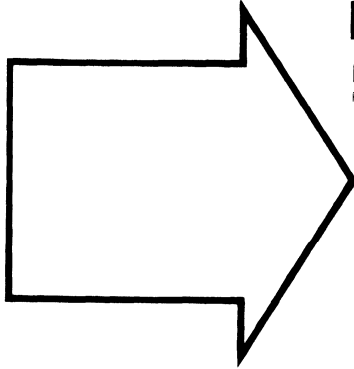


# PAL®/PLE™ Device Programmable Logic Array

Handbook  
FIFTH EDITION



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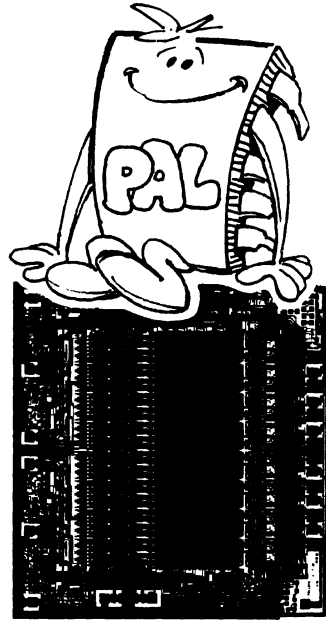
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### **The PAL<sup>®</sup> Device Concept**

*Monolithic Memories' family of PAL devices gives designers a powerful tool with unique capabilities for use in new and existing logic designs. The PAL device saves time and money by solving many of the system partitioning and interface problems brought about by increases in semiconductor device technology.*

*Rapid advances in large scale integration technology have led to larger and larger standard logic functions; single I.C.s now perform functions that formerly required complete circuit cards. While LSI offers many advantages, advances have been made at the expense of device flexibility. Most LSI devices still require large numbers of SSI/MSI devices for interfacing with user systems. Designers are still forced to turn to random logic for many applications.*

*The designer is confronted with another problem when a product is designed. Often the function is well defined and could derive significant benefits from fabrication as an integrated circuit. However, the design cycle for a custom circuit is long and the costs can be very high. This makes the risk significant enough to deter most users. The technology to support maximum flexibility combined with fast turnaround on custom logic has simply not been available. Monolithic Memories offers the programmable solution.*

*The PAL device family offers a fresh approach to using fuse programmable logic. PAL circuits are a conceptually unified group of devices which combine programmable flexibility with high speed and an extensive selection of interface options. PAL devices can lower inventory, cut design cycles and provide high complexity with maximum flexibility. These features, combined with lower package count and high reliability, truly make the PAL device a circuit designer's best friend.*



## PAL® Device Introduction

### The PAL Device — Teaching Old PROMs New Tricks



CD00910M

Monolithic Memories developed the modern PROM and introduced many of the architectures and techniques now regarded as industry standards. As the world's largest PROM manufacturer, Monolithic Memories has the proven technology and high volume production capability required to manufacture and support the PAL device.

The PAL device is an extension of the fusible link technology pioneered by Monolithic Memories for use in bipolar PROMs. The fusible link PROM first gave the digital systems designer the power to "write on silicon". In a few seconds he was able to transform a blank PROM from a general purpose device into one containing a custom algorithm, microprogram, or Boolean transfer function. This opened up new horizons for the use of PROMs in computer control stores, character generators, data storage tables and many other applications. The wide acceptance of this technology is clearly demonstrated by today's multi-million dollar PROM market.

The key to the PROM's success is that it allows the designer to customize the chip quickly and easily to fit his unique requirements. The PAL device extends this programmable flexibility by utilizing proven fusible link technology to implement logic functions. By using PAL circuits the designer can quickly and effectively implement custom logic varying in complexity from random gates to complex arithmetic functions.

### ANDs and ORs

The PAL device implements the familiar sum-of-products logic by using a programmable AND array whose output terms feed a fixed OR array. Since the sum-of-products form can express any Boolean transfer function, the PAL circuit uses are only limited by the number of terms available in the AND — OR arrays. PAL devices come in different sizes to allow for effective logic optimization.

Figure 1 shows the basic PAL device structure for a two-input, one-output logic segment. The general logic equation for this segment is:

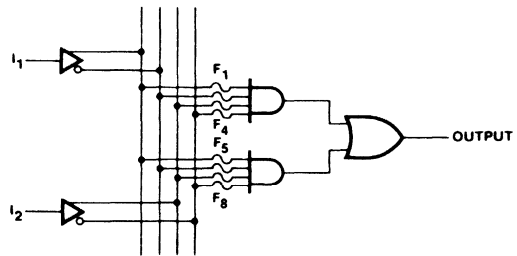
$$\text{Output} = (I_1 + \bar{f}_1)(\bar{I}_1 + \bar{f}_2)(I_2 + \bar{f}_3)(\bar{I}_2 + \bar{f}_4) + (I_1 + \bar{f}_5)(\bar{I}_1 + \bar{f}_6)(I_2 + \bar{f}_7)(\bar{I}_2 + \bar{f}_8)$$

where the "f" terms represent the state of the fusible links in the PAL device AND array. An unblown link represents a logic 1. Thus:

fuse blown,  $f = 0$

fuse intact,  $f = 1$

An unprogrammed PAL device has all fuses intact.

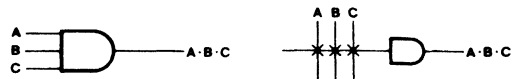


LD00860M

Figure 1

### PAL Device Notation

Logic equations, while convenient for small functions, rapidly become cumbersome in large systems. To reduce possible confusion, complex logic networks are generally defined by logic diagrams and truth tables. Figure 2 shows the logic convention adopted to keep PAL device logic easy to understand and use; in the figure, an "x" represents an intact fuse used to perform the logic AND function. (Note: the input terms on the common line with the x's are not connected together.) The logic symbology shown in Figure 2 has been informally adopted by integrated circuit manufacturers because it clearly establishes a one-to-one correspondence between the chip layout and the logic diagram. It also allows the logic diagram and truth table to be combined into a compact and easy to read form, thereby serving as a convenient shorthand for PAL circuits. The two-input, one-output example from Figure 1, redrawn using the new logic convention, is shown in Figure 3.



LD00870M

Figure 2

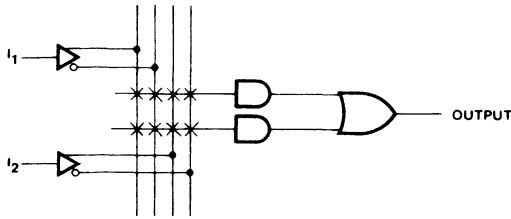


Figure 3

As a simple PAL device example, consider the implementation of the transfer function:

$$\text{Output} = I_1\bar{I}_2 + \bar{I}_1I_2$$

The normal combinatorial logic diagram for this function is shown in Figure 4, with the PAL device logic equivalent shown in Figure 5.

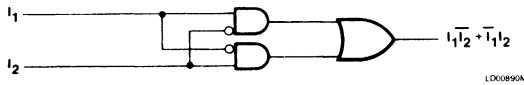


Figure 4

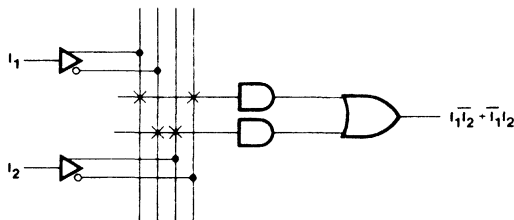


Figure 5

Using this logic convention it is now possible to compare the PAL device structure to the structure of the more familiar PROM (Programmable Read-Only Memory) and PLA (Programmable Logic Array). The basic logic structure of a PROM consists of a fixed AND array whose outputs feed a programmable OR array (Figure 6). PROMs are low-cost, easy to program, and available in a variety of sizes and organizations. They are most commonly used to store computer programs and data. In these applications the fixed input is a computer

memory address; the output is the content of that memory location.

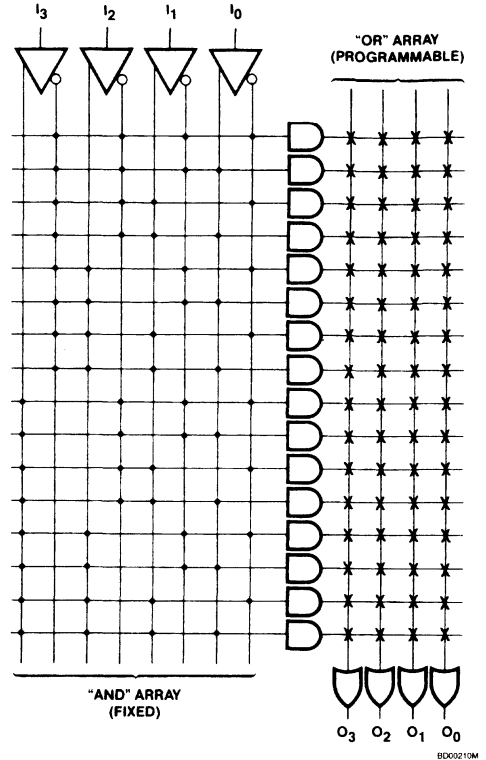


Figure 6

The basic logic structure of the PLA consists of a programmable AND array whose outputs feed a programmable OR array (Figure 7). Since the designer has complete control over all inputs and outputs, the PLA provides the ultimate flexibility for implementing logic functions. They are used in a wide variety of applications. However, this generality can make PLAs expensive, quite formidable to understand, and costly to program.

The basic logic structure of the PAL (Programmable Array Logic) device, as mentioned earlier, consists of a programmable AND array whose outputs feed a fixed OR array (Figure 8). The PAL device combines much of the flexibility of the PLA with the low cost and easy programmability of the PROM. Table 1 summarizes the characteristics of the PROM, PLA, and PAL device logic families.

## PAL<sup>®</sup> Device Introduction

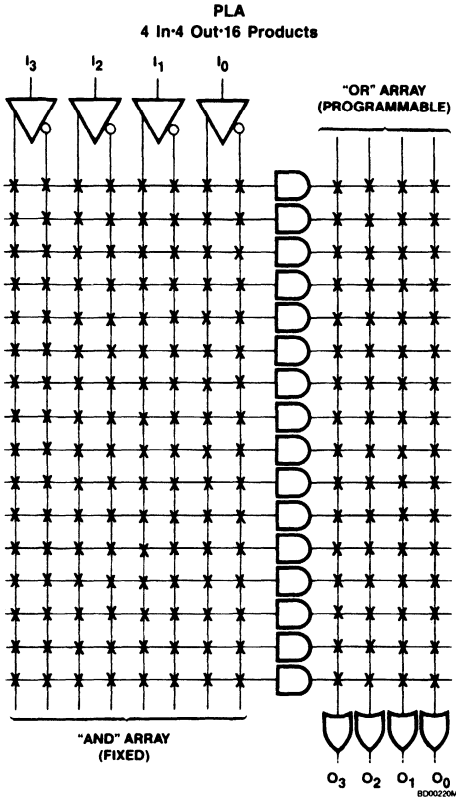


Figure 7

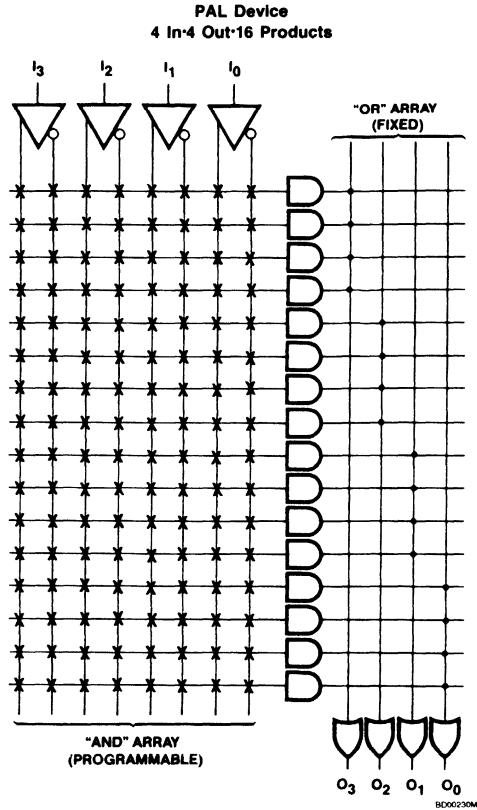


Figure 8

|            | AND   | OR    | OUTPUT OPTIONS                                 |
|------------|-------|-------|--|
| PROM       | Fixed | Prog  | TS, OC   |
| PLA        | Prog  | Prog  | TS, OC, Prog. Polarity                         |
| PAL Device | Prog  | Fixed | TS, Registered Feedback,<br>I/O Prog. Polarity |

Table 1.

### PAL Devices For Every Task

The members of the PAL device family and their characteristics are summarized in the PAL device menu. They are designed to cover the spectrum of logic functions at reduced cost and lower package count. This allows the designer to select the PAL device that best fits his application. PAL device units come in the following basic configurations:

PAL device logic arrays are available in sizes from 6 x 16 (6 input terms, 16 output terms) to 64 x 32, with both active high and active low output configurations available (ref. PAL device menu). This wide variety of input/output formats allows the PAL device to replace many different sized blocks of logic with single packages.

