 through 24 are device dependent messages.

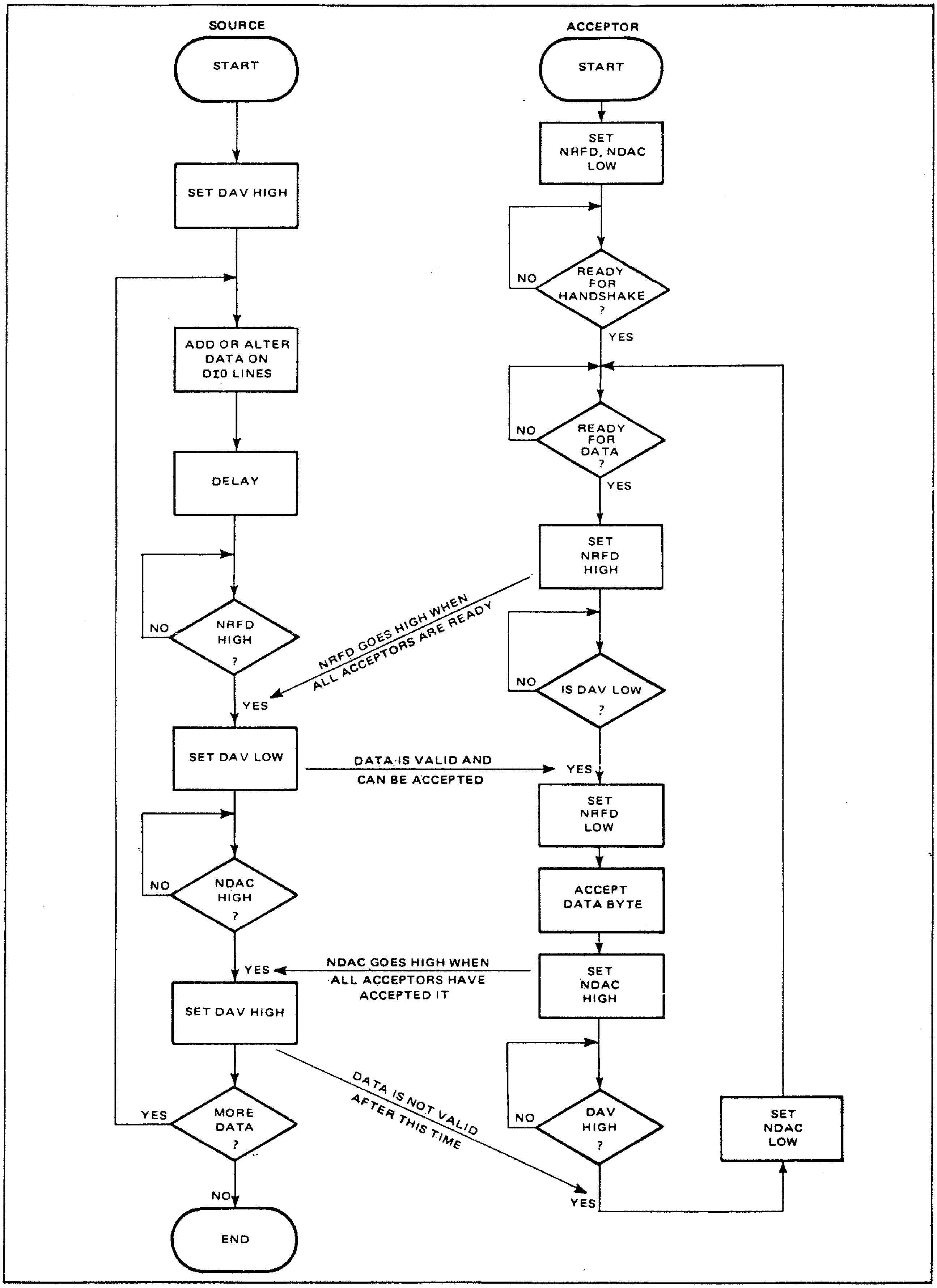
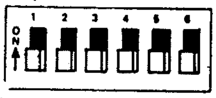
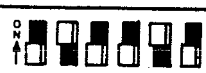
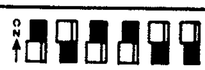
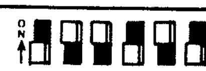
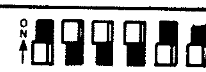


Figure 3.18 - Handshake Flow Chart

Table 3.8 - Instrument Address Selector

ASCII CHARACTERS TALK	ASCII CHARACTERS LISTEN	D7 TALK	D6 LISTEN	D5 (ADDRESS 16)	D4 (ADDRESS 8)	D3 (ADDRESS 4)	D2 (ADDRESS 2)	D1 (ADDRESS 1)	ADDRESS SWITCH SETTING (TALK ONLY, A5 A4 A3 A2 A1)	DECIMAL ADDRESS
	SP	0	1	0	0	0	0	0		00
@		1	0	0	0	0	0	0		
	!	0	1	0	0	0	0	1		01
A		1	0	0	0	0	0	1		
	"	0	1	0	0	0	1	0		02
B		1	0	0	0	0	1	0		
	#	0	1	0	0	0	1	1		03
C		1	0	0	0	0	1	1		
	$	0	1	0	0	1	0	0		04
D		1	0	0	0	1	0	0		
	%	0	1	0	0	1	0	1		05
E		1	0	0	0	1	0	1		
	&	0	1	0	0	1	1	0		06
F		1	0	0	0	1	1	0		
	' (APOSTROPHE)	0	1	0	0	1	1	1		07
G		1	0	0	0	1	1	1		
	(	0	1	0	1	0	0	0		08
H		1	0	0	1	0	0	0		
	)	0	1	0	1	0	0	1		09
I		1	0	0	1	0	0	1		
	*	0	1	0	1	0	1	0		10
J		1	0	0	1	0	1	0		
	+	0	1	0	1	0	1	1		11
K		1	0	0	1	0	1	1		
	,	0	1	0	1	1	0	0		12
L		1	0	0	1	1	0	0		
	–	0	1	0	1	1	0	1		13
M		1	0	0	1	1	0	1		
	.	0	1	0	1	1	1	0		14
N		1	0	0	1	1	1	0		
	/	0	1	0	1	1	1	1		15
O		1	0	0	1	1	1	1		

ASCII CHARACTERS TALK	ASCII CHARACTERS LISTEN	D7 TALK
	Ø	0
P		1
	1	0
Q		1
	2	0
R		1
	3	0
S		1
	4	0
T		1
	5	0
U		1
	6	0
V		1
	7	0
W		1
	8	0
X		1
	9	0
Y		1
	:	0
Z		1
	;	0
[		1
	<	0
\		1
	=	0
]		1
	>	0
^		!
NONE		

S	DATA LINES							ADDRESS SWITCH SETTING	DECIMAL ADDRESS
	D_7	D_6	D_5	D_4	D_3	D_2	D_1	TALK ONLY A5 A4 A3 A2 A1 1  0	
	TALK	LISTEN	ADDRESS						
			16	8	4	2	1		
	0	1	1	0	0	0	0		16
	1	0	1	0	0	0	0		
	0	1	1	0	0	0	1		17
	1	0	1	0	0	0	1		
	0	1	1	0	0	1	0		18
	1	0	1	0	0	1	0		
	0	1	1	0	0	1	1		19
	1	0	1	0	0	1	1		
	0	1	1	0	1	0	0		20
	1	0	1	0	1	0	0		
	0	1	1	0	1	0	1		21
	1	0	1	0	1	0	1		
	0	1	1	0	1	1	0		22
	1	0	1	0	1	1	0		
	0	1	1	0	1	1	1		23
	1	0	1	0	1	1	1		
	0	1	1	1	0	0	0		24
	1	0	1	1	0	0	0		
	0	1	1	1	0	0	1		25
	1	0	1	1	0	0	1		
	0	1	1	1	0	1	0		26
	1	0	1	1	0	1	0		
	0	1	1	1	0	1	1		27
	1	0	1	1	0	1	1		
	0	1	1	1	1	0	0		28
	1	0	1	1	1	0	0		
	0	1	1	1	1	0	1		29
	1	0	1	1	1	0	1		
	0	1	1	1	1	1	0		30
	1	0	1	1	1	1	0		
ILLEGAL								NONE	31