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## Monolithic Memories PAL<sup>®</sup> Device Menu

| FAMILY                      | PART NUMBER | PACKAGE             | DESCRIPTION |               |            | MAXIMUM          |                |
|-----------------------------|-------------|---------------------|-------------|---------------|------------|------------------|----------------|
|                             |             |                     | INPUTS      | OUTPUTS       |            | $t_{PD}^*$<br>ns | $I_{CC}$<br>mA |
|                             |             |                     |             | COMBINATORIAL | REGISTERED |                  |                |
| Small 20<br>Combinatorial   | PAL10H8     | 20N, J, NL,<br>F, L | 10          | 8             | -          | 35               | 90             |
|                             | PAL12H6     |                     | 12          | 6             | -          | 35               |                |
|                             | PAL14H4     |                     | 14          | 4             | -          | 35               |                |
|                             | PAL16H2     |                     | 16          | 2             | -          | 35               |                |
|                             | PAL16C1     |                     | 16          | 2             | -          | 40               |                |
|                             | PAL10L8     |                     | 10          | 8             | -          | 35               |                |
|                             | PAL12L6     |                     | 12          | 6             | -          | 35               |                |
|                             | PAL14L4     |                     | 14          | 4             | -          | 35               |                |
|                             | PAL16L2     |                     | 16          | 2             | -          | 35               |                |
| Small 20-2<br>Combinatorial | PAL10H8-2   | 20N, J, NL,<br>F, L | 10          | 8             | -          | 60               | 45             |
|                             | PAL12H6-2   |                     | 12          | 6             | -          |                  |                |
|                             | PAL14H4-2   |                     | 14          | 4             | -          |                  |                |
|                             | PAL16H2-2   |                     | 16          | 2             | -          |                  |                |
|                             | PAL16C1-2   |                     | 16          | 2             | -          |                  |                |
|                             | PAL10L8-2   |                     | 10          | 8             | -          |                  |                |
|                             | PAL12L6-2   |                     | 12          | 6             | -          |                  |                |
|                             | PAL14L4-2   |                     | 14          | 4             | -          |                  |                |
|                             | PAL16L2-2   |                     | 16          | 2             | -          |                  |                |
| Medium 20<br>Standard       | PAL16L8     | 20N, J, NL          | 16          | 8             | -          | 35               | 180            |
|                             | PAL16R8     |                     | 16          | -             | 8          |                  |                |
|                             | PAL16R6     |                     | 16          | 2             | 6          |                  |                |
|                             | PAL16R4     |                     | 16          | 4             | 4          |                  |                |
| Medium 20A<br>Standard      | PAL16L8A    | 20N, J, NL,<br>W, L | 16          | 8             | -          | 25               | 180            |
|                             | PAL16R8A    |                     | 16          | -             | 8          |                  |                |
|                             | PAL16R6A    |                     | 16          | 2             | 6          |                  |                |
|                             | PAL16R4A    |                     | 16          | 4             | 4          |                  |                |
| Medium 20A-2<br>Standard    | PAL16L8A-2  | 20N, J, NL,<br>F, L | 16          | 8             | -          | 35               | 90             |
|                             | PAL16R8A-2  |                     | 16          | -             | 8          |                  |                |
|                             | PAL16R6A-2  |                     | 16          | 2             | 6          |                  |                |
|                             | PAL16R4A-2  |                     | 16          | 4             | 4          |                  |                |
| Medium 20A-4<br>Standard    | PAL16L8A-4  | 20N, J, NL,<br>F, L | 16          | 8             | -          | 55               | 50             |
|                             | PAL16R8A-4  |                     | 16          | -             | 8          |                  |                |
|                             | PAL16R6A-4  |                     | 16          | 2             | 6          |                  |                |
|                             | PAL16R4A-4  |                     | 16          | 4             | 4          |                  |                |
| Medium 20B<br>Standard      | PAL16L8B    | 20N, J, NL,<br>W, L | 16          | 8             | -          | 15               | 180            |
|                             | PAL16R8B    |                     | 16          | -             | 8          |                  |                |
|                             | PAL16R6B    |                     | 16          | 2             | 6          |                  |                |
|                             | PAL16R4B    |                     | 16          | 4             | 4          |                  |                |
| Medium 20B-2<br>Standard    | PAL16L8B-2  | 20N, J, NL,<br>W, L | 16          | 8             | -          | 25               | 90             |
|                             | PAL16R8B-2  |                     | 16          | -             | 8          |                  |                |
|                             | PAL16R6B-2  |                     | 16          | 2             | 6          |                  |                |
|                             | PAL16R4B-2  |                     | 16          | 4             | 4          |                  |                |
| Medium 20B-4<br>Standard    | PAL16L8B-4  | 20N, J, NL,<br>W, L | 16          | 8             | -          | 35               | 55             |
|                             | PAL16R8B-4  |                     | 16          | -             | 8          |                  |                |
|                             | PAL16R6B-4  |                     | 16          | 2             | 6          |                  |                |
|                             | PAL16R4B-4  |                     | 16          | 4             | 4          |                  |                |
| Medium 20D<br>Standard      | PAL16L8D    | 20N, J, NL          | 16          | 8             | -          | 10               | 180            |
|                             | PAL16R8D    |                     | 16          | -             | 8          |                  |                |
|                             | PAL16R6D    |                     | 16          | 2             | 6          |                  |                |
|                             | PAL16R4D    |                     | 16          | 4             | 4          |                  |                |

## Monolithic Memories PAL<sup>®</sup> Device Menu

| FAMILY                                  | PART NUMBER | PACKAGE             | DESCRIPTION |               |            | MAXIMUM          |                |
|---|-------------|---------------------|-------------|---------------|------------|------------------|----------------|
|   |             |                     | INPUTS      | OUTPUTS       |            | $t_{PD}^*$<br>ns | $I_{CC}$<br>mA |
|   |             |                     |             | COMBINATORIAL | REGISTERED |                  |                |
| Medium 20AP<br>Programmable<br>Polarity | PAL16P8A    | 20N, J, NL          | 16          | 8             | -          | 25/30**          | 180            |
|   | PAL16RP8A   |                     | 16          | -             | 8          |                  |                |
|   | PAL16RP6A   |                     | 16          | 2             | 6          |                  |                |
|   | PAL16RP4A   |                     | 16          | 4             | 4          |                  |                |
| Large 20<br>Arithmetic                  | PAL16X4     | 20N, J, NL,<br>F, L | 16          | 4             | 4          | 40               | 225<br>240     |
|   | PAL16A4     |                     | 16          | 4             | 4          |                  |                |
| Large 20RA<br>Asynchronous              | PAL16RA8    | 20N, J, NL          | 16          | -             | 8          | 30/35**          | 170            |

\* Minimum commercial  $t_{SU}$  for devices with all registered outputs.

\*\* Polarity fuse programmed (active High).

N = Plastic DIP

NS = Plastic SKINNYDIP

J = Ceramic DIP

JS = Ceramic SKINNYDIP

NL = Plastic Leaded Chip Carrier (PLCC)

P = Pin Grid Array

L = Leadless Chip Carrier (LCC)

W = Cerpack

F = Ceramic Solder Seal Flat Pack

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## Monolithic Memories PAL<sup>®</sup> Device Menu

### PAL Circuit Series 24

| FAMILY                                | PART NUMBER | PACKAGE                   | DESCRIPTION |               |            | MAXIMUM                            |                       |
|---------------------------------------|-------------|---------------------------|-------------|---------------|------------|------------------------------------|-----------------------|
|                                       |             |                           | INPUTS      | OUTPUTS       |            | t <sub>PD</sub> <sup>+</sup><br>ns | I <sub>CC</sub><br>mA |
|                                       |             |                           |             | COMBINATORIAL | REGISTERED |                                    |                       |
| Small 24<br>Combinatorial             | PAL12L10    | 24NS, JS, W,<br>28NL, 28L | 10          | 10            | -          | 40                                 | 100                   |
|                                       | PAL14L8     |                           | 14          | 8             | -          |                                    |                       |
|                                       | PAL16L6     |                           | 16          | 6             | -          |                                    |                       |
|                                       | PAL18L4     |                           | 18          | 4             | -          |                                    |                       |
|                                       | PAL20L2     |                           | 20          | 2             | -          |                                    |                       |
|                                       | PAL20C1     |                           | 20          | 2             | -          |                                    |                       |
| Small 24A<br>Decoder                  | PAL6L16A    | 24NS, JS,<br>28NL         | 6           | 16            | -          | 25                                 | 90                    |
|                                       | PAL8L14A    |                           | 8           | 14            | -          |                                    |                       |
| Medium 24A<br>Standard                | PAL20L8A    | 24NS, JS, W,<br>28NL, 28L | 20          | 8             | -          | 25                                 | 210                   |
|                                       | PAL20R8A    |                           | 20          | -             | 8          |                                    |                       |
|                                       | PAL20R6A    |                           | 20          | 2             | 6          |                                    |                       |
|                                       | PAL20R4A    |                           | 20          | 4             | 4          |                                    |                       |
| Medium 24A-2<br>Standard              | PAL20L8A-2  | 24NS, JS, W,<br>28NL, 28L | 20          | 8             | -          | 35                                 | 105                   |
|                                       | PAL20R8A-2  |                           | 20          | -             | 8          |                                    |                       |
|                                       | PAL20R6A-2  |                           | 20          | 2             | 6          |                                    |                       |
|                                       | PAL20R4A-2  |                           | 20          | 4             | 4          |                                    |                       |
| Medium 24B<br>Standard                | PAL20L8B    | 24NS, JS, W,<br>28NL, 28L | 20          | 8             | -          | 15                                 | 210                   |
|                                       | PAL20R8B    |                           | 20          | -             | 8          |                                    |                       |
|                                       | PAL20R6B    |                           | 20          | 2             | 6          |                                    |                       |
|                                       | PAL20R4B    |                           | 20          | 4             | 4          |                                    |                       |
| Medium 24X<br>Exclusive OR            | PAL20L10    | 24NS, JS, W,<br>28NL, 28L | 20          | 10            | -          | 50                                 | 165                   |
|                                       | PAL20X10    |                           | 20          | -             | 10         |                                    |                       |
|                                       | PAL20X8     |                           | 20          | 2             | 8          |                                    |                       |
|                                       | PAL20X4     |                           | 20          | 4             | 4          |                                    |                       |
| Medium 24XA<br>Exclusive OR           | PAL20L10A   | 24NS, JS, W,<br>28NL, 28L | 20          | 10            | -          | 30                                 | 165                   |
|                                       | PAL20X10A   |                           | 20          | -             | 10         |                                    |                       |
|                                       | PAL20X8A    |                           | 20          | 2             | 8          |                                    |                       |
|                                       | PAL20X4A    |                           | 20          | 6             | 4          |                                    |                       |
| Large 24RS<br>Shared Product<br>Terms | PAL20S10    | 24NS, JS, W,<br>28NL, 28L | 20          | 10            | -          | 35/40**                            | 240                   |
|                                       | PAL20RS10   |                           | 20          | -             | 10         | 35                                 | 240                   |
|                                       | PAL20RS8    |                           | 20          | 2             | 8          | 35/40**                            | 240                   |
|                                       | PAL20RS4    |                           | 20          | 6             | 4          | 35/40**                            | 240                   |
| Large 24RA<br>Asynchronous            | PAL20RA10   | 24NS, JS, W,<br>28NL, 28L | 20          | -             | 10         | 30/35**                            | 200                   |
| Large 24VX<br>Varied XOR              | PAL32VX10   | 24NS, JS,<br>28NL         | 32          | -             | 10         | 30                                 | 180                   |
|                                       | PAL32VX10A  |                           |             |               |            | 25                                 |                       |
| ECL                                   | PAL10H20P8  | 24NS, JS,<br>28NL         | 20          | 8             | -          | 6                                  | 210                   |

### PAL Circuit Series MegaPAL<sup>™</sup>

| FAMILY     | PART NUMBER           | PACKAGE           | DESCRIPTION |                    | MAXIMUM                            |                       |
|------------|-----------------------|-------------------|-------------|--------------------|------------------------------------|-----------------------|
|            |                       |                   | INPUTS      | REGISTERED OUTPUTS | t <sub>PD</sub> <sup>+</sup><br>ns | I <sub>CC</sub><br>mA |
| 1500 Gates | PAL 32R16<br>PAL64R32 | 40N, J, 44NL, 44L | 32          | 16                 | 40/45**                            | 280                   |
| 5000 Gates |                       | 88P, 84L          | 64          | 32                 | 50/55**                            | 640                   |

## PAL<sup>®</sup> Device Introduction

### Basic PAL Device Features

PAL devices offer a number of different types of outputs. The basic types include the following:

- Combinatorial
- Programmable I/O
- Registered Outputs with Feedback
- XOR Outputs

### Combinatorial

The simplest PAL devices have combinatorial outputs with no feedback. The basic structure shown in Figure 9 depicts four product terms summed at an active-low output.

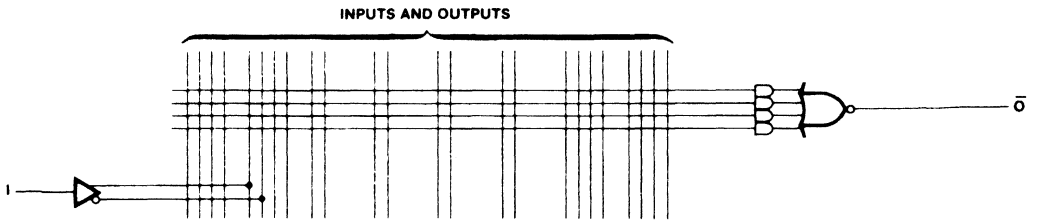


Figure 9

### Programmable I/O

A feature of the high-end members of the PAL device family is programmable input/output. This allows the product terms to directly control the outputs of the PAL device (Figure 10). One product term is used to enable the three-state buffer, which in turn gates the summation term to the output pin. The output is

also fed back into the PAL device array as an input. Thus the PAL device drives the I/O pin when the three-state gate is enabled; the I/O pin is an input to the PAL device array when the three-state gate is disabled. This feature can be used to allocate available pins for I/O functions or to provide bi-directional output pins for operations such as shifting and rotating serial data.

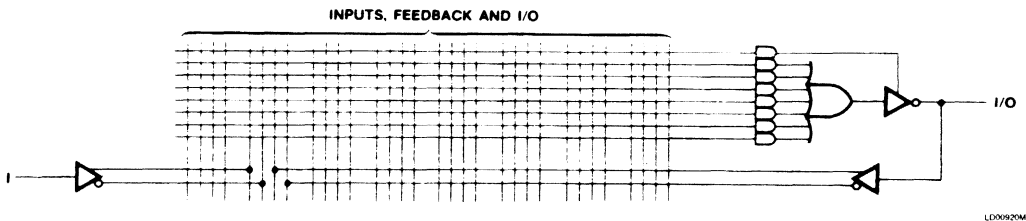


Figure 10

### Registered Outputs with Feedback

Another feature of the high-end members of the PAL device family is registered data outputs with registered feedback. Each product term is summed into a D-type output flip-flop on the rising edge of the system clock (Figure 11). The Q output of the flip-flop can then be gated to the output pin by enabling the active low three-state buffer.

In addition to being available for transmission, the Q output is fed back into the PAL device array as an input term. This feedback allows the PAL device to "remember" the previous state, and it can alter its function based upon that state. This allows the designer to configure the PAL device as a state sequencer which can be programmed to execute such elementary functions as count up, count down, skip, shift, and branch. These functions can be executed by the registered PAL device at rates of up to 55.5MHz.

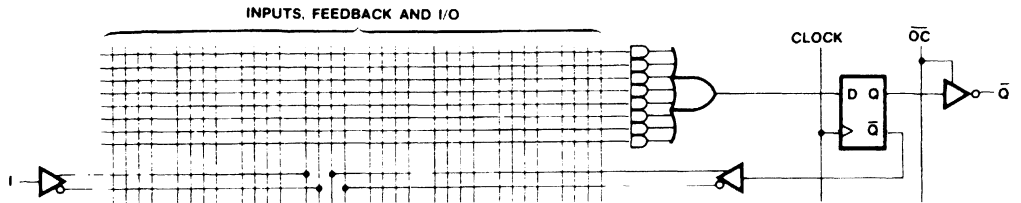


Figure 11

**XOR Outputs**

These PAL devices feature an exclusive-OR (XOR) function. The sum of products is segmented into two sums which are then exclusive ORed at the input of the D-type flip-flop (Figure

12). All of the features of the Registered PAL devices are included in the XOR PAL unit. The XOR function provides an easy implementation of the HOLD operation used in counters and other state sequencers.

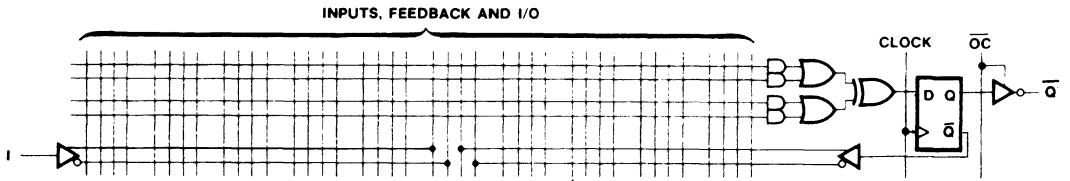


Figure 12

**PAL Device Programming**

PAL devices can be programmed in most standard PROM programmers with the addition of a PAL device personality card. For details on programming equipment, see the PAL Device Programmer Reference Guide in this handbook.

**PALASM (PAL Device Assembler)**

PALASM is the software used to define, simulate, build, and test PAL device units. PALASM accepts the PAL device Design Specification as an input file. It verifies the design against an optional function table and generates the fuse plot which is used to program the PAL devices. PALASM is available upon request for many computers.

**HAL (Hard Array Logic) Device**

The HAL device family is the mask programmed version of a PAL device. The HAL device is to a PAL device just as a ROM is to a PROM. A standard wafer is fabricated as far as the metal mask. Then a custom metal mask is used to fabricate aluminum links for a HAL device instead of the programmable TiW fuses used in a PAL device.

**PAL Device Technology**

PAL circuits are manufactured using the proven TTL Schottky bipolar TiW fuse process to make fusible-link PROMs. An NPN emitter follower array forms the programmable AND array. PNP inputs provide high impedance inputs (0.25mA max) to the array. All outputs are standard TTL drivers with internal active pull-up transistors.

**PAL Device Data Security**

The circuitry used for programming and logic verification can be used at any time to determine the logic pattern stored in the PAL device array. For security, the PAL device has a "last

fuse" which can be blown to disable the verification logic. This provides a significant deterrent to potential copiers, and it can be used to protect proprietary designs.

**PAL Device Part Numbers**

The PAL device part number is unique in that the part number code also defines the part's logic operation. The PAL device numbering system is shown in Figure 13. For example, a PAL 14L4CN would be a 14-input term, 4-output term, active-low PAL device with a commercial temperature range packaged in a 20-pin plastic DIP.

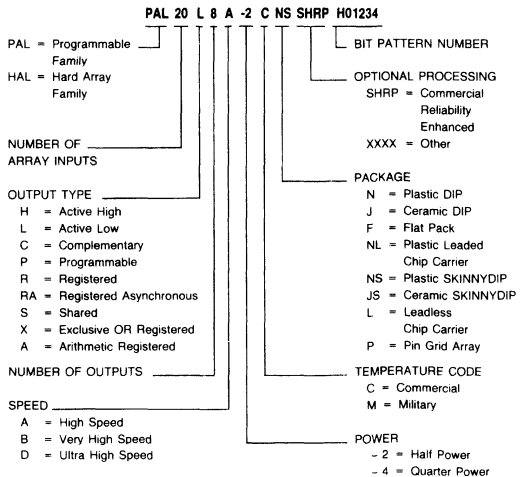


Figure 13



### PAL Device Logic Symbols

The logic symbols for each of the individual PAL devices gives a concise functional description of the PAL device logic function. This symbol makes a convenient reference when selecting the PAL device that best fits a specific application. Figure 14 shows the logic symbol for a PAL10H8 array.

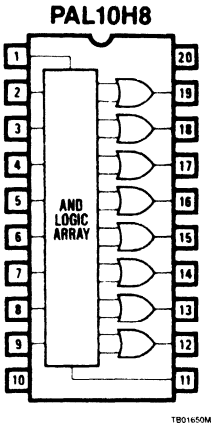


Figure 14

### A PAL Device Example

As an example of how the PAL device enables the designer to reduce costs and simplify logic design, consider the design of a simple, high-volume consumer product: an electronic dice game. This type of product will be produced in extremely high volume, so it is essential that every possible production cost be minimized.

The electronic dice game is simply constructed using a free running oscillator whose output is used to drive two asynchronous modulo six counters. When the user "rolls" the dice (presses a button), the current state of the counters is decoded and latched into a display resembling the pattern seen on an ordinary pair of dice.

A conventional logic diagram for the dice game is shown in Figure 15. It is implemented using standard TTL, SSI and MSI parts, with a total I.C. count of eight: six quad gate packages and two quad D-latches. Looks like a nice clean logic design, right? Wrong!!

1

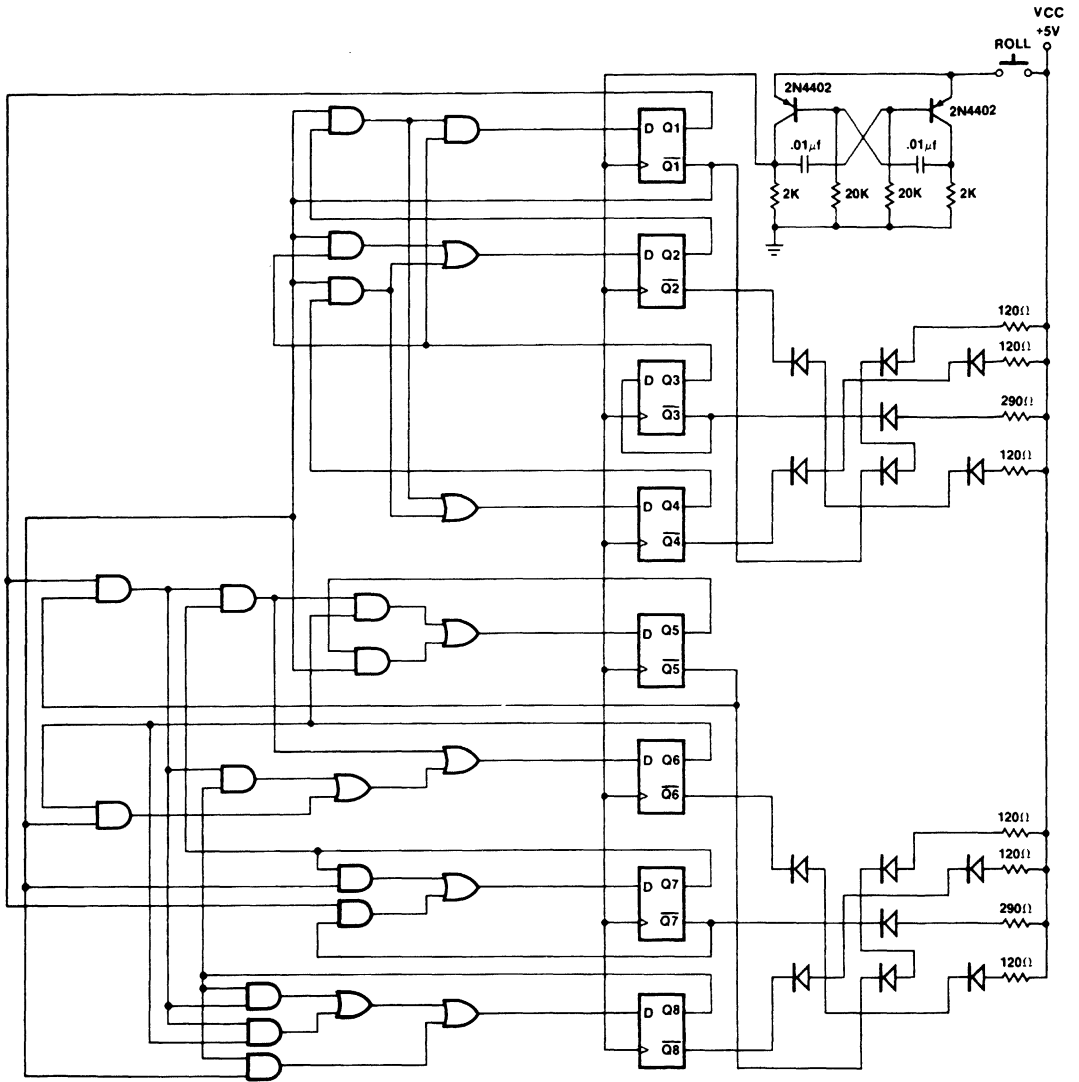


Figure 15

8000250M

## PAL<sup>®</sup> Device Introduction

A brief examination of Figure 15 reveals two basic facts: first, the circuit contains mostly simple, combinatorial logic, and second, it uses a clocked state transition sequence. Remembering that the PAL device family contains ample provision for these features, the PAL device catalog is consulted. The PAL16R8 has all the required functions, and the entire logic content of the circuit can be programmed into a single PAL device shown in Figure 16.

In this example, the PAL device effected an eight-to-one package count reduction and a significant cost savings. This is typical of the power and cost-effective performance that the PAL device family brings to logic design.

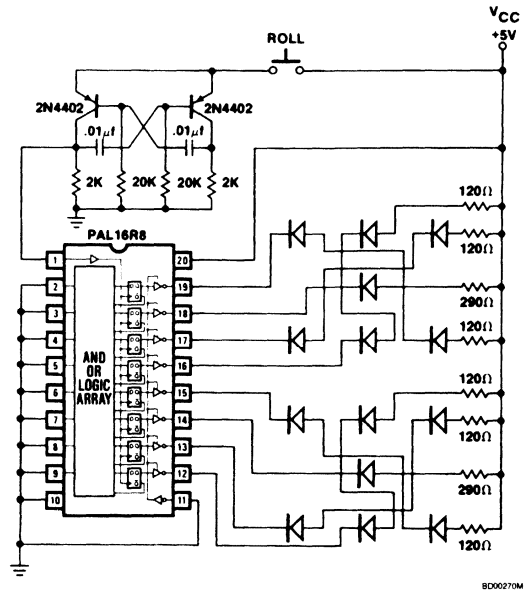
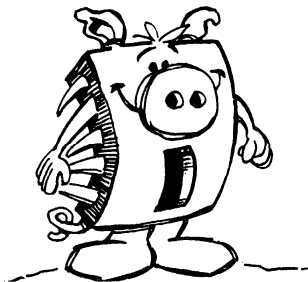


Figure 16

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## Advantages of Using PAL Devices



CD00920M

The PAL device has a unique place in the world of logic design. Not only does it offer many advantages over conventional logic, it also provides many features not found anywhere else. Among the benefits of the PAL device family:

- Programmable replacement for conventional TTL logic.
- Reduces IC inventories substantially and simplifies their control.
- Reduces chip count by at least 4 to 1.
- Expedites and simplifies prototyping and board layout.
- Saves space with 20-pin and 24-pin SKINNYDIP packages, and surface-mount PLCC packages.
- High speed: 10ns maximum propagation delay, on D series.
- Programmed on standard PROM programmers.
- Programmable three-state outputs.
- Special feature eliminates possibility of copying by competitors.

All of these features combine together to lower product development costs and increase product cost effectiveness. The bottom line is that PAL devices save money.

## Direct Logic Replacement



CD00940M

In both new and existing designs, the PAL device can be used to replace various logic functions. This allows the designer to optimize a circuit in many ways never before possible. The PAL device is particularly effective when used to provide

interfaces required by many LSI functions. The combination of PAL device flexibility and LSI function density makes a powerful team.

## Design Flexibility

The PAL device offers the systems logic designer a whole new world of options. Until now, the decision on logic system implementation was usually between SSI/MSI logic functions on one hand and microprocessors on the other. In many cases the function required is too awkward to implement the first way and too simple to justify the second. Now the PAL device offers the designer high functional density, high speed, and low cost. Even better, PAL devices come in a variety of sizes and functions, thereby further increasing the designer's options.