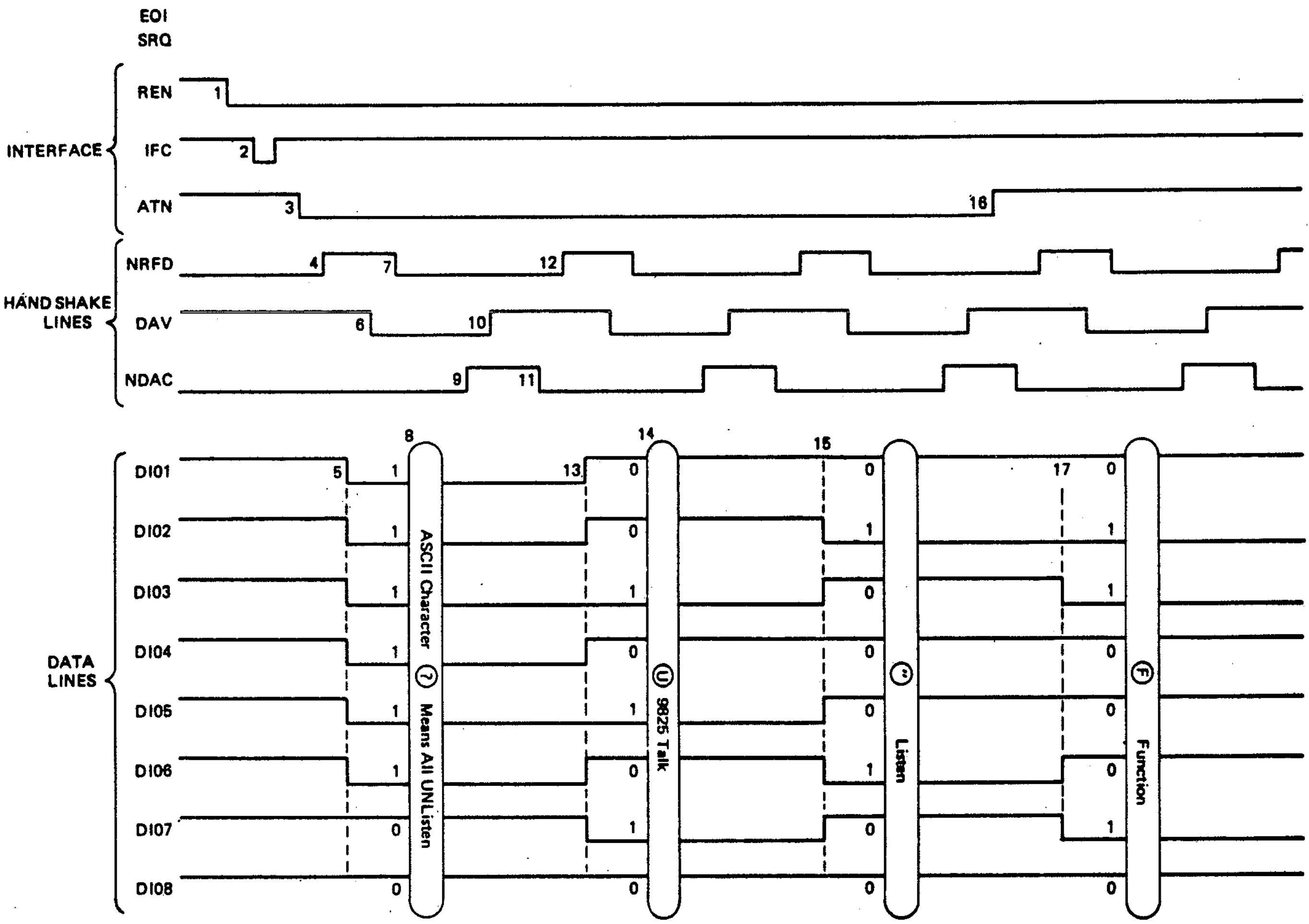


Figure 3.19 - Interface Timing

Table 3.9 - Bus Operation Sequence

	HANDSHAKE LINES	BUS LINES	DATA LINES	MEANING OR FUNCTION
1		REN Lo		Arms bus peripherals to go to remote mode.
2		IFC		Stops activity on the bus.
3		ATN Lo		Signifies that data byte will be a "Bus Message".
4	NRFD Hi			DMM says ready for data.
5			?	UNL (Unlisten) message (ASCII character ?) on data bus by controller means "all bus peripherals unlisten".
6	DAV Lo			Controller says data on bus is valid.
7	NRFD Lo			DMM says its not ready for new data; do not change data lines while DMM is accepting data.
8				DMM reads data lines.
9	NDAC Hi		↓	DMM says it has read data.
10	DAV Hi		?	Controller says data no longer valid.
11	NDAC Lo			DMM removes data accepted flag.
12	NRFD Hi			DMM says it's ready for next data byte.
13				Controller removes or changes data on bus.
14			U	"I talk", controller becomes talker (HP9825 talker address).
15			"	"You listen", addressed peripheral becomes listener (In this case it is the DMM set to decimal address 02; see table 3.9).
16		ATN Hi		Signifies that data byte will be a "Device Dependent Message" as opposed to an "Interface Message".
17			F	Function
18			1	DC Volts
19			R	Range
20			5	10 Volts
21			T	Trigger
22			1	Continuous
23			CR	End of transmission by HP9825.
24			LF	
25		ATN Lo		Byte to follow is a Bus Message.
26			?	UNL (unlisten) bus message.
27			B	"You talk", DMM talk address (02).
28			5	"I listen", HP9825 listen address.
29		ATN Hi		Message to be transmitted by DVM is Data.
30			+	Measurement data transmitted by DMM (rows 30–37)
31			1	
32			•	
33			0	
34			2	
35			5	
36			4	
37			6	
38			E	Exponent Indicator means X 10^{01}
39			+	Sign of exponent.
40			0	Exponent. Here it indicates 10^{10} (rows 40–41)
41			1	
42			CR	End of data message. (rows 42–43)
43			LF	

3.5.6.11 Having transmitted the program string of device dependent messages to the DMM, the controller then sets the ATN line low which indicates that the characters to follow in lines 26 through 28 are bus messages. These bus messages change the talker/listener relationship of the controller and DMM; the DMM is made a talker and the controller becomes a listener.

3.5.6.12 Lines 30 through 43 illustrate the sequence of the transmission of data by the DMM. The handshake sequence is the same when the DMM is transmitting data as that outlined in lines 1 through 13 of the table, except that the DMM is controlling the handshake lines.

3.5.6.13 Upon completion of the data transmission, the DMM transmits a carriage return (CR) and line feed (LF) to indicate the end of the data transmission. Refer to Table 3.10 for the GPIB programming requirements.

Table 3.10 - GPIB Programming Requirements

1.	Character Code: 7 bit ASCII, upper or lower case.
2.	All program strings transmitted to the DMM should end in a terminating character. Acceptable terminators are: A. CR - Carriage Return B. LF - Line Feed C. EOI - This GPIB message EOI, true during transfer of the last byte of a string. D. X - ASCII letter.
3.	Programming numerical constant over the GPIB The following units are assumed when programming numerical constants over the GPIB: Volts Kohms, Hours . Minutes Seconds

3.5.7 Interface Message Repertoire.

3.5.7.1 The DMM is equipped with a standard GPIB interface which conforms to the specifications contained in IEEE-488-1978. The specification includes the definition of multi-line interface messages and this definition divides the messages into two groups; the primary command group and the secondary command group. The DMM includes none of the secondary command group in its interface message repertoire.

3.5.7.2 The primary command group of interface messages is further broken down into four lower categories: (1) the listen address group, (2) the talk address group, (3) the universal command group and (4) the addressed command group. The DMM is designed to include in its interface message repertoire 31 listen addresses and 31 talk addresses. The listen and talk addresses to which the DMM may be set are listed in Table 3.8.

3.5.7.3 The interface messages to which the DMM is designed to respond are listed in Table 3.11 along with their decimal equivalents, hex equivalents, meanings and data line codes. The function of the DMM in response to each of these commands is described in the following paragraphs.

3.5.7.4 GO TO LOCAL (GTL).

3.5.7.4.1 As shown in Table 3.11, the GTL command means go to local and the decimal and hex equivalent are both 01. Upon receipt of this interface message, the DMM, if previously programmed for remote, will return to its local operational state. This means that the instrument will then perform the function according to the settings of the front panel controls on the instrument until such time as it returns to remote control.

3.5.7.5 SELECTED DEVICE CLEAR (SDC).

3.5.7.5.1 Upon receipt of the SDC command, the DMM will go to the home state. The decimal and hex equivalent are both 04. The SDC message has the same effect as transmitting the GPIB program code 'Z' to the DMM.

3.5.7.6 GROUP EXECUTE TRIGGER (GET).

3.5.7.6.1 As shown in Table 3.11, the decimal and hex equivalents of the GET command are both 08. Upon receipt of the GET interface message, the DMM will trigger a reading if it had previously been placed in the HOLD mode. The group execute trigger command is used to trigger the simultaneous execution of a number of functions by a number of bus members at the same time. To use this command, one or more bus members are programmed to perform a function on receiving the GET interface message. Subsequently, the controller will transmit the GET command and all bus members previously programmed will begin execution on receipt of the command.

3.5.7.7 LOCAL LOCK OUT (LLO).

3.5.7.7.1 The DMM may be brought back into local control by pressing the "Local" key on the keyboard. If, however, the DMM receives an LLO (Hex 11 or decimal 17) command while in remote operation, it may not be brought back into local control through keyboard operation.

3.5.7.8 DEVICE CLEAR (DCL).

3.5.7.8.1 The decimal equivalent of the DCL command (as shown in Table 3.11) is 20, and the hex equivalent is 14. This command is identical in operation to the SDC command except that the DMM need not be a listener in order to respond to DCL. When this command is transmitted on the bus, all devices on the bus which respond to the DCL will clear. The DCL message has the same effect on the 5005 as transmitting the GPIB program code 'Z'.

3.5.7.9 SERIAL POLL ENABLE (SPE).

3.5.7.9.1 As shown in Table 3.11, the decimal equivalent of this interface command is 24; the hex equivalent is 18. The function of this command is to notify all bus members that they should output their serial poll status if made into a talker. Thus, when a bus member has transmitted a service request (SRQ), the bus controller can transmit the serial poll enable command, command each bus member to transmit its status byte by sequentially making each bus member a talker and thus identify the bus member requesting attention. Upon receipt of the DMM's talk address plus the SPE interface message, the DMM immediately prepares a status byte for transmission to the controller. If the DMM has previously transmitted an SRQ, it will set bit 7 of the status byte to 1. The serial poll allows a bus member to set the service request line to the 1 state, thus indicating to the controller that it wants attention. The controller may then sequentially interrogate each bus member to determine which one has requested service and the purpose of the request. The meanings of the bits in the status bytes are shown in Figure 3.20 and listed below:

a) Requested Service (DIO7). This bit indicates whether the DMM caused the SRQ (service request) line to be driven to the 'true' state; thus the controller can determine if the DMM is requesting service.

b) Abnormal Condition (DIO6). If true, this bit indicates the presence of an illegal or abnormal condition in the DMM, and is always in the same logical state as the DIO4 bit (see below).

c) Signal Integrate (DIO5). This bit is true during the time that the input (or external reference) signal is being measured by the DMM. In measurement systems where high throughput is important, this can be sampled by the controller to determine the earliest moment that the DMM's input signal can be changed, thus allowing multiple input signals to be measured in rapid succession. Note however that if the DMM is programmed to AUTO range, the Signal Integrate bit will go true multiple times as the DMM upranges or downranges.

d) Error Number Available (DIO4). This bit, which tracks bit DIO6 exactly, indicates that the DMM's Error Message register has been updated with a new error message. The error message can be retrieved

Table 3.11 - Interface Messages Used With The DMM

Message	Meaning	HEX CODE	Decimal Equiv.	DATA LINE CODE 7	6	5	4	3	2	1
GTL	Go To Local	01	1	0	0	0	0	0	0	1
SDC*	Selected Device Clear	04	4	0	0	0	0	1	0	0
GET*	Group Execute Trigger	08	8	0	0	0	1	0	0	0
LLO	Local Lock Out	11	17	0	0	1	0	0	0	1
DCL	Device Clear	14	20	0	0	1	0	1	0	0
SPE	Serial Poll Enable	18	24	0	0	1	1	0	0	0
SPD	Serial Poll Disable	19	25	0	0	1	1	0	0	1
UNL	Unlisten	3F	63	0	1	1	1	1	1	1
UNT	Untalk	5F	95	1	0	1	1	1	1	1

*Instrument will ignore message unless it is a listener over the bus by use of the 'Y' command which is described in Section 3.5.20.

e) Data Ready (DIO1). This bit is affected by the completion of a reading as well as the most recently programmed Interrupt Command (D0-D3). Section 3.5.22 gives more details on the Interrupt (D0-D3) commands.

3.5.7.10 SERIAL POLL DISABLE (SPD).

3.5.7.10.1 As shown in Table 3.11 the decimal equivalent to the SPD command is 25; the hex equivalent is 19. The function of this command is to return the bus members to their original states after the serial poll transaction has been completed.

STANDARD OUTPUT: ±D.DDDDD E ± DD CR LF

USED FOR OUTPUT OF READINGS AND NUMERICAL CONSTANTS.

WHERE D = DATA BYTE
E ± DD = EXPONENT DATA BYTES
CR = CARRIAGE RETURN
LF = LINE FEED

OUTPUT UNITS (IMPLIED)

READING OUTPUT: VOLTS, OHMS
CONSTANT OUTPUT: VOLTS, KOHMS, HOURS. MINUTES SECONDS

SERIAL POLL OUTPUT (SINGLE BYTE)

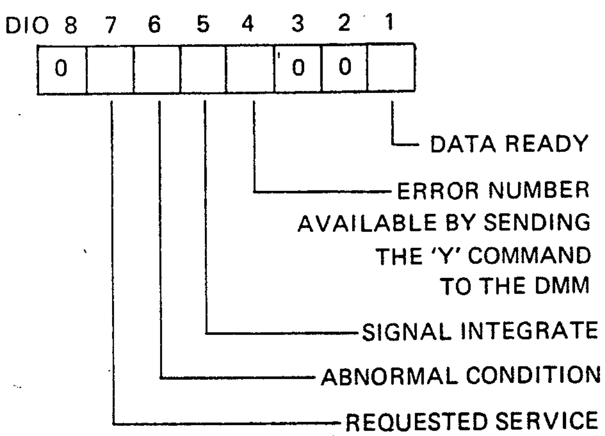


Figure 3.20 - GPIB Output Formats

3.5.7.11 UNLISTEN (UNL).

3.5.7.11.1 As shown in Table 3.11 the decimal equivalent of this command is 63; the hex equivalent is 3F. This command is also a universal interface message understood by all members of the bus as a command to go to the unlisten state. When this command is transmitted, all bus members previously in the listen state will return to the unlisten state.

3.5.8 Device Dependent Messages.

3.5.8.1 The messages which control the operation of the DMM when in system operation are referred to as device dependent messages. These messages listed in Table 3.12 are simply combinations of ASCII characters which the instrument recognizes as specific instructions. To program the instrument for a specific operation, the operator programs the controller to transmit a sequence of these messages (referred to as a program string). The program string is variable in length and has no fixed format. Individual commands may be transmitted in any order and require no delimiters or spacing for the instrument to understand. A terminator character(s) should be sent as the last character in each program string. Acceptable terminators are CR (Carriage Return), LF (Line Feed), the GPIB message EOI in conjunction with the last byte of the string, also ASCII x lower case or X uppercase, or any combination of these. Most controllers will add terminator to the program string automatically. Alphabetic characters may be either upper or lower case. Table 3.10 summarizes the GPIB programming requirements.

3.5.8.2 The device dependent messages are listed in Table 3.12 along with the DMM operation and any special notes that apply. The device dependent messages applicable to the DMM are divided into subcategories such as Function Commands and Range Commands. In general, the various commands cause the instrument to perform the same functions as the front panel controls. There are special cases however, where there are extra functions available under remote control which are not available in the bench operation mode. Further, there are some special situations requiring special attention to the operation sequence used with the DMM.

3.5.8.3 To assemble a program string, first list the requirements of the program, and then select the appropriate program codes from Table 3.12. Table 3.9 shows a program string listing for a typical measurement procedure.

3.5.9 GPIB STORE and RECALL Commands.

3.5.9.1 Two main buffers are used during GPIB STORE/RECALL Commands. These commands cause readings and numerical constants to be moved from one memory location to another inside the DMM. To understand how these commands operate, refer to Figure 3.21. The output buffer

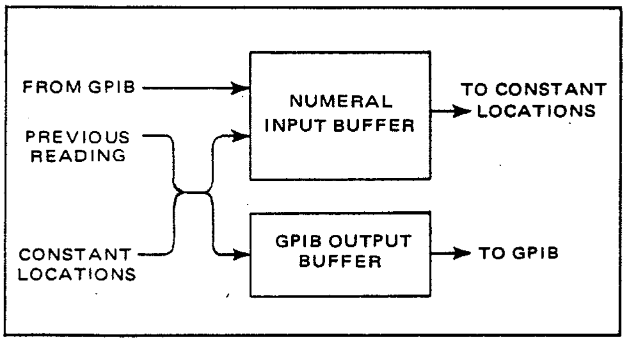


Figure 3.21 - GPIB Numerical Buffers

holds the ASCII characters which are waiting to be transmitted to the controller. The input buffer has two uses. During the entry of numerical constants from the bus, the input buffer is used as the holding register. Also, the input buffer is used to hold the number which was most recently transferred to the output buffer.

3.5.9.2 GPIB Store Commands cause the contents of the Numerical Input Buffer to be transferred to a constant location in the DMM's memory as follows:

a) N2, store as a NULL constant.

b) P2, store as a Percent constant.

c) L6, store as a LAH cycle constant, 'C'.

d) S2-S7, store as TIME constants.

Either the previous reading or a GPIB entered constant can be stored. For instance, if a reading is completed and then an N2 command is sent to the DMM, the reading will be stored as the NULL constant. If any of the following command strings are transmitted to the DMM:

–2.5e-3 N2

–2500000 E-9 N2

–000000000.0025 N2

–.000000000025E+08 N2

then –.0025 will be stored as the Null Constant.

3.5.9.3 GPIB RECALL Commands cause numerical constant(s) to be copied into the Numerical Input and GPIB Output Buffers for transmission to the controller as follows:

a) N3, transmit NULL Constant.

b) P3, transmit Percent Constant.

c) L7, transmit 5 LAH constants.

d) S8, transmit 6 TIME constants.

e) C1, transmit contents of Data Buffer.

3.5.9.4 The following points should be kept in mind when using GPIB recall commands:

a) The outputting of the above-mentioned data and constants takes priority over outputting of readings to the bus. In other words, readings will be displayed but not saved for GPIB output if the GPIB Output buffer is occupied by an out-going constant.

b) When the outputting of constant(s) is completed, the DMM will automatically resort to outputting readings.

c) Output Commands are not "stored" internally, therefore if more than one is sent, only the most recently transmitted output command will be honored.

3.5.9.5 The following apply only when outputting multiple constants (GPIB commands L7, S8, C1).

a) In keeping with the IEC and IEEE recommendations, multiple constants are separated by commas (,) and a terminator(s) CR LF appears after the last constant. This may require special programming on some controllers which do not meet IEC/IEEE recommendations.

b) As each constant is outputted, the DMM aborts any reading presently in progress and will re-start the reading. This may lower the read rate for a split second as the constants are output.

Table 3.12 - Model 5005/5006 Device Dependent Program Code

INITIALIZE COMMANDS

Operation	Program Code	Special Notes
Initialize	Z	Same as G0T1N0P0L0S0

FUNCTION COMMANDS

Operation	Program Code	Special Notes
DC Volts	F1	
AC Volts	F2	
Ohms	F3	
Ohms	F4	

RANGE COMMANDS

Operation	Program Code	Special Notes
AUTO Range	R0	
.1V, .1KΩ	R3	
1V, 1KΩ	R4	
10V, 10KΩ	R5	
100V, 100KΩ	R6	
1000V, 1000KΩ	R7	
10,000KΩ	R8	

TRIGGER COMMANDS

Operation	Program Code	Special Notes
Trigger Immediate	T0	Normally used in conjunction with T3.
Internal Trigger	T1	Causes continuous readings.
External Trigger	T2	Waits for trigger from rear panel BNC.
Hold/Manual	T3	Waits for trigger from GPIB or from keyboard.
External Trigger with Timeouts	T4	Same as T_2 and T_3, except that an internal time delay is inserted to allow for analog settling times.
Hold/Manual with Timeouts	T5	

Table 3.12 - Model 5005/5006 Device Dependent Program Code continued

LOW/HIGH RESOLUTION COMMANDS

Operation	Program Code	Special Notes
4 1/2 digit display	I1	
5 1/2 digit display	{I2, I3}	

FILTER COMMANDS

Operation	Program Code	Special Notes
Filter Out	J0	
Filter In	J1	Selects the 3-pole active filter.

INTERRUPT COMMANDS

Operation	Program Code	Special Notes
No SRQ when Reading is Ready	D0	
SRQ when Reading is Ready	D1	
SRQ if Reading* is < 0	D2	
SRQ if Reading* is ≥ 0	D3	

*Reading after being modified by Null, % and LAH.

SIGNAL/REFERENCE INPUT COMMANDS

Operation	Program Code	Special Notes
Signal Input	V0	Measurements taken from the signal input terminals.
Reference Input	V1	Measurements taken from the Reference input terminals.