## Space Efficiency

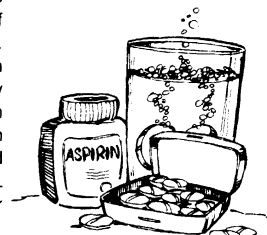


CD00939M

By allowing designers to replace many simple logic functions with single packages, the PAL device allows more compact P.C. board layouts. The PAL device space-saving 20-pin and 24-pin SKINNYDIP packages help to reduce board area further while simplifying board layout and fabrication. This means that many multi-card systems can now be reduced to one or two cards, and that can make the difference between a profitable success or an expensive disaster.

## Smaller Inventory

The PAL device family can be used to replace up to 90% of the conventional TTL family. This considerably lowers both shelving and inventory cataloging requirements. In addition, small custom modifications to the standard functions are easy for PAL device users, but not so easy for standard TTL users.



CD00950M

## PAL<sup>®</sup> Device Introduction

### High Speed



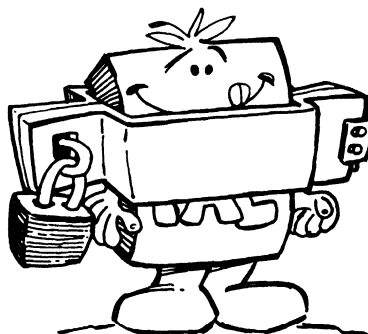
CD00960M

The PAL device family runs faster than or equal to the best of bipolar logic circuits. This makes the PAL device the ideal choice for most logical operations or control sequences which require a medium complexity and high speed. Also, in many microcomputer systems, the PAL device can be used to handle high-speed data interfaces that are not feasible for the microprocessor alone. This can be used to significantly extend the capabilities of the low-cost, low-speed NMOS microprocessors into areas formerly requiring high-cost bipolar microprocessors.

### Easy Programming

The members of the PAL device family can be quickly and easily programmed using standard PROM programmers. This allows designers to use PAL devices with a minimum investment in special equipment. Many types of programmable logic, such as the PLA, require an expensive, dedicated programmer.

### Secure Data



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The PAL device verification logic can be completely disabled by blowing out a special "last link". This prevents the unauthorized copying of valuable data, and makes the PAL device perfect for use in any application where data integrity must be carefully guarded.

### Summary

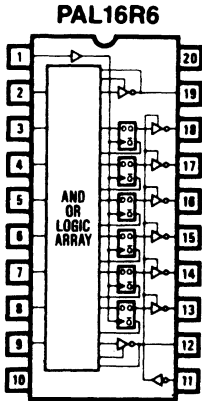
The PAL device family of logic devices offers logic designers new options in the implementation of sequential and combinatorial logic designs. The family is fast, compact, flexible, and easy to use in both new and existing designs. It promises to reduce costs in most areas of design and production with a corresponding increase in product profitability.

## A Great Performer!

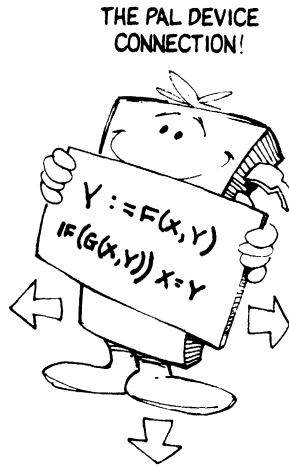


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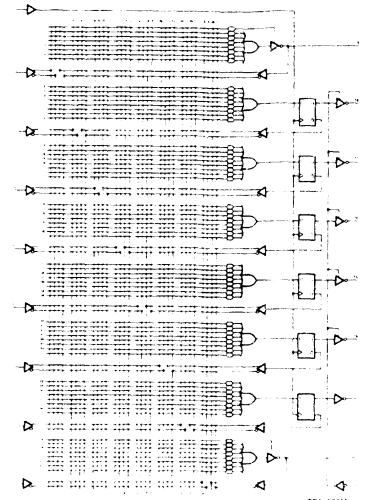
# PAL<sup>®</sup> Device Introduction



TB01670M



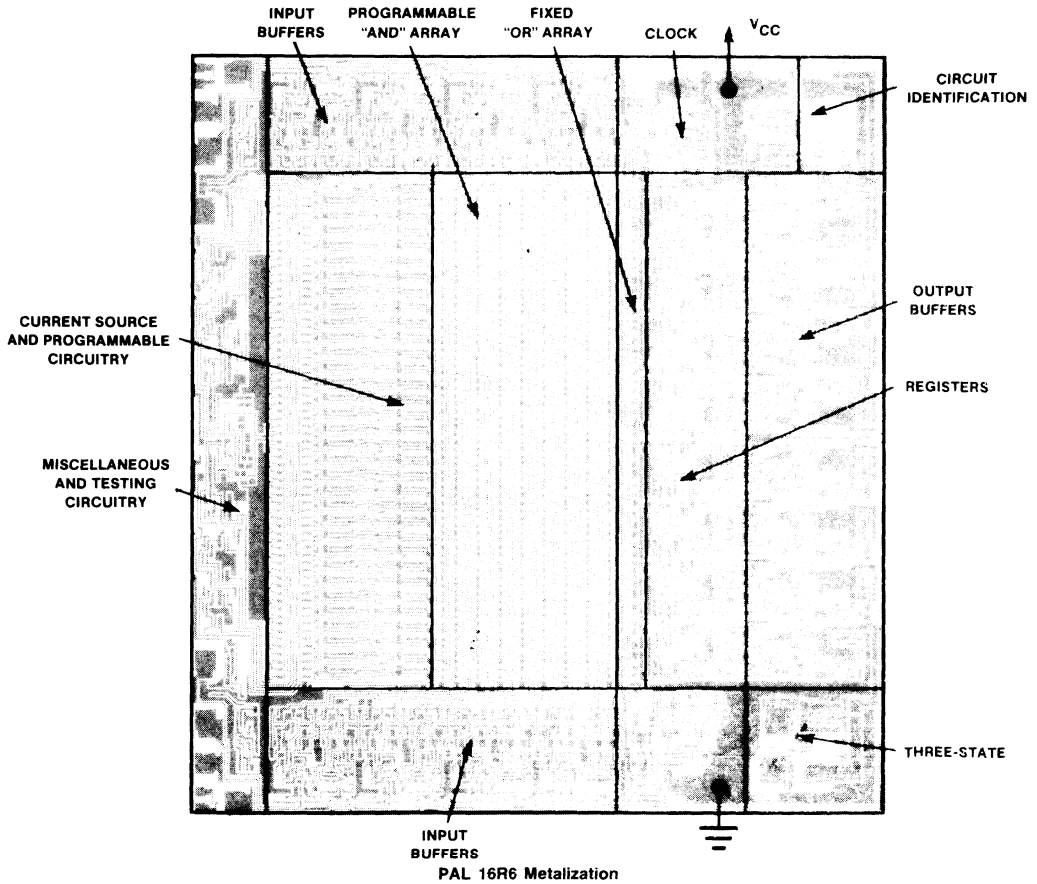
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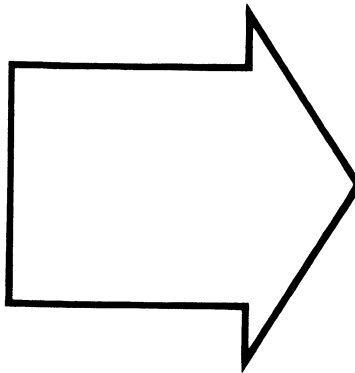


TB0168M

PAL1646 Logic Symbols

PAL16R6 Logic Diagram





|   |           |
|---|-----------|
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# PAL<sup>®</sup> (Programmable Array Logic) Devices

## HAL<sup>®</sup> (Hard Array Logic) Devices

### Features/Benefits

- Reduces SSI/MSI chip count greater than 4 to 1
- Saves space with SKINNYDIP<sup>®</sup> and PLCC packages
- Reduces IC inventories substantially
- Expedites and simplifies prototyping and board layout
- PALASM<sup>®</sup> 2 silicon compiler provides easy design entry
- Security fuse reduces possibility of copying by competitors

### Description

The PAL device family utilizes an advanced Schottky TTL process and the Bipolar PROM fusible link technology to provide user-programmable logic for replacing conventional SSI/MSI gates and flip-flops at reduced chip count.

The HAL device family utilizes standard Low-Power Schottky TTL process and automated mask pattern generation directly from logic equations to provide a semi-custom gate array for replacing conventional SSI/MSI gates and flip-flops at reduced chip count.

The PAL device lets the systems engineer "design his own chip" by blowing fusible links to configure AND and OR gates to perform his desired logic function. Complex interconnections which previously required time-consuming layout are thus "lifted" from PC board etch and placed on silicon where they can be easily modified during prototype check-out or production.

The PAL/HAL device transfer function is the familiar sum of products. Like the PROM, the PAL device has a single array of fusible links. Unlike the PROM, the PAL device is a programmable AND array driving a fixed OR array (the PROM is a fixed AND array driving a programmable OR array).

In addition the PAL/HAL device provides these options:

- Variable input/output pin ratio
- Programmable three-state outputs
- Registers with feedback
- Arithmetic capability
- Exclusive-OR gates

Unused input pins should be tied directly to  $V_{CC}$  or GND. Product terms with all fuses blown assume the logical high state, and product terms connected to both true and complement of any single input assume the logical low state. Registers consist of D-type flip-flops which are loaded on the low-to-high transition of the clock. PAL/HAL device Logic Diagrams are shown with all fuses blown, enabling the designer to use the diagrams as coding sheets. PALASM 2 software automatically generates a similar diagram, called the fuse plot.

The entire PAL device family is programmed using inexpensive conventional PROM programmers with appropriate personality and socket adapter cards. Once the PAL device is programmed and verified, two additional fuses may be blown to defeat verification. This feature gives the user a proprietary circuit which is very difficult to copy.

To design a HAL, the user first programs and debugs a PAL device using PALASM 2 software and the "PAL DEVICE DESIGN SPECIFICATION" standard format. This specification is submitted to Monolithic Memories where it is computer-processed and assigned a bit pattern number, e.g., H01234.

Monolithic Memories will provide a PAL device sample for customer qualification. The user then submits a purchase order for a HAL of the specified bit pattern number, e.g., HAL18L4 H01234. For details on ordering HAL devices, please refer to the brochure, *ProPAL, HAL, and ZHAL Devices: The Logical Solutions for Volume Programmable Logic*, available from Monolithic Memories.

2

### Register Bypass (MegaPAL Devices)

Outputs within a bank must either be all registered or all combinatorial. Whether or not a bank of registers is bypassed depends on how the outputs are defined in the equations. A colon followed by an equal sign [: = ] specifies a registered output with feedback which is updated after the low-to-high transition of the clock. An equal sign [= ] defines a combinatorial output which bypasses the register. Registers are bypassed in banks of eight. Bypassing a bank of registers eliminates the feedback lines for those outputs.

### Output Polarity

Output polarity is defined by comparison of the pin list and the equations. If the logic sense of a specific output in the pin list is different from the logic sense of that output as defined by its equation, the output is inverted or active low polarity. If the logic sense of a specific output in the pin list is the same as the logic sense of that output as defined by its equation, the output is active high polarity. Note that the P, RA, RS, and MegaPAL devices have programmable output polarity.

### Product Term Sharing (RS, MegaPAL Devices)

The basic configuration is sixteen product terms shared between two output cells. For a typical output pair, each product term can be used by either output; but, since product term sharing is exclusive, a product term can be used by only one output, not both. If equations call for an output pair to use the same product term, two product terms are generated, one for each output. This should be taken into account when writing equations. PAL device assemblers configure product terms automatically.

### Product Term Editing

A unique feature of product term sharing is the ability to edit the design after the device has been programmed. Without this feature, a new PAL device had to be programmed if the user needed to change his design. Product term editing allows the user to delete an unwanted product term and reprogram a previously unused product term to the desired fuse pattern. This feature is made possible by the product term sharing architecture. Since each product term can be routed to either output in a given pair by selecting one of two steering fuses, it is possible to blow both of the steering fuses thereby completely disabling that product term. Once disabled, that product term is powered down, saving typically 0.25mA. The desired change may now be programmed into one of the previously unused product terms corresponding to that output pair. Additional edits can be made as long as there are unused product terms for the output in question.

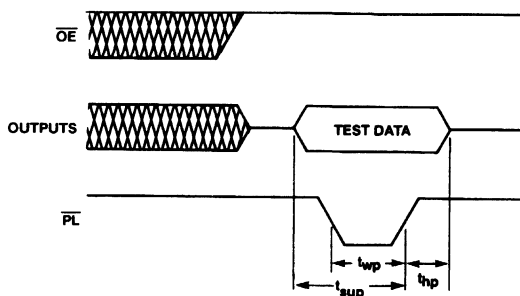
### PRESET Feature (PAL64R32 only)

Register banks of eight may be PRESET to all highs on the outputs by setting the PRESET pin (PS) to a Low level. Note from the Logic Diagram that when the state of an output is High, the state of the register is Low due to the inverting tri-state buffer.

### TTL-Level Preload Features (RA, MegaPAL Devices)

Preload pins have been added to enable the testability of each state in state-machine design. Typically, for a modulo-n counter or a state machine there are many unreachable states for the registers. These states, and the logic which controls them are untestable without a way to "set-in" the desired starting state of the registers. In addition, long test sequences are sometimes needed to test a state machine simply to reach those starting states which are legal. Since complete logic verification is needed to ensure the proper exit from "illegal" or unused states, a way to enter these states must be provided. The ability to preload a given bank of registers is provided in this device.

To use the preload feature, several steps must be followed. First, a high level on an assertive-low output enable pin disables the outputs for that bank of registers. Next, the data to be loaded is presented at the output pins. This data is then loaded into the register by placing a low level on the PRELOAD pin, PRELOAD is asynchronous with respect to the clock.



### Programmable Set and Reset (RA Family only)

In each SMAC, two product lines are dedicated to asynchronous set and reset. If the set product line is high, the register output becomes a logic 1. If the reset product line is high, the register output becomes a logic 0. The operation of the programmable set and reset overrides the clock. Note that set and reset are in reference to the register, independent of polarity.