Table 3.12 - Model 5005/5006 Device Dependent Program Code continued

COMMAND STRING TERMINATOR (OPTIONAL)

Operation	Code	Special Notes
Terminator	X	Use is required only when the DMM is being programmed from a controller which does not terminate the program string with a CR, LF, or EOI.

ERROR OUTPUT COMMAND

Operation	Program Code	Special Notes
Error Output	Y	Output most recent error number.

DIGITAL ZERO COMMAND

Operation	Program Code	Special Notes
Ignored	K0	
Ignored	K1	
Zero Command	K2	DC Function 0.1V range (F1R3), must have been previously selected, and a short must be supplied across the input terminals.

CALIBRATION COMMANDS

Operation	Program Code	Special Notes
Decrease offset, this range	K3	These commands have no effect unless the front panel calibration button is depressed, or shorted as described in maintenance section 5.1.6.
Nominal offset, this range	K4	
Increase offset, this range	K5	
Decrease scale, this range	K6	
Nominal scale, this range	K7	
Increase scale, this range	K8	
Calculate and Store Checksum	K9	

Table 3.12 - Model 5005/5006 Device Dependent Program Code continued

NULL COMMANDS

Operation	Program Code	Special Notes
Disable Null	N0	
Enable Null	N1	Subtracts null constant from reading.
Store as Null	N2	Stores previous reading or entered constant as null constant.
Transmit Null	N3	Output null constant to GPIB.

PERCENT COMMANDS

Operation	Program Code	Special Notes
Disable % equation	P0	
Enable % equation	P1	
Store as % constant	P2	
Transmit % constant	P3	

LOW AVG HIGH (LAH)

Operation	Program Code	Special Notes
Disable LAH	L0	
Enable and display/ output reading	L1	
Enable and display/ output Low	L2	
Enable and display/ output Avg	L3	
Enable and display/ output High	L4	
Enable and display/ output #rdgs so far	L5	
Store as number to be averaged	L6	
Transmit constants:	L7	Outputs to GPIB: Low, Avg, High, #rdgs (n), Average cycle constant (c)

Table 3.12 - Model 5005/5006 Device Dependent Program Code continued

PROGRAM BUFFER STORE COMMANDS

Operation	Program Code	Special Notes
Store to Pgm 0	A0	Store present machine setting to program buffer location 0.
Store to Pgm 1	A1	Store present machine setting to program buffer location 1.
Store to Pgm 2	A2	Store present machine setting to program buffer location 2.
Store to Pgm 3	A3	Store present machine setting to program buffer location 3.
Store to Pgm 4	A4	Store present machine setting to program buffer location 4.
Store to Pgm 5	A5	Store present machine setting to program buffer location 5.
Store to Pgm 6	A6	Store present machine setting to program buffer location 6.
Store to Pgm 7	A7	Store present machine setting to program buffer location 7.
Store to Pgm 8	A8	Store present machine setting to program buffer location 8.
Store to Pgm 9	A9	Store present machine setting to program buffer location 9.

PROGRAM BUFFER RECALL COMMANDS

Operation	Program Code	Special Notes
Recall Program 0	B0	Recall the machine setting previously stored at location 0.
Recall Program 1	B1	Recall the machine setting previously stored at location 1.
Recall Program 2	B2	Recall the machine setting previously stored at location 2.
Recall Program 3	B3	Recall the machine setting previously stored at location 3.
Recall Program 4	B4	Recall the machine setting previously stored at location 4.
Recall Program 5	B5	Recall the machine setting previously stored at location 5.
Recall Program 6	B6	Recall the machine setting previously stored at location 6.
Recall Program 7	B7	Recall the machine setting previously stored at location 7.
Recall Program 8	B8	Recall the machine setting previously stored at location 8.
Recall Program 9	B9	Recall the machine setting previously stored at location 9.

DATA BUFFER COMMANDS

Operation	Program Code	Special Notes
Clear Data Buffer	C0	
Output Contents of Data Buffer to the GPIB	C1	Outputs entire contents of data buffer

Table 3.12 - Model 5005/5006 Device Dependent Program Code continued

EXTERNAL REFERENCE FUNCTION COMMANDS (SOFTWARE RATIO)

Operation	Program Code	Special Notes
Internal Reference	G0	Disables Software Ratio.
DC Reference	G1	Enable Software Ratio.
AC Reference	G2	
Ohms Reference	G3	
Ohms Reference	G4	

EXTERNAL REFERENCE RANGE COMMANDS

Operation	Program Code	Special Notes
AUTO Range	Q0	Returning the DMM to internal reference will not affect the external reference range setting.
.1V, .1KΩ	Q3	
1V, 1KΩ	Q4	
10V, 10KΩ	Q5	
100V, 100KΩ	Q6	
1000V, 1000KΩ	Q7	
10000KΩ	Q8	

TIME

Operation	Program Code	Special Notes
Disable Time	S0	
Enable Time function	S1	DMM should be in HOLD mode (T3-Command) when TIME function is enabled.
Store as start Time	S2	
Store as stop Time	S3	
Store as interval	S4	
Store as subinterval	S5	
Store as N	S6	
Store as present Time	S7	
Output time constants to the GPIB	S8	Output Present time, N, Subinterval, Interval, Stop time, and Start time.

3.5.10 Initialize Command.

3.5.10.1 The program code 'Z' is normally used by the controller to place the DMM into a known state. This program code is equivalent to the following string: G0T1N0.

- G0 - Internal reference
- T1 - Internal trigger
- N0 - Disable NULL
- P0 - Disable percent
- L0 - Disable LAH
- S0 - Disable Time

3.5.11 Function Commands.

3.5.11.1 Function commands are available to program the instrument to perform any operation which may be commanded through use of front panel keyboard controls. Note that in Table 3.9 the DMM Operation column lists the functions available on the instrument and that the Program Code column shows the ASCII characters required to program the instrument for each of these functions. To program a function the controller need only transmit the ASCII characters required for the desired function (eg: to program the measurement function DC volts, the controller simply transmits the two ASCII characters F and 1 over the bus to the DMM).

3.5.12 Range Commands.

3.5.12.1 Seven individual range commands are available to the controller; one to command the autorange and six additional commands for selecting specific ranges for the instrument. Note that the commands R3 through R7 all serve dual purposes; they command ranges for voltage measurements and for resistance measurements.

3.5.13 Trigger.

3.5.13.1 Trigger commands T0 through T5 control the beginning of a measurement cycle. When the T1 command is transmitted, the instrument operates on the internal trigger on its normal measurement timing cycle (see Figure 3.22). When the T2 command is transmitted, the instrument must be triggered by an external signal inputted through a BNC connector on the rear panel of the instrument. When the T3 command is transmitted, the instrument is put in the "Hold" state and will stay there until it is triggered either from the front panel or from the GPIB. Trigger commands from the GPIB can be either a T0 command or a Group Execute Trigger. Trigger commands are given from the keyboard by pressing 'Track' or 'Single' when the DMM is in local control. Upon receipt of the T4 program code the instrument goes into the External trigger mode and must be triggered by an external signal connected to the rear panel BNC connector. After being triggered via the rear panel BNC, the DMM executes a timeout which allows time for analog signals to settle. The timeout will vary, depending upon which functions and ranges are selected, before triggering a single reading. When program code T5 is transmitted, the instrument goes into the "Hold" mode described above except that its measurement cycle is again affected by the timeouts applicable to each function and range. For a complete description of 'TIME-OUTS' see paragraph 3.6.

3.5.14 HI-LO Resolution Commands.

3.5.14.1 The measurement accuracy of the DMM is directly proportional to the signal integration time (ie: the longer the integration time, the more accurate the measurement). If the measurement time is available, more accuracy may be obtained by programming the longer integration period. In situations where speed is required, the shorter integration time may be programmed at some sacrifice in measurement accuracy. The program codes I1, I2 and I3 select the resolution, the accuracy and the reading rate. Code I1 enables the 4 1/2 digit display which generates higher speed at the sacrifice of accuracy. Codes I2 and I3 develop greater accuracy at reduced speed.

3.5.15 Null Commands.

3.4.15.1 Program codes N0 through N3 call for the Null functions. The N1 program code enables the Null function. Upon receipt of N1 from the interface, a flag is set in

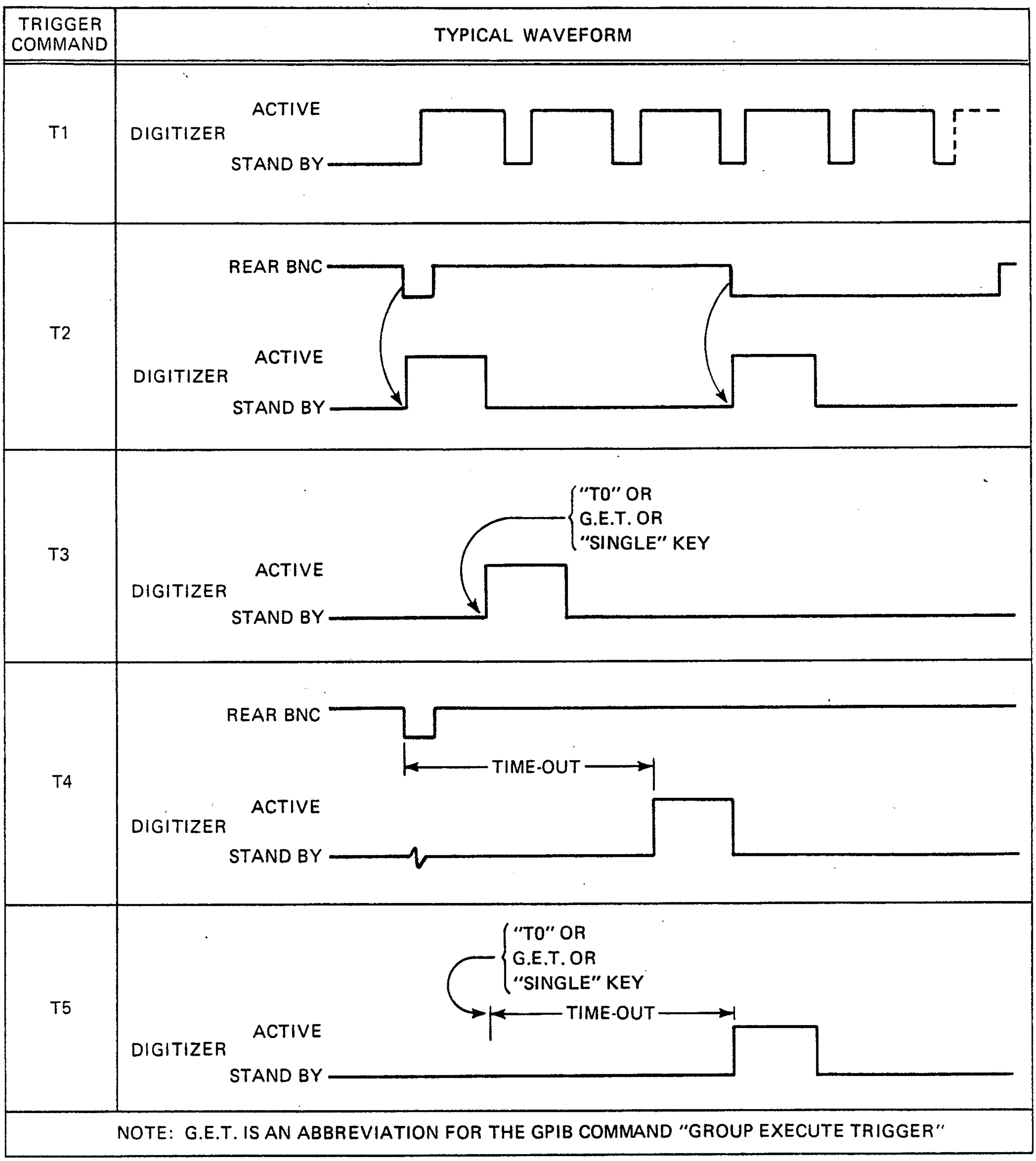


Figure 3.22 - Trigger Command Measurement Timing

memory which signals the Computer to subtract the Null constant from future readings. The N2 program code allows for the storage of Null constants. Upon receipt of the N2 command, the previous reading or a constant enter via the GPIB is stored into memory for use as the Null constant. The N3 program code causes the DMM to transmit the Null constant to the controller.

3.5.15.2 The N1N2 program string accomplishes the same operation as selection of the "Null" key on the keyboard. Program code N0 disables the Null function but does not change the Null constant.

3.5.16 Interrupt Commands.

3.5.16.1 Commands may be transmitted by the controller to instruct the DMM to send an SRQ (Service Request) signal over the GPIB. When the SRQ occurs, the controller can read the DMM's Serial Poll status byte to determine the cause of the SRQ. Figure 3.20 identifies the Data Ready bit in the status byte which will set to 1 if the SRQ was sent to inform the controller that a reading is ready for transmission over the bus.

3.5.16.2 The Interrupt Commands D0-D3 determine what type of readings will cause the SRQ and Data Ready messages to become true, as shown in Table 3.13 and explained below. If the D0 command is programmed, the DMM will not send an SRQ or set the Data Ready bit true when a reading becomes available for GPIB output. If the D1 command is programmed, the DMM will always send an SRQ and set the Data Ready bit in the status byte.

Table 3.13 - Effects of D0 Thru D3 Interrupt Commands

Most Recently Transmitted 'D' Command	Newly Completed DMM Reading (after Null, %, etc.)	Service Request SRQ	Serial Poll Status Byte: Requested Service Bit (DIO7)	Serial Poll Status Byte: Data Ready Bit (DIO1)
D0	+ or – polarity	False ①	0 ②	0
D1	+ or – polarity	True	1	1
D2	– polarity	True	1	1
	+ polarity	False ①	0 ②	0
D3	+ polarity	True	1	1
	– polarity	False ①	0 ②	0

① May be driven True by another bus member.

② Usually zero, but may be set to one for reason other than Data Ready.
See Section 3.5.7.9 for further explanation.

3.5.16.3 If the D2 command is programmed, an SRQ will be sent and the Data Ready bit will be set, but only if the reading (after Null, %, etc.) has a negative polarity sign (number is less than zero). If the D3 command is programmed, an SRQ will be sent and the Data Ready bit will be set, but only if the reading (after Null, %, etc.) has a positive polarity sign (number is greater than or equal to zero).

3.5.16.4 The D2 and D3 commands can be used to notify the controller that the DMM's input signal has increased or decreased across an important boundary. For instance, if +2.0 is programmed as the Null constant and Null is enabled, the D2 or D3 command can be used to notify the controller that the input signal has moved across +2 volts.

3.5.16.5 The following should be kept in mind when using the D1, D2 or D3 commands:

a) The SRQ line and Data Ready bits can be reset to their home state in the following ways:

   1) Both are reset whenever the DMM is reprogrammed over the bus.

   2) Both are reset by making the DMM a talker and accepting the entire reading from the DMM over the bus.

   e) SRQ will be reset whenever the controller reads the DMM's serial poll status byte.

b) If the DMM is programmed with the D2 or D3 command, the SRQ line and Data Ready bit will remain true even though the most recent reading may not be the proper polarity to cause them to be set true. For example, if the D2 command is programmed and then a negative reading followed by a positive reading is taken, the SRQ line and Data Ready bits will remain set, assuming of course, that none of the procedures listed in a) take place.

3.5.17 Filter Commands.

3.5.17.1 Control of the active filter in the remote mode is the same as manual control of the filter except that the controller transmits the program code commands J0 and J1 (as shown in Table 3.12).

3.5.18 Digital Zero Command.

3.5.18.1 The code F1R3 must precede the Digital Zero command code K2 to enable the Digital Zero command. Furthermore, the HI-LO INPUT terminals on the front or rear panel of the DMM must be shorted.

3.5.19 Command String Terminator.

3.5.19.1 The terminator code "X" permits the controller to terminate the program string when other terminating codes were not included in the string: typical terminators are CR, LF, or EOI. Most modern controllers will append a terminator to program strings automatically, making the use of 'X' program code unnecessary.

3.5.20 Error Output Command.

3.5.20.1 When a programming error or operational error is discovered by the DMM when in remote, an SRQ is sent to the controller. Upon receiving the SRQ, the controller should read the DMM's status byte to determine why the SRQ was sent. If the status byte contains '1' in the DIO-4 position (see Figure 3.20) then an error has occured and an error number can be transmitted to the controller. To obtain this error message number, the controller first sends the program code 'Y' (why) to the DMM and then reads the error message number from the DMM. Table 3.6 can then be used to determine the nature of the problem.

3.5.21 Calibration Commands.

3.5.21.1 If a CAL LAB is handling more than ten 5004 series voltmeters, it may be advantageous to automate the calibration of the DMM's. To do this, the front panel "CAL" switch on the main PCB is shorted and commands K3 through K8 are transmitted to the DMM to modify Non-Volatile memory constants. After all other Cal commands are completed, the K9 command should be transmitted to the DMM. When the calibration is completed, the short across the Cal switch *must* be removed. Additional details are presented in Section 5.3.4.

3.5.22 Signal/Reference Input Commands

3.5.22.1 The Signal/Reference input command is an Extended Software Capability feature of the DMM. This feature allows the External Reference Input Terminals to be utilized as an additional pair of signal input terminals when not used for ratio measurements.

3.5.22.2 Neither is this feature selectable from the keyboard nor are front panel LED annunciators provided to indicate which set of input terminals are presently selected.

3.5.22.3 Program code V0 selects the Signal input terminals for measurements and code. V1 selects the Reference input terminals. The following guidlines will be observed when using the V1 command:

a) Ohms measurements cannot be made through the Reference Input terminals.

b) The V1 command reverses the role of the Signal and Reference inputs during External Reference (Software Ratio) measurements. Further information is provided in Section 3.5.19.

3.5.23 Time Commands.

3.5.23.1 Program Codes S0 through S8 address the DMM real-time clock as it is applied to readings in progress. The Start Time, Stop Time, Time Interval, Subinterval Time and number of readings per interval can be selected and stored.

3.5.24 Percent Commands.

3.5.24.1 The Percent Commands of P0 and P3 can enable or disable the % equation

$$\left(\frac{\text{READING-REFERENCE}}{\text{REFERENCE}}\right) \text{X } 100$$

which is the percentage deviation of the input reading from a reference value. Storing as a % constant or transmitting as a % constant completes this message group.

3.5.25 LOW-AVERAGE-HIGH Commands (LAH).

3.5.25.1 The program codes L0 through L7 can disable or enable the LAH function or execute the LAH modes which are described in section 3.4.8. They store the number to be averaged or Transmit the LAH constants included in this group of device dependent messages.

3.5.26 Program Buffer Store Commands.

3.5.26.1 Up to 10 instruments settings can be stored with the program codes A0 through A9. Each code stores to one program number. The detail operation of the Program Buffer is presented in section 3.4.12.2.

3.5.27 Program Buffer Recall Commands.

3.5.27.1 The 10 instrument settings can be recalled with the program codes B0 through B9. The setting stored to a program number can be recalled in any sequence. The operation of the recall function of the program buffer is presented in section 3.4.12.2.

3.5.28 Data Buffer Commands.

3.5.28.1 The two program codes for Data Buffer can address the two buffer modes which are:

a) Clear the Data Buffer.

b) Recall previous readings from the Data Buffer to the GPIB. (See also section 3.5.9)

Table 3.14 - Signal/Reference and Software Ratio Codes

Most Recent GPIB Program Code	Signal Input Terminals	Ext. Ref Input Terminals*	Ratio Displayed
V0 (Signal Input terminals selected)	Measurement Signal	Reference Signal	Ratio = $\frac{\text{Signal Terminals}}{\text{Ext. Ref Terminals}}$
V1 (Ext. Ref. Input terminals selected)	Reference Signal	Measurement Signal	Ratio = $\frac{\text{Ext. Ref Terminals}}{\text{Signal Terminals}}$

*ohms measurements cannot be made through Ext. Reference Input Terminals

3.5.29 Software Ratio Commands (External Reference).

3.5.29.1 When in the Software Ratio mode, the DMM reads the External Reference Signal, then calculates:

$$\text{Ratio} = \frac{\text{Measurement Signal}}{\text{External Reference Signal}}$$

More details are supplied in Section 3.4.12.