### Individually Programmable Register Bypass (RA Family only)

If both the set and reset product lines are high, the sum-of-products bypasses the register and appears immediately at the output, thus making the output combinatorial. This allows each output to be configured in the registered or combinatorial mode.

### Programmable Clock (RA Family only)

One of the product lines in each group is connected to the clock. This provides the user with the additional flexibility of a programmable clock, so each output can be clocked independently of all the others.

**Small 20 Series**  
**10H8, 12H6, 14H4, 16H2, 16C1, 10L8, 12L6, 14L4, 16L2**

**Small 20 Series**

|         | INPUTS | OUTPUTS | POLARITY | STANDARD                |                         | HALF POWER              |                         |
|---------|--------|---------|----------|-------------------------|-------------------------|-------------------------|-------------------------|
|         |        |         |          | t <sub>PD</sub><br>(ns) | I <sub>CC</sub><br>(mA) | t <sub>PD</sub><br>(ns) | I <sub>CC</sub><br>(mA) |
| PAL10H8 | 10     | 8       | HIGH     | 35                      | 90                      | 65                      | 40                      |
| PAL12H6 | 12     | 6       | HIGH     | 35                      | 90                      | 65                      | 40                      |
| PAL14H4 | 14     | 4       | HIGH     | 35                      | 90                      | 65                      | 40                      |
| PAL16H2 | 16     | 2       | HIGH     | 35                      | 90                      | 65                      | 40                      |
| PAL16C1 | 16     | 2       | BOTH     | 40                      | 90                      | 65                      | 40                      |
| PAL10L8 | 10     | 8       | LOW      | 35                      | 90                      | 65                      | 40                      |
| PAL12L6 | 12     | 6       | LOW      | 35                      | 90                      | 65                      | 40                      |
| PAL14L4 | 14     | 4       | LOW      | 35                      | 90                      | 65                      | 40                      |
| PAL16L2 | 16     | 2       | LOW      | 35                      | 90                      | 65                      | 40                      |

**2**

**Description**

The Small 20 Series is made up of nine combinatorial 20-pin PAL devices. They implement simple combinatorial logic, with no feedback. Each has sixteen product terms total, divided among the outputs, with two to sixteen product terms per output.

**Polarity**

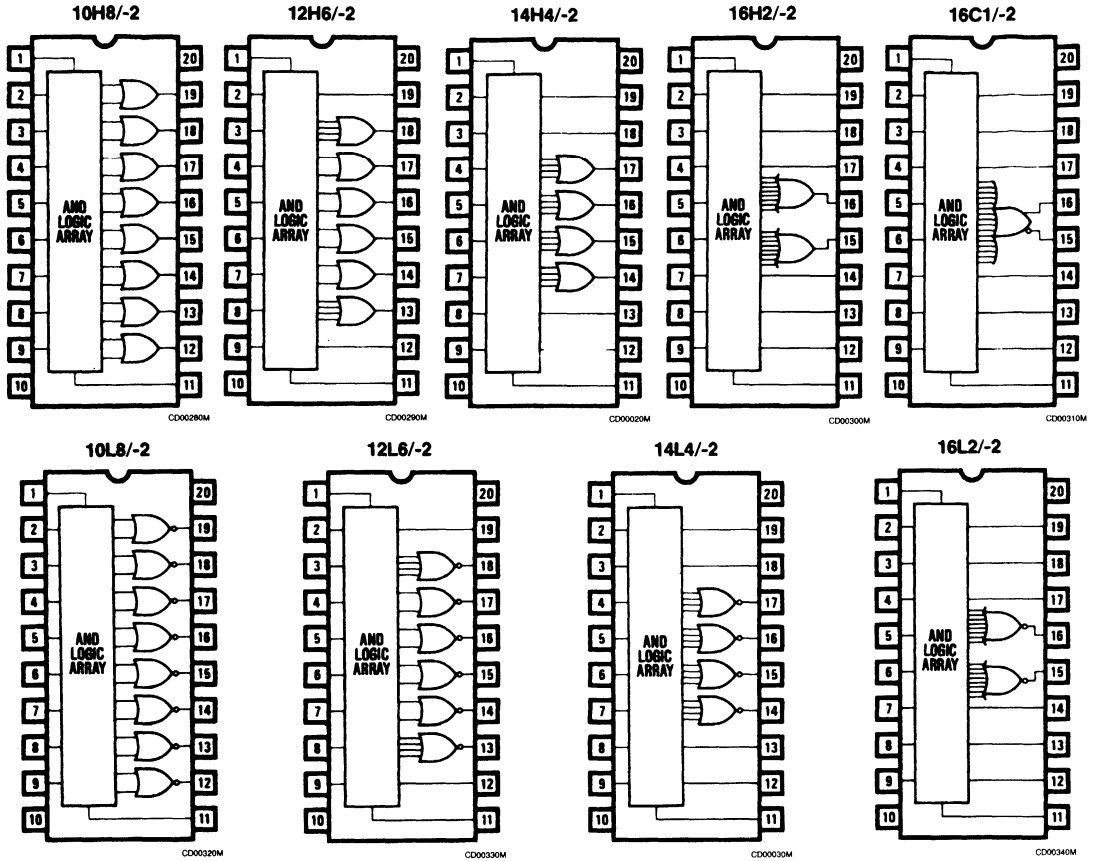
Both active high and active low versions are available for each architecture. The 16C1 offers both polarities of its single output.

**Performance**

Two performance options are available. The standard series has a propagation delay (tpd) of 35 nanoseconds (ns), except for the 16C1 at 40ns. Standard supply current is 90 milliamps (mA). The half-power version consumes only 40mA, with a speed of 65ns.

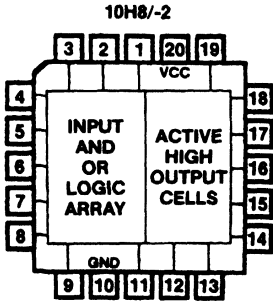
**Small 20 Series**  
**10H8, 12H6, 14H4, 16H2, 16C1, 10L8, 12L6, 14L4, 16L2**

**DIP Pinouts**

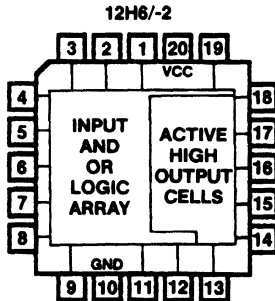


**Small 20 Series**  
**10H8, 12H6, 14H4, 16H2, 16C1, 10L8, 12L6, 14L4, 16L2**

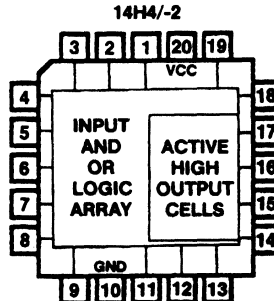
**PLCC Pinouts**



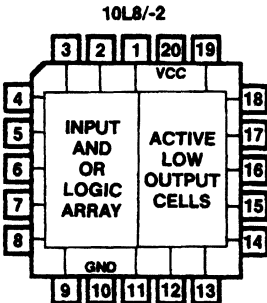
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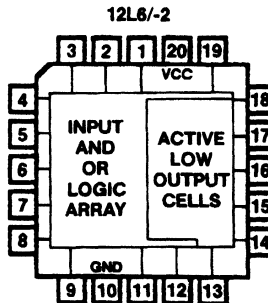
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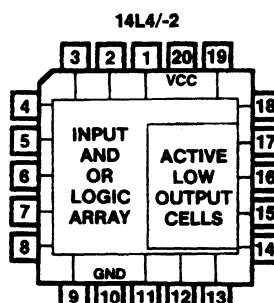
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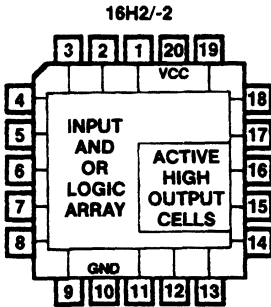
CD00460M



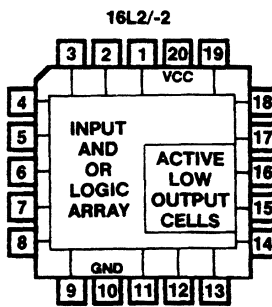
CD00070M



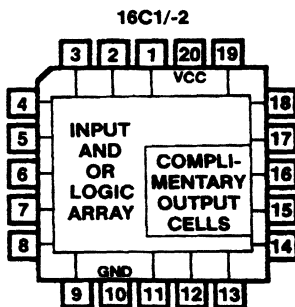
CD00470M



CD00480M



CD00060M



CD00490M

**Small 20 Series**  
**10H8, 12H6, 14H4, 16H2, 16C1, 10L8, 12L6, 14L4, 16L2**

**Operating Conditions**

| SYMBOL          | PARAMETER                      | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|-----------------|--------------------------------|----------|-----|-----|------------|-----|------|------|
|                 |                                | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                 | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| T <sub>A</sub>  | Operating free-air temperature | -55      |     |     | 0          |     | 75   | °C   |
| T <sub>C</sub>  | Operating case temperature     |          |     | 125 |            |     |      | °C   |

**Electrical Characteristics Over Operating Conditions**

| SYMBOL                       | PARAMETER                    | TEST CONDITIONS       |                              | MIN | TYP   | MAX   | UNIT |
|------------------------------|------------------------------|-----------------------|------------------------------|-----|-------|-------|------|
| V <sub>IL</sub> <sup>1</sup> | Low-level input voltage      |                       |                              |     |       | 0.8   | V    |
| V <sub>IH</sub> <sup>1</sup> | High-level input voltage     |                       |                              | 2   |       |       | V    |
| V <sub>IC</sub>              | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA       |     | -0.8  | -1.5  | V    |
| I <sub>IL</sub>              | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V        |     | -0.02 | -0.25 | mA   |
| I <sub>IH</sub>              | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V        |     |       | 25    | μA   |
| I <sub>I</sub>               | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V        |     |       | 1     | mA   |
| V <sub>OL</sub>              | Low-level output voltage     | V <sub>CC</sub> = MIN | MIL I <sub>OL</sub> = 8mA    |     | 0.3   | 0.5   | V    |
|                              |                              |                       | COM I <sub>OL</sub> = 8mA    |     |       |       |      |
| V <sub>OH</sub>              | High-level output voltage    | V <sub>CC</sub> = MIN | MIL I <sub>OH</sub> = -2mA   | 2.4 | 2.8   |       | V    |
|                              |                              |                       | COM I <sub>OH</sub> = -3.2mA |     |       |       |      |
| I <sub>OS</sub> <sup>2</sup> | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V          | -30 | -70   | -130  | mA   |
| I <sub>CC</sub>              | Supply current               | V <sub>CC</sub> = MAX |                              |     | 55    | 90    | mA   |

**Switching Characteristics**

| SYMBOL          | PARAMETER                   |             | TEST CONDITIONS                                 | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|-----------------|-----------------------------|-------------|---|----------|-----|-----|------------|-----|-----|------|
|                 |                             |             |   | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| t <sub>PD</sub> | Input or feedback to output | Except 16C1 | R <sub>1</sub> = 560Ω<br>R <sub>2</sub> = 1.1kΩ |          | 25  | 45  |            | 25  | 35  | ns   |
|                 |                             | 16C1        |   |          | 25  | 45  |            | 25  | 40  |      |

1. These are absolute values with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Small 20-2 Series**  
**10H8-2, 12H6-2, 14H4-2, 16H2-2, 16C1-2, 10L8-2, 12L6-2, 14L4-2, 16L2-2**

**Operating Conditions**

| SYMBOL   | PARAMETER                      | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|----------|--------------------------------|----------|-----|-----|------------|-----|------|------|
|          |                                | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                 | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| $T_A$    | Operating free-air temperature | -55      |     | 125 | 0          |     | 75   | °C   |

**Electrical Characteristics Over Operating Conditions**

| SYMBOL     | PARAMETER                    | TEST CONDITIONS       |                            | MIN | TYP   | MAX   | UNIT          |
|------------|------------------------------|-----------------------|----------------------------|-----|-------|-------|---------------|
| $V_{IL}^1$ | Low-level input voltage      |                       |                            |     |       | 0.8   | V             |
| $V_{IH}^1$ | High-level input voltage     |                       |                            | 2   |       |       | V             |
| $V_{IC}$   | Input clamp voltage          | $V_{CC} = \text{MIN}$ | $I_I = -18\text{mA}$       |     | -0.8  | -1.5  | V             |
| $I_{IL}$   | Low-level input current      | $V_{CC} = \text{MAX}$ | $V_I = 0.4\text{V}$        |     | -0.02 | -0.25 | mA            |
| $I_{IH}$   | High-level input current     | $V_{CC} = \text{MAX}$ | $V_I = 2.4\text{V}$        |     |       | 25    | $\mu\text{A}$ |
| $I_I$      | Maximum input current        | $V_{CC} = \text{MAX}$ | $V_I = 5.5\text{V}$        |     |       | 1     | mA            |
| $V_{OL}$   | Low-level output voltage     | $V_{CC} = \text{MIN}$ | Mil $I_{OL} = 4\text{mA}$  |     | 0.3   | 0.5   | V             |
|            |                              |                       | Com $I_{OL} = 4\text{mA}$  |     |       |       |               |
| $V_{OH}$   | High-level output voltage    | $V_{CC} = \text{MIN}$ | Mil $I_{OH} = -1\text{mA}$ | 2.4 | 2.8   |       | V             |
|            |                              |                       | Com $I_{OH} = -1\text{mA}$ |     |       |       |               |
| $I_{OS}^2$ | Output short-circuit current | $V_{CC} = 5\text{V}$  | $V_O = 0\text{V}$          | -30 | -70   | -130  | mA            |
| $I_{CC}$   | Supply current               | $V_{CC} = \text{MAX}$ |                            |     | 30    | 45    | mA            |