3.5.29.2 The Measurement and Reference signals are connected to the DMM's signal and reference input terminals. Table 3.14 indicates how the GPIB Signal/Reference Commands V0 and V1 determine which Input terminals are used for Measurement Signal and Rèference Signal connection. Note that the External Reference input terminals cannot be used for ohms measurements.

3.5.29.4 When in Software Ratio mode, the time to complete a reading can be calculated from Figure 3.25 or Figure 3.26, which, along with the GPIB throughput calculations in paragraph 3.7, supply the necessary information to calculate the time required to program, trigger, and transfer a reading back to the controller.

3.5.29.5 EXTERNAL REFERENCE FUNCTION COMMANDS.

3.5.29.5.1 External reference function commands are used to select the voltage reference used by the digital multimeter in making measurements. The controller may select the normal internal reference (ratio disabled) or an external ratio reference. Transmission of the G0 program code by the controller causes the DMM to use internal reference for all measurements. When using the instrument in the external reference mode, the reference is applied to the Signal or External Reference inputs as shown in Table 3.14.

3.5.29.5.2 When using a DC external reference, the user first connects the signal and reference as described above and then transmits the program code G1. For AC external reference, the same hook up is made followed by a G2 command. For ohms external reference, either the G3 or G4 commands may be used.

3.5.29.6 EXTERNAL REFERENCE RANGE COMMANDS

3.5.29.6.1 There are six ranges for external reference signals applied to the Input connector of the DMM. These are listed in Table 3.12 under the Operation column heading. When using an external reference in remote mode, the controller must transmit the appropriate program code Q3 through Q8 to select the correct range. Q0 selects the reference auto-range function.

3.6 TIME-OUTS: A PRACTICAL TREATISE.

3.6.1 TIME-OUTS are variable delays which are inserted at the proper point in the measurement sequence in order to guarantee that the signal has settled sufficiently before a reading is taken.

3.6.2 Like many other Racal-Dana DMM's, these Models provide 2 types of time-outs. Together, these time-outs reduce the burden on the GPIB programmer because most of the system timing problems involving insufficient

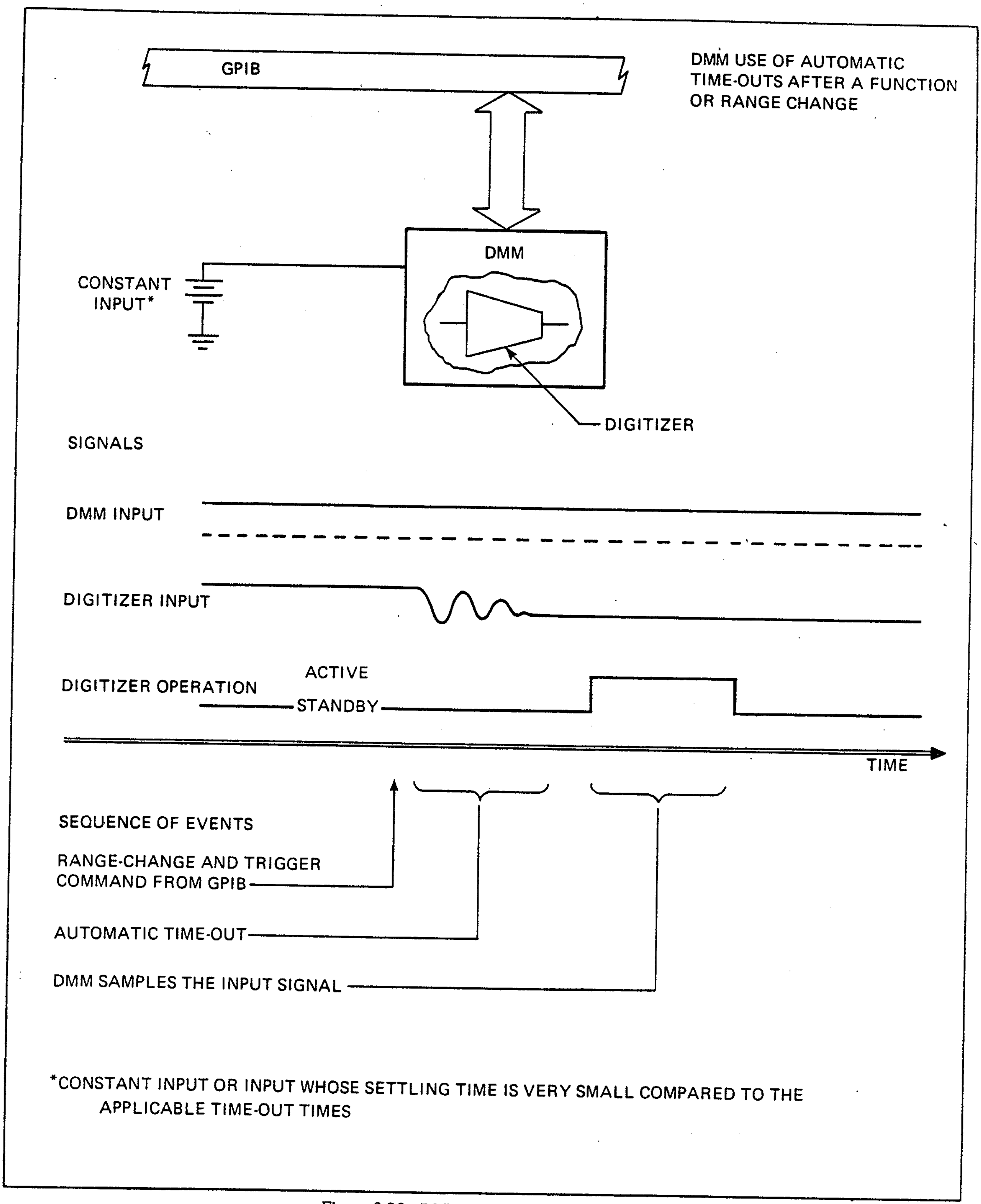


Figure 3.23 - DMM Automatic Time-Out

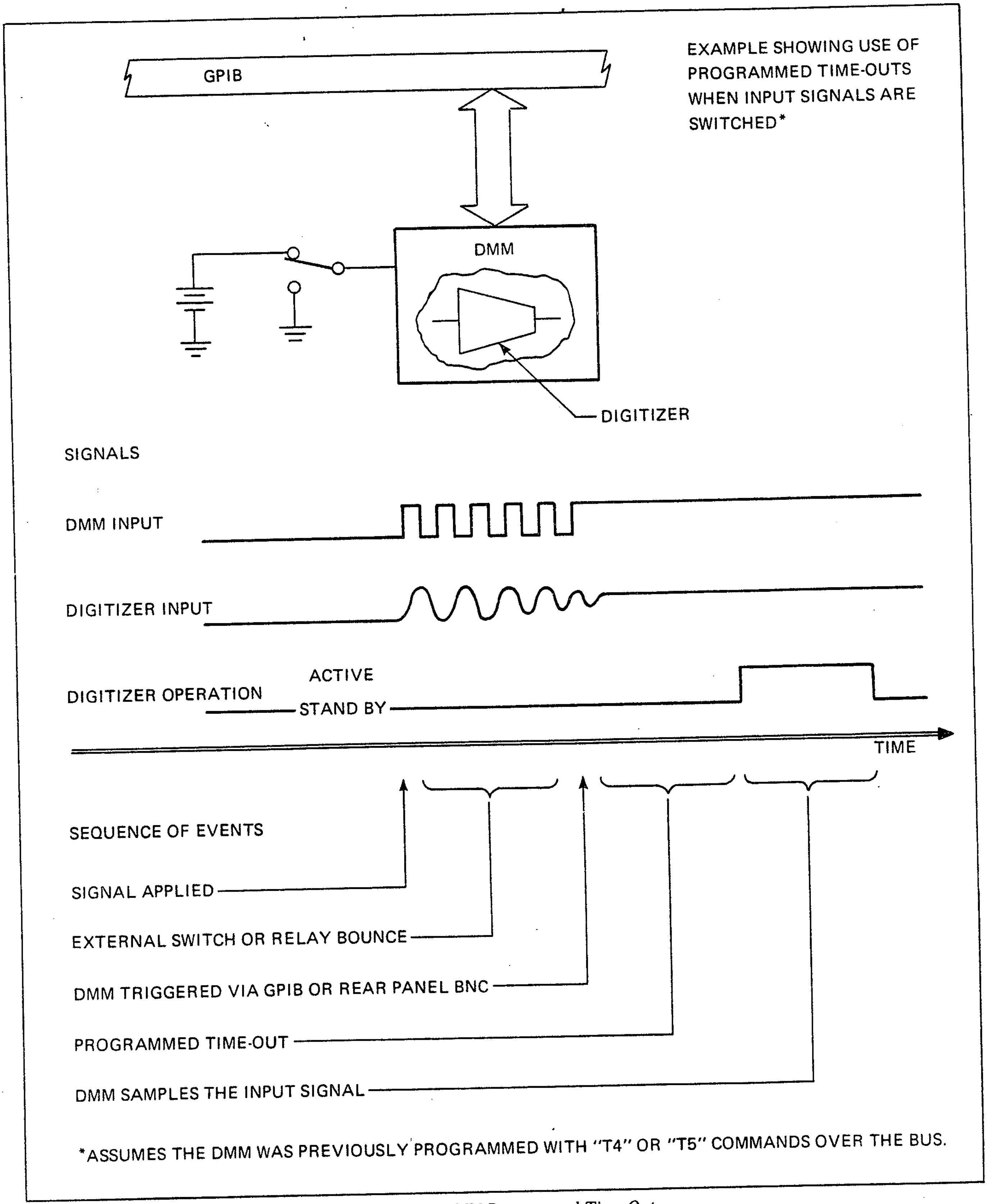


Figure 3.24 - DMM Programmed Time-Out

settling times and first reading errors are taken care of automatically inside the DMM. "First Reading Error" is an erroneous reading output by an instrument immediately following a function or range change.