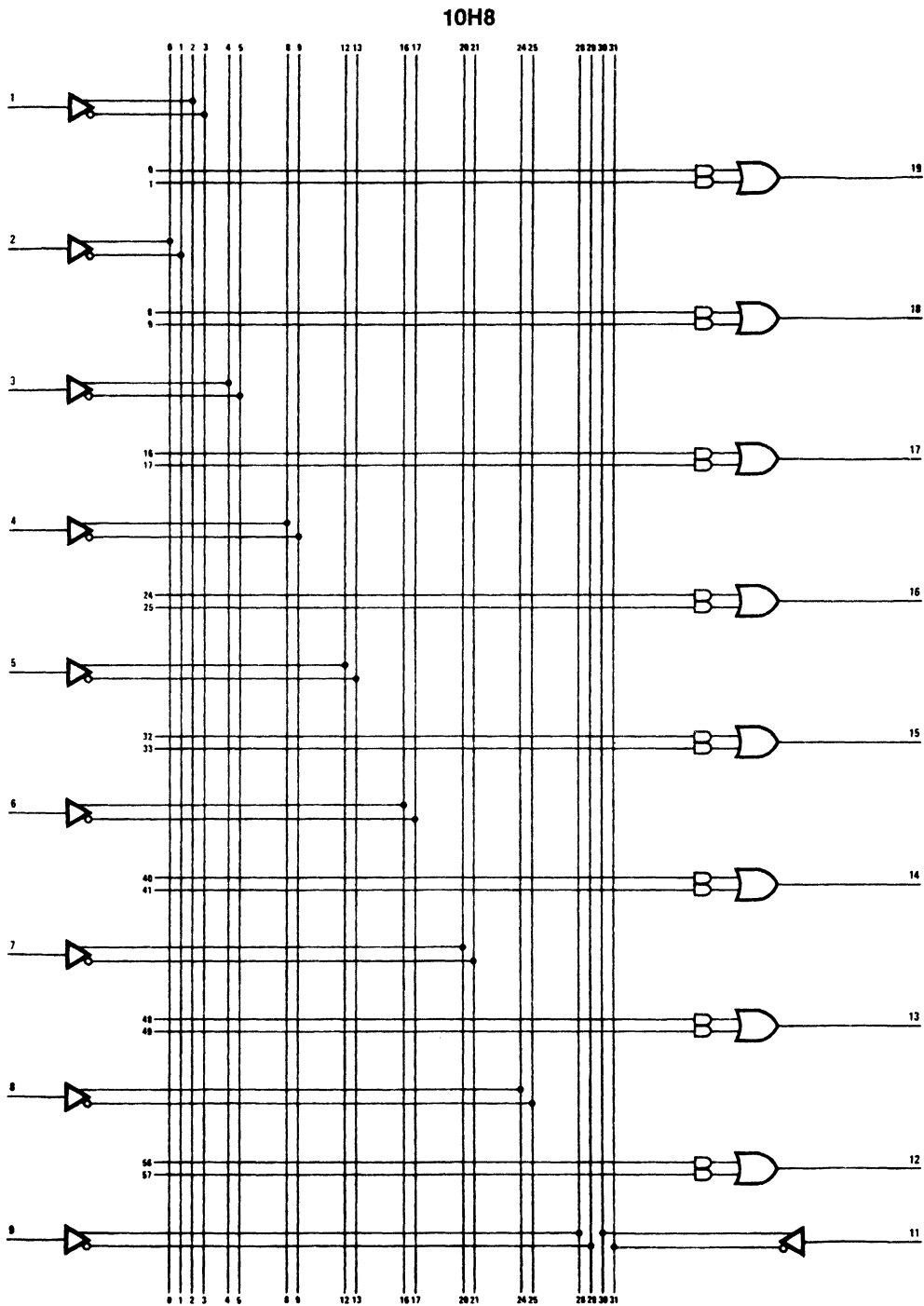
**2**

**Switching Characteristics Over Operating Conditions**

| SYMBOL   | PARAMETER                   | TEST  | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|----------|-----------------------------|---|----------|-----|-----|------------|-----|-----|------|
|          |                             |   | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{PD}$ | Input or feedback to output | $R_1 = 1.12\text{k}\Omega$<br>$R_2 = 2.2\text{k}\Omega$ |          | 45  | 80  |            | 45  | 60  | ns   |

1. These are absolute values with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Small 20 Series  
10H8 Logic Diagram**

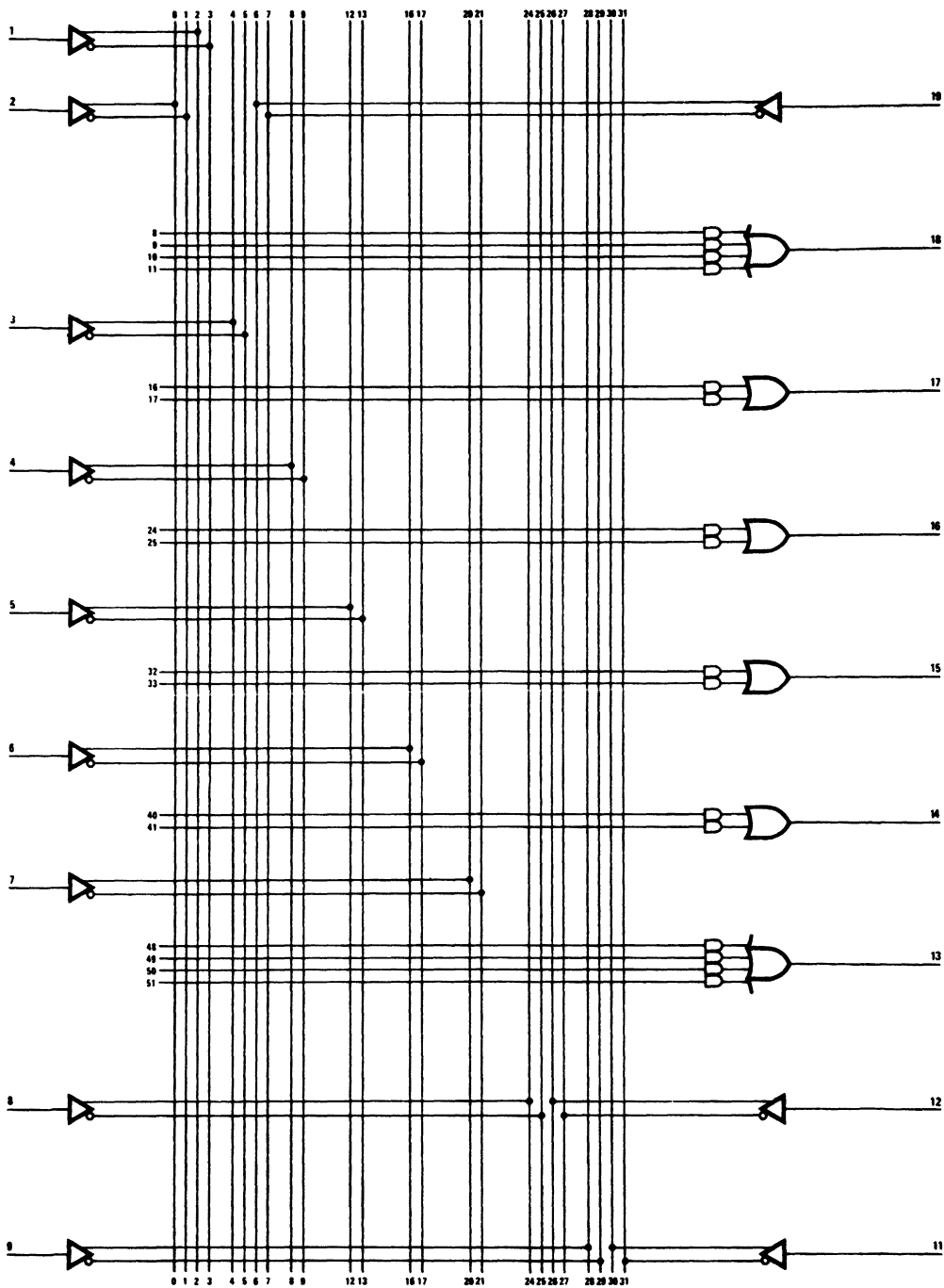


L000320M



Small 20 Series  
12H6 Logic Diagram

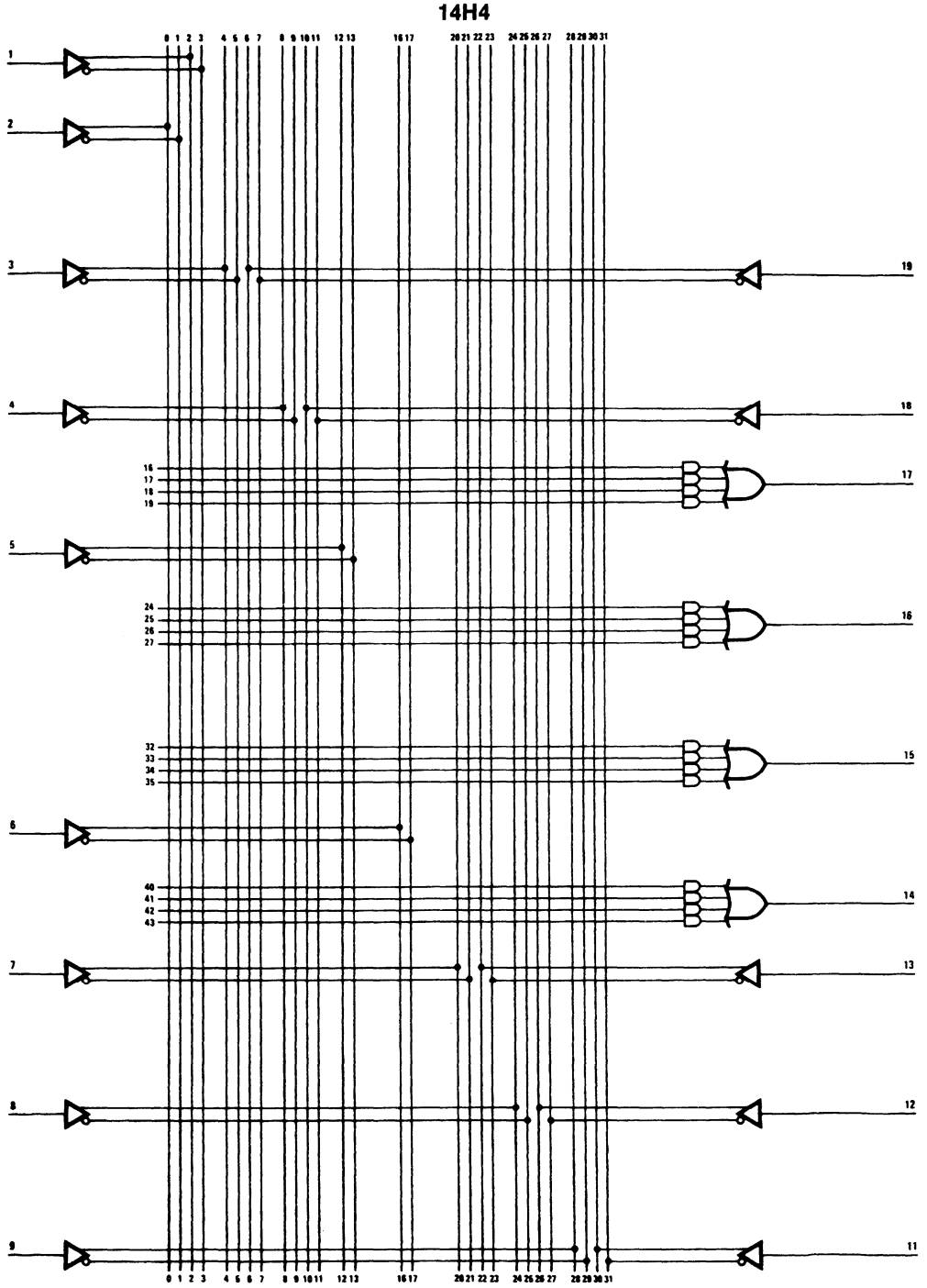
12H6



2

LD00230M

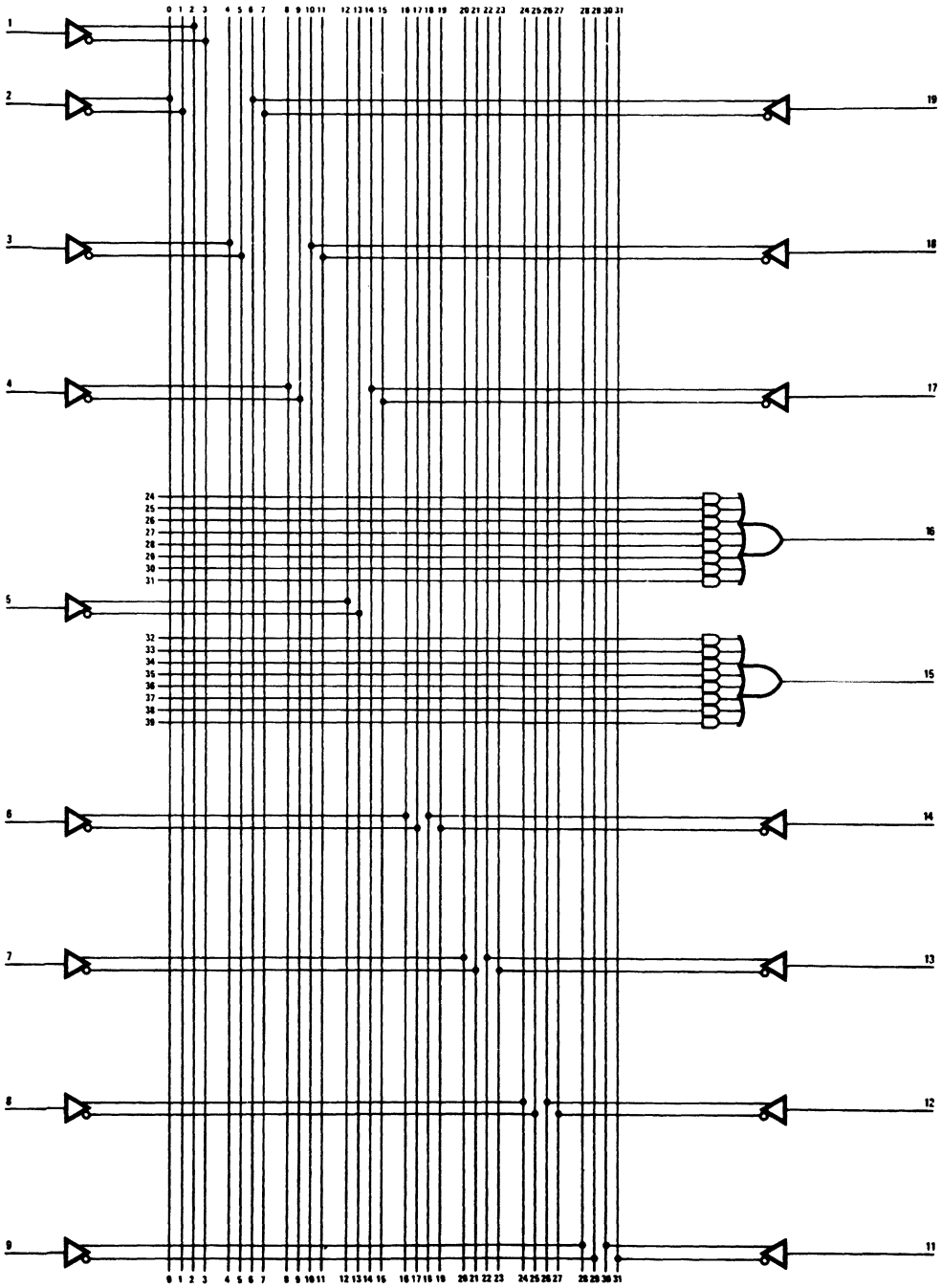
**Small 20 Series  
14H4 Logic Diagram**