Table 3.15 - Time-Out Times

Function	Time-Outs	Digits Error	
		5 1/2 Mode	4 1/2 Mode
DC	30 mS	10	1
AC*	400 mS	100	10
KΩ .1-1K	40 mS	10	1
10K	300 mS	10	1
Any Function Plus Filter	500 mS	10	1

*Time-out will be insufficient if incoming signal has a DC level other than zero volts.

3.6.3 Table 3.15 lists the time-out times and also lists the remaining digits of error which are not compensated for by the time-outs.

3.6.4 When any DMM is being programmed and triggered over the GPIB, a typical chain of events may occur something like this:

1) Apply input signal to DMM.
2) Program DMM and trigger reading.
3) Take reading from DMM.

Figure 3.23 shows this sequence graphically and also shows how the DMM automatic timeout feature prevents it from outputting bad data after a function, range change, or other GPIB command. Notice in the figure that the input signal is assumed to have already settled before the sequence begins.

3.6.5 Another chain of events which commonly occurs is listed below. This situation is found more often when many inputs of the same type are being measured:

1) Apply input signal to DMM.
2) Trigger DMM (without changing function or range).
3) Take reading from DMM.

Figure 3.24 shows this sequence and also shows how the use of programmed time-outs (T4 and T5 commands) allow the programmer to pass the responsibility for settling time over to the DMM. Here again it is assumed that the input signal has already settled before the DMM is triggered, since it would be impossible for the DMM to compensate for an unknown settling time caused by conditions external to the DMM.

3.6.6 In the previous paragraphs it was mentioned how the DMM handled its own settling time problems in various ways, but no mention was made of how the programmer might deal with settling time problems which originate external to the DMM. When low impedance measurements are being made, the main cause of delay times external to the DMM occur either in the signal source or in the signal scanner. Unless compensated for, these delays can cause large measurement errors.

3.6.7 One way of dealing with this situation is to place a delay in the controller's software between the signal setup routines and the DMM trigger routines, thus guaranteeing that the signal has settled before the DMM is triggered. A complication arises because the required delay time may vary considerably depending upon which signal source function and range is selected, etc. In systems where test time is not critical, the programmer may decide to use the worst case required delay during all measurements.

3.6.8 If throughput is a consideration, the programmer may decide to use a variable delay which depends upon the selected signal source and scanner settings, but this approach may require intimate knowledge of the devices' internal workings or repeated experimentation. Recently another alternative has been made available in the form of smart signal sources and scanners which can control system timing to guarantee that the signal has settled before the next operation is allowed to proceed. One example of this class of smart scanners is the Racal-Dana Model 1200. When programmed to do so, it will hold off further GPIB activity until all of its relays have switched to their new positions and have ceased bouncing. In most cases this guarantees that the Model 1200's output signal has completely settled before the controller has a chance to trigger the measurement device.

3.7 GPIB THROUGHPUT CALCULATIONS: A PRACTICAL TREATISE.

3.7.1 This section which presents GPIB Throughput Calculations is included as an aid to systems designers who must determine how much time is required to program, trigger, and obtain a reading from the DMM when operated over the GPIB.

3.7.2 The HANDSHAKE TIMES listed in Table 3.16 are typical times required to handshake characters over the bus. These numbers can be used to estimate the bus time required