LD00340M

**Small 20 Series  
16H2 Logic Diagram**

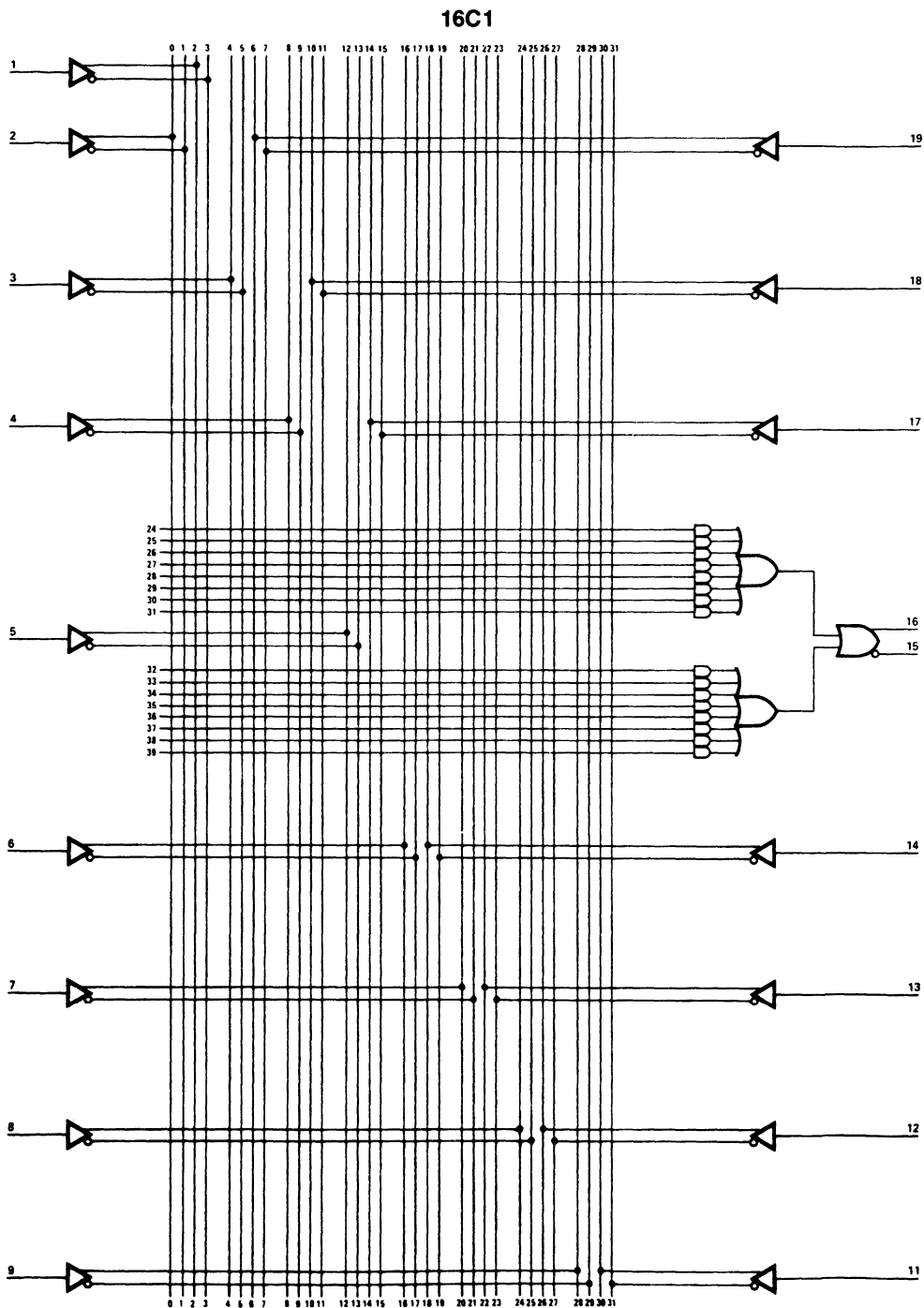
**16H2**



**2**

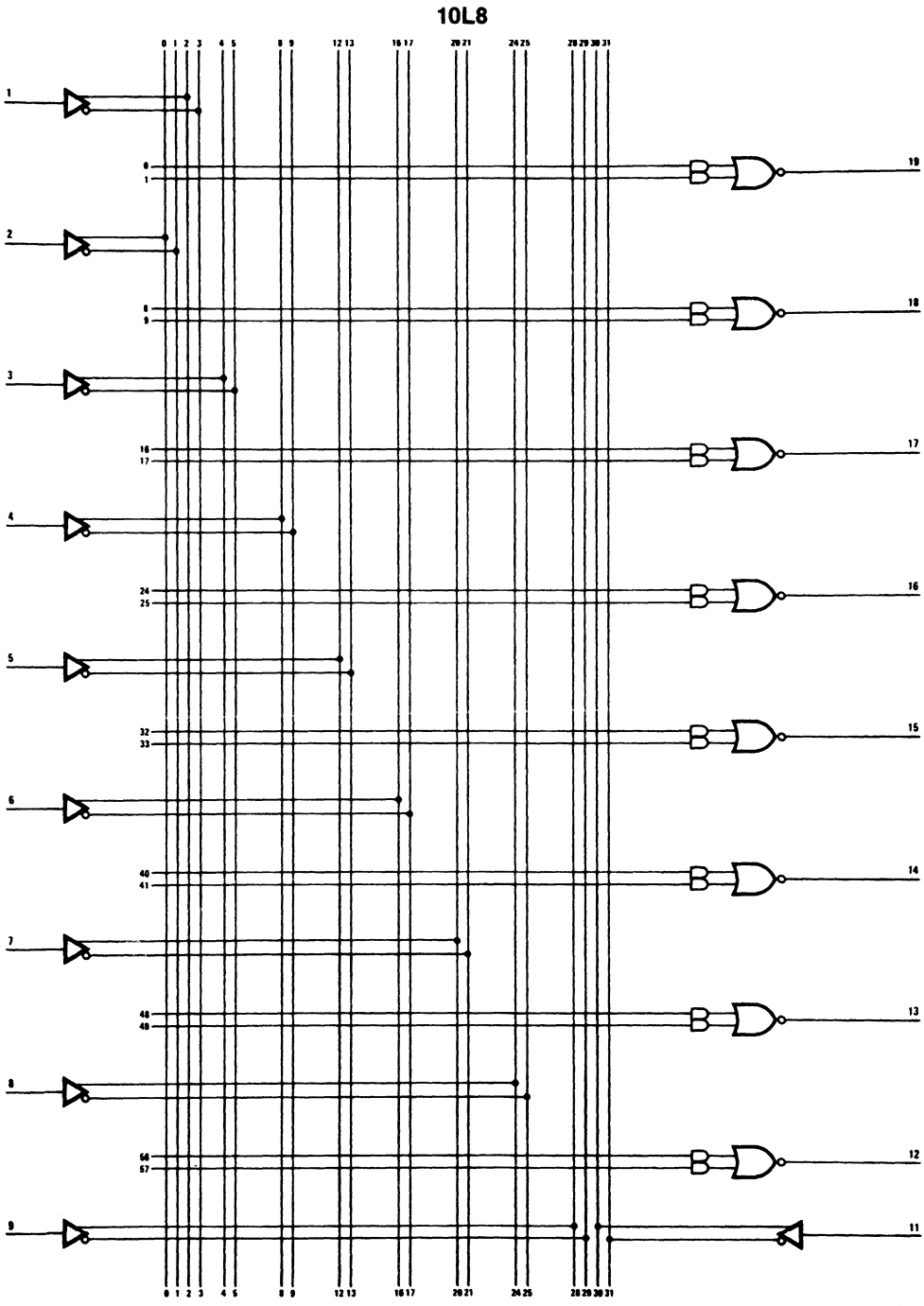
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**Small 20 Series  
16C1 Logic Diagram**



L000360M

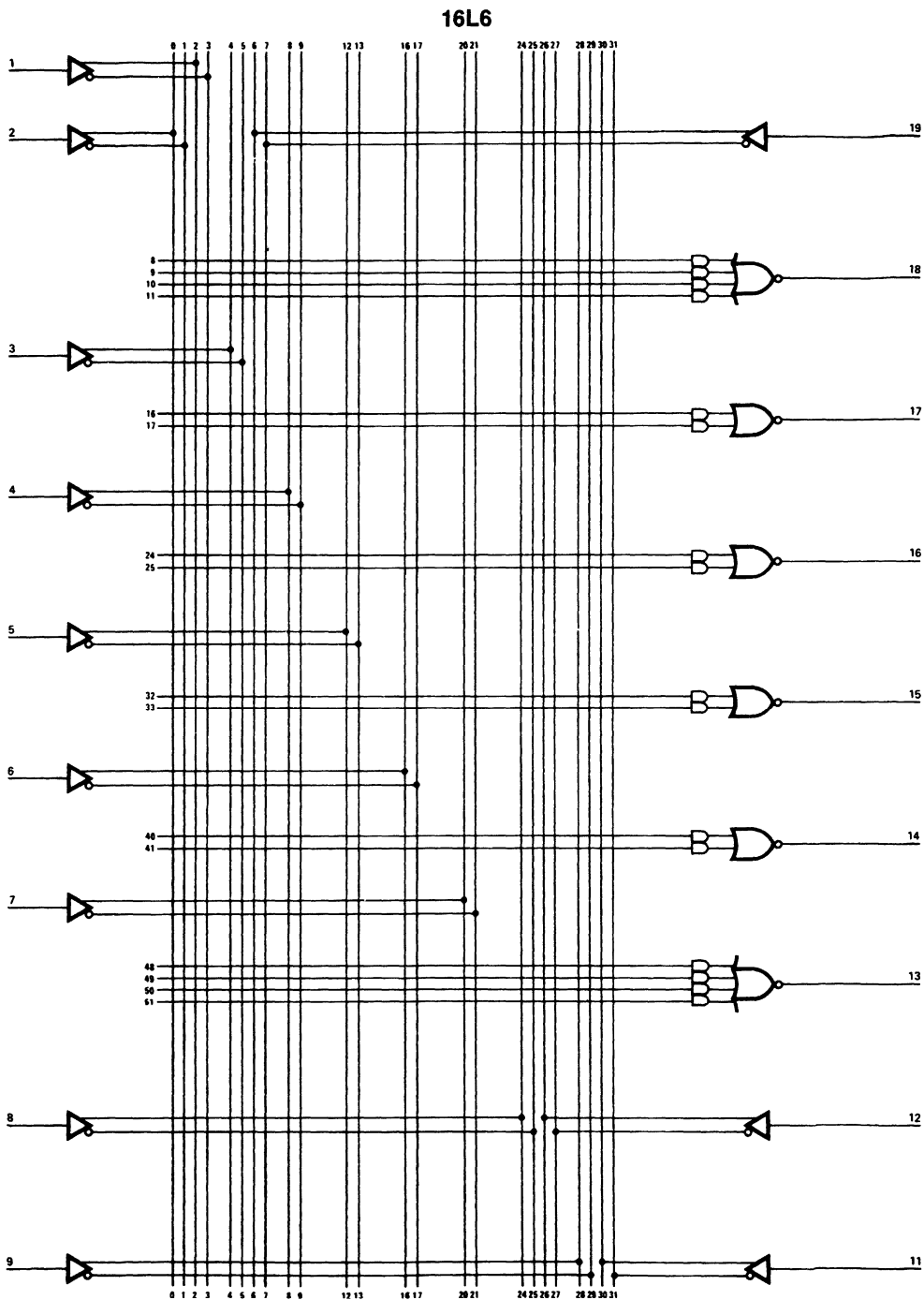
**Small 20 Series  
10L8 Logic Diagram**