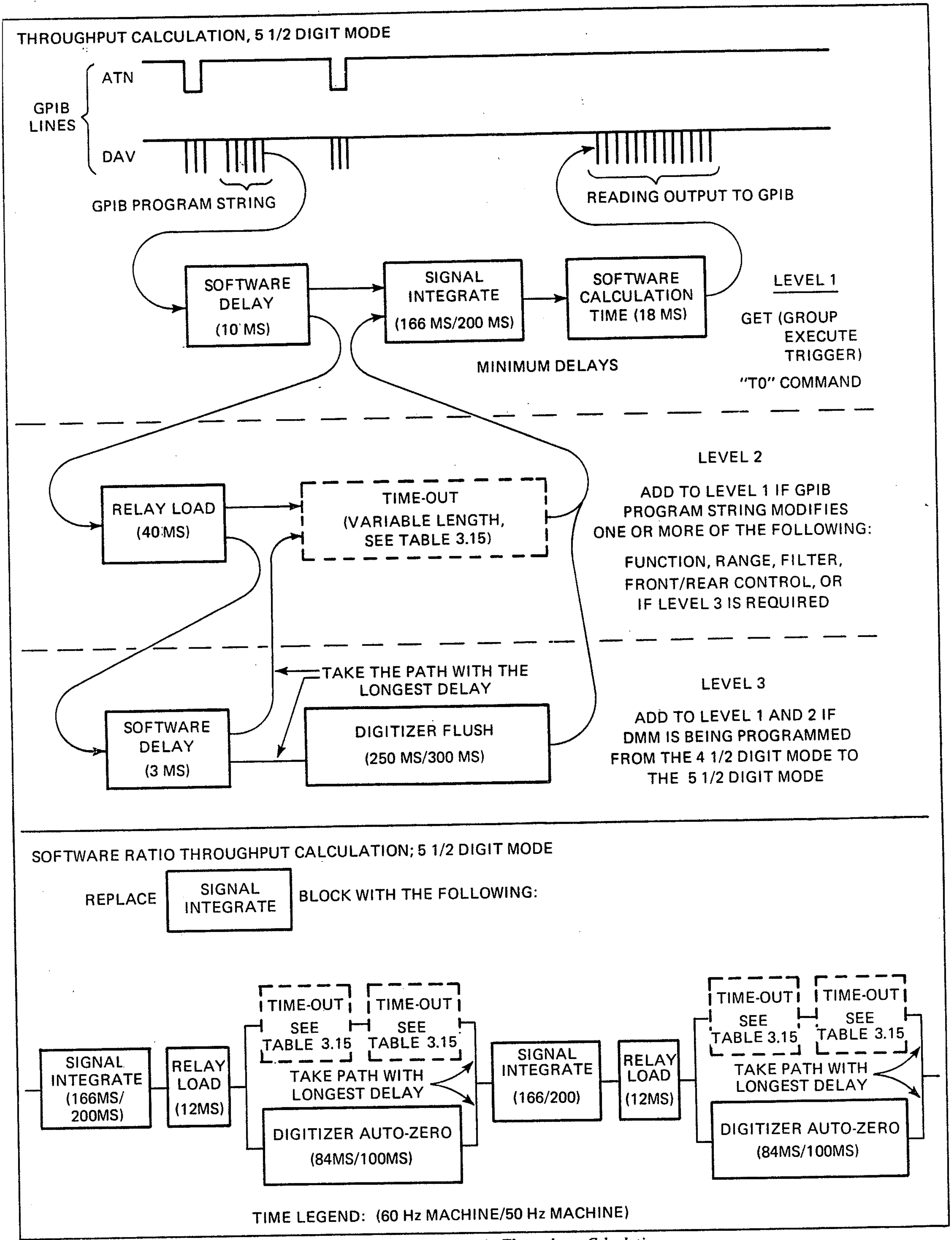


Figure 3.25 - 5 1/2 Digit Software Ratio Throughput Calculation

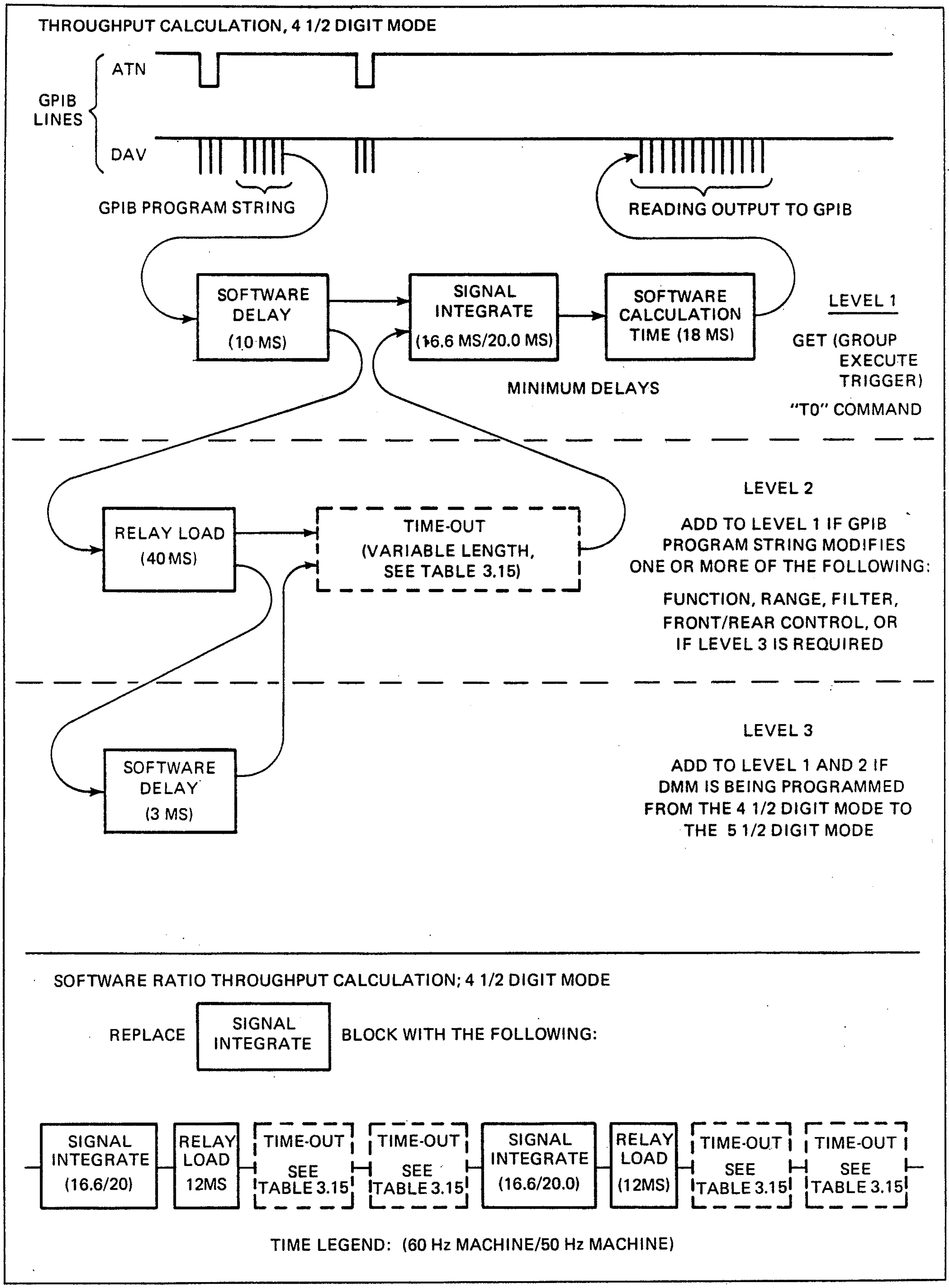


Figure 3.26 - 4 1/2 Digit Software Ratio Throughput Calculation

to exchange various data. For an example, to transmit the string "F1R5CRLF" to the DMM (6 characters) 400 μS/character = 2.4 mS are required approximately.

3.7.3 The time necessary to PROGRAM, TRIGGER and OUTPUT a reading from the DMM is presented in Figure 3.25 and Figure 3.26. The Figure 3.25 is used when in the 5 1/2 digit mode or when in the 4 1/2 digit mode and the DMM is being programmed to the 5 1/2 digit mode. Figure 3.24 is used when the DMM is in the 4 1/2 digit mode or when the DMM is being programmed from 5 1/2 to 4 1/2 digit mode. Notice that the times shown do not include the actual bus time necessary to transfer data to or from the DMM, but this time can be estimated using Table 3.16. The throughput equations shown in the preceding 2 figures are based upon the assumption that the DMM is in 'HOLD' and is waiting to be triggered or re-programmed. This assumption is made because when not in hold, delays become much more difficult to estimate due to the random timing between incoming GPIB commands and readings already in progress. Since this section is an aid to computing the time required to obtain a reading, it is also assumed that each program string contains a DMM trigger such as the "T0" command, or is followed closely by a GET (Group Execute Trigger). This accounts for the 2 figures showing a Signal Integrate delay and also showing a reading being output to the GPIB.

3.7.4 Both Figures 3.25 and 3.26 show 2 GPIB lines at the top of the page. These are shown for reference only, and to identify when bytes are being transferred to or from the DMM. To ease the task of calculating DMM throughput, each figure is divided into three levels. Level 1 delays are the minimum delay that can occur whenever the DMM is programmed over the bus. GPIB commands which cause only level 1 delays are those commands which cause no modifications to the configuration. Examples of these are trigger commands, Null commands, R0 (auto-range) command, and Z (initialize) command. These are all processed very rapidly, and the majority of level 1 delays occur due to the "T0" or GET (Group Execute Trigger) which is assumed to accompany the program string.

Table 3.16 - Typical GPIB Handshake Times

Bus Operation	Typical Time Req.
Handshake Interface Messages	12 μS
Handshake and Process an Incoming String of Characters	400 μS/Character
Output the Serial Poll Status Byte	300 μS
Output a Reading (15 Characters)	130 μS/Character

3.7.5 If the GPIB command modifies one or more of the following: function, range, filter, front/rear control, then level 2 delays should be added to level 1 delays when performing delay calculations. Examples of commands which will cause a level 2 delay are: F1 (DC) if the DMM is in some other function, or R5 (10V range) if the DMM is in some other range. Note that level 2 delays will only occur if the GPIB command modifies the function, range, etc. For instance, if the DMM is already in DC and the "F1" command is sent, only level 1 delays will occur. Level 3 delays should be added if the DMM is being programmed from one digit mode (integrate time) to another. For example, if the DMM is in the 4 1/2 digit mode and an "I2" or "I3" command is received, the DMM will experience level 3 as well as level 1 and 2 delays.

3A.1 Purpose.

3.A.1.1. The section contains Manual and System application examples for the digital multimeter. Each example contains a statement of purpose along with keyboard or GPIB programming details. Paragraph 3A.2 presents the Manual application while paragraph 3A.3 presents the GPIB system application using an HP 9825 calculator connected to the DMM through the IEEE-488-1978 Standard Interface.

3A.2 Manual Applications.

3A.2.1 Purpose: Configure the DMM and 1200 Scanner to do the following:

a) Scan 5 noisy input signals at 1 hour intervals.

b) Read each input signal 4 times and average the 4 readings to reduce noise effects.

c) Store the averaged readings to the DMM's Data Buffer for later recall.

3A.2.2 The DMM's Time function will be used to sequence the measurements, and the LAH function will be employed to average 4 readings into one to reduce noise effects. The 1200 scanner will accept trigger pulses from the DMM which will cause it to scan to the next channel. To prepare the Model 1200, do the following:

a) Turn AC power off.

b) Remove all relay cards except one, which should be installed in the location nearest to the power switch.

c) When triggered, the Model 1200 will scan channels 1, 2, 3 ... 9, 10 and then back to 1, etc. Since only 5 signals are to be scanned, the 10 channels should be paralleled as shown in Figure 3A.1 (see 1200 manual for hookup details peculiar to the switch decade assembly being used).

3A.2.3 After connecting the 1200 and the DMM as shown in Figure 3A.2 and applying power, the key sequence shown in Table 3A.1 is performed. The DMM will then begin sequence described below.

a) The system will remain dormant for approximately 12 minutes.

b) The DMM will take 4 readings at one-second intervals and average them.

c) The averaged reading will then be copied into the Data Buffer and also displayed.

d) The DMM will send a pulse to the scanner, causing it to sequence to the next input. (Go to step a)).

3A.2.4 The timing diagram in Figure 3.29 shows the system timing as the first two inputs are measured, averaged, and stored into the buffer memory. Notice that as the sequence begins, no relay channels are selected. This causes the contents of buffer location 0 to be unuseable. Valid data can be found starting with buffer location 1.

3A.2.5 The need for noise rejection required that the Time Function's subinterval and N registers be used to trigger multiple readings for averaging purposes. If this requirement did not exist, these Time registers could instead be used to allow the sampling of all 5 inputs within seconds of one another. The following changes would be required to bring this about:

a) LAH function disabled.

b) 1.0 programmed as Time 3 (Interval = 1 hour).

c) .0001* programmed as Time 4 (Subinterval = 1 second).

*2-4 seconds may be required for certain combinations such as Filter + Autorange.

d) 5 programmed as Time 5 (Number of readings = 5).

e) The Model 1200 should be pre-triggered, causing the first channel to be selected.

The resulting timing diagram is shown in Figure 3A.4.

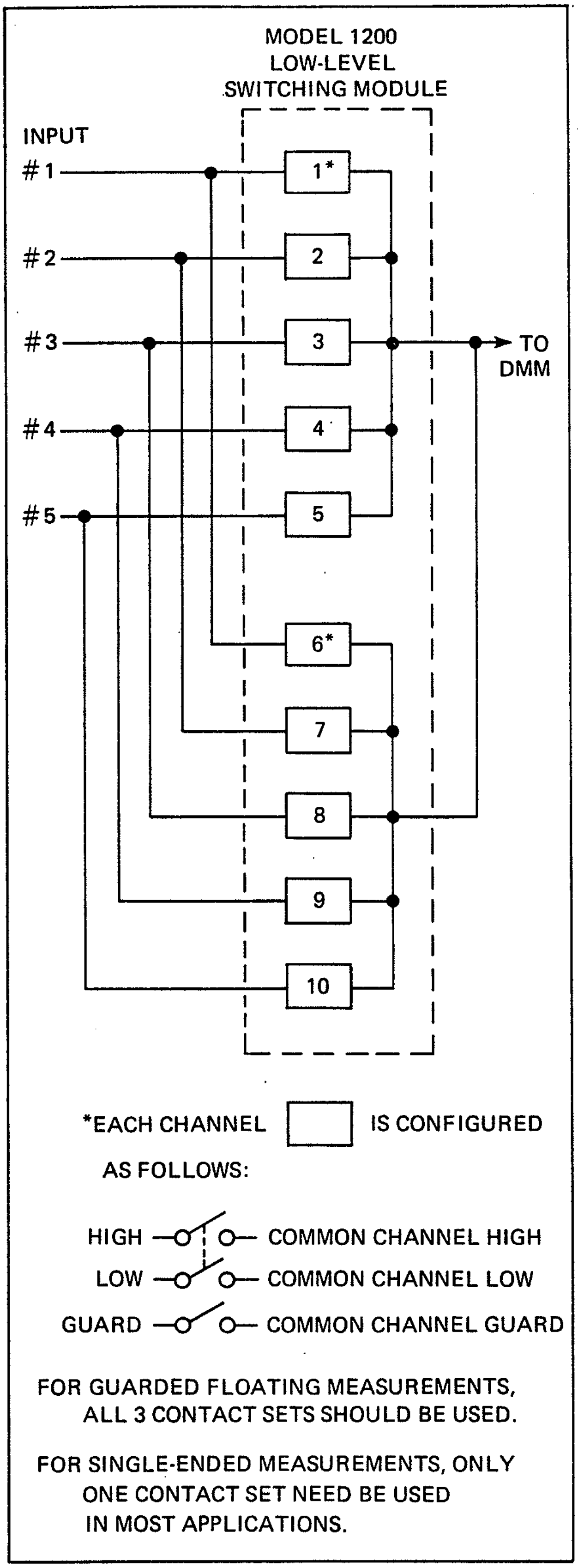


Figure 3A.1 - Wiring of Switching Module For Bench Application # 1