**2**

LD00370M

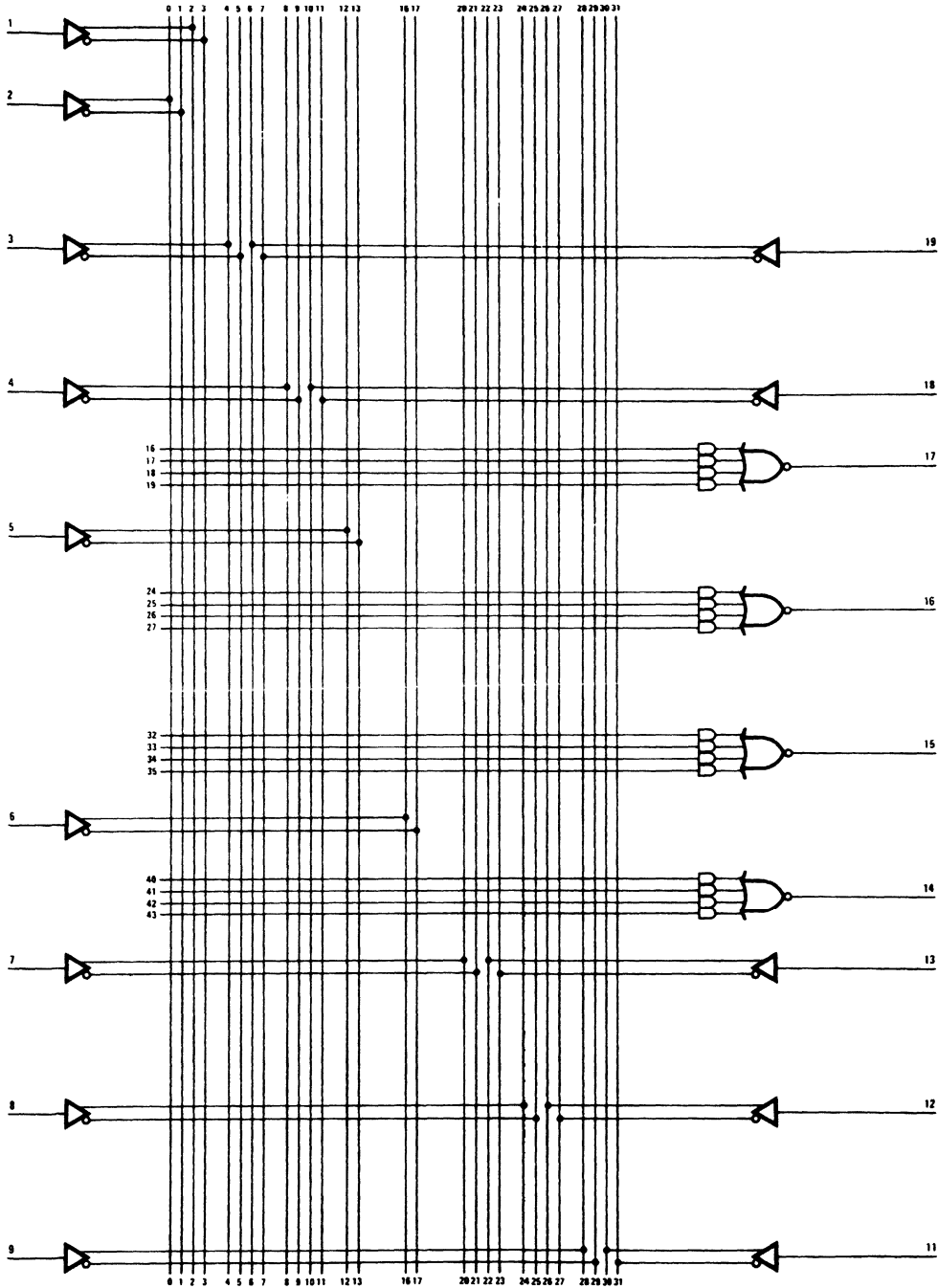
**Small 20 Series  
16L6 Logic Diagram**



L000300M

**Small 20 Series  
14L4 Logic Diagram**

**14L4**

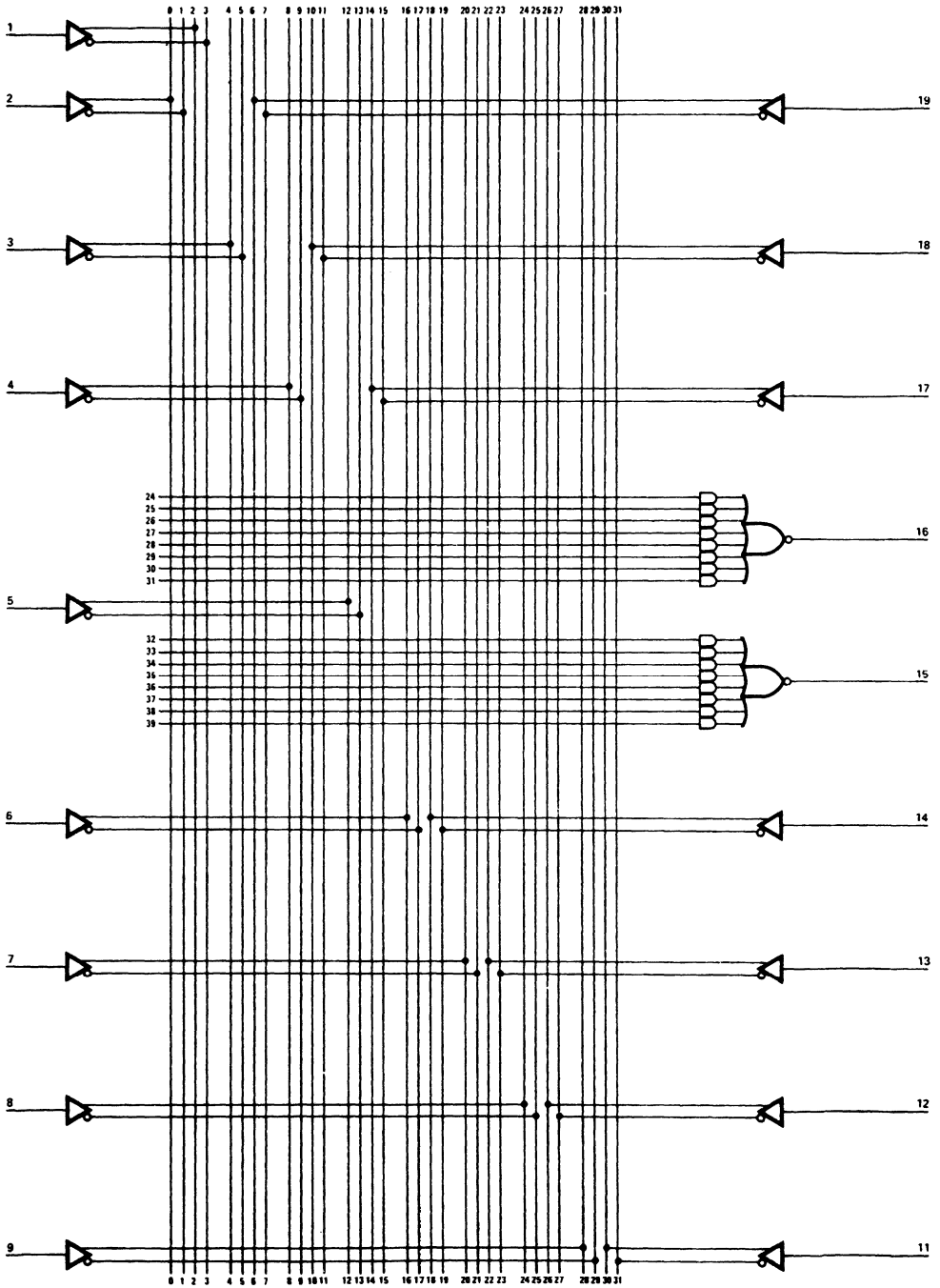


**2**

LD00090M

**Small 20 Series  
16L2 Logic Diagram**

**16L2**



L000400M



**Medium 20 Series**  
**16L8, 16R8, 16R6, 16R4**

**Medium 20 Series**

|         | DEDICATED INPUTS | OUTPUTS       |            |
|---------|------------------|---------------|------------|
|         |                  | COMBINATORIAL | REGISTERED |
| PAL16L8 | 10               | 8 (6 I/O)     | 0          |
| PAL16R8 | 8                | 0             | 8          |
| PAL16R6 | 8                | 2 I/O         | 6          |
| PAL16R4 | 8                | 4 I/O         | 4          |

**Description**

The Medium 20 Series offers the four most popular PAL device architectures. It also provides the fastest PAL devices in the industry.

The Medium 20 Series consists of four devices, each with sixteen array inputs and eight outputs. The devices have either 0, 4, 6, or 8 registered outputs, with the remaining being combinatorial. Each of the registered outputs feeds back into the array, for sequential designs. The combinatorial outputs also feed back into the array, except for two of the outputs on the 16L8. This feedback allows the output to also operate as an input if the output is disabled.

**Enable**

The combinatorial outputs are enabled by a product term. The registered outputs are enabled by a common enable pin.

**Polarity**

All outputs are active low.

**Performance**

Several speed/power versions are available:

| Suffix     | t <sub>PD</sub><br>(ns) | I <sub>CC</sub><br>(mA) |
|------------|-------------------------|-------------------------|
| (standard) | 35                      | 180                     |
| A          | 25                      | 180                     |
| A-2        | 35                      | 90                      |
| A-4        | 55                      | 50                      |
| B or BP*   | 15                      | 180                     |
| B-2        | 25                      | 90                      |
| B-4        | 35                      | 55                      |
| D          | 10                      | 180                     |

\* contact Monolithic Memories for datasheet

The D Series offers the fastest TTL programmable logic devices in the industry, at 10ns tpd.

**Preload and Power-up Reset**

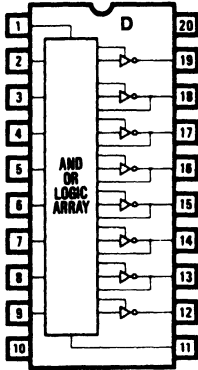
The BP Series offers register preload for device testability. The registers can be preloaded from the outputs by using supervoltages (see waveforms at end of section) in order to simplify functional testing. The PAL20BP Series also offers Power-up Reset, whereby the registers power up to a logic LOW, setting the active-low outputs to a logic HIGH.

**2**

**Medium 20 Series**  
**16L8, 16R8, 16R6, 16R4**

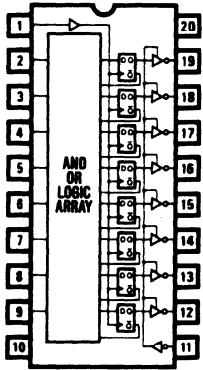
**DIP Pinouts**

**16L8/A/A-2/A-4/  
B/B-2/B-4/D**



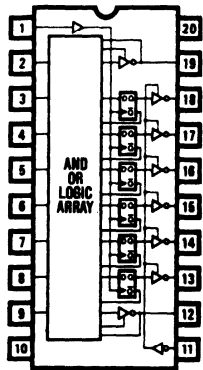
CD00052M

**16R8/A/A-2/A-4/  
B/B-2/B-4/D**



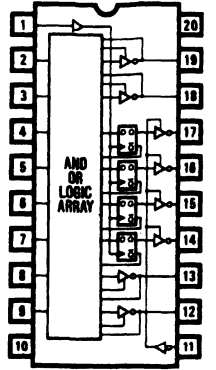
CD00062M

**16R6/A/A-2/A-4/  
B/B-2/B-4/D**



CD00072M

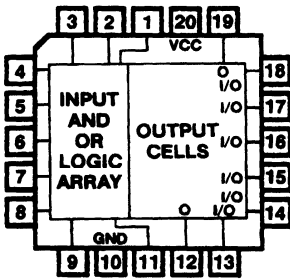
**16R4/A/A-2/A-4/  
B/B-2/B-4/D**



CD00042M

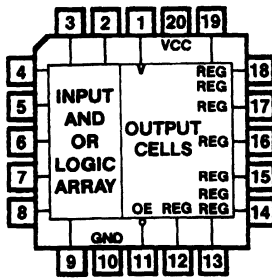
**PLCC Pinouts**

**16L8/A/A-2/A-4/  
B/B-2/B-4/D**



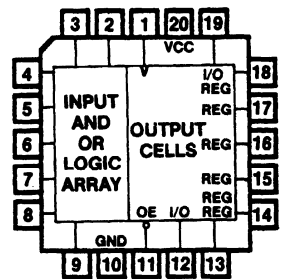
CD00052M

**16R8/A/A-2/A-4/  
B/B-2/B-4/D**



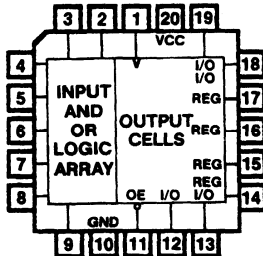
CD00062M

**16R6/A/A-2/A-4/  
B/B-2/B-4/D**



CD00052M

**16R4/A/A-2/A-4/  
B/B-2/B-4/D**



CD00111M

**Medium 20 Series**  
**16L8, 16R8, 16R6, 16R4**

**Operating Conditions**

| SYMBOL          | PARAMETER                                   |                  | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|-----------------|---|------------------|-------------------------|-----|------|------|
|                 |   |                  | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                              |                  | 4.75                    | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                              | Low              | 25                      | 10  |      | ns   |
|                 |   | High             | 25                      | 10  |      |      |
| t <sub>su</sub> | Set up time from input or feedback to clock | 16R8, 16R6, 16R4 | 35                      | 25  |      | ns   |
| t <sub>h</sub>  | Hold time                                   |                  | 0                       | -15 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature              |                  | 0                       |     | 75   | °C   |
| T <sub>C</sub>  | Operating case temperature                  |                  |                         |     |      | °C   |

**2**

**Electrical Characteristics**

| SYMBOL                        | PARAMETER                    | TEST CONDITIONS       |                              | MIN | TYP   | MAX   | UNIT |
|-------------------------------|------------------------------|-----------------------|------------------------------|-----|-------|-------|------|
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |                       |                              |     |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |                       |                              | 2   |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA       |     | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V        |     | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V        |     |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V        |     |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN | Com I <sub>OL</sub> = 24mA   |     | 0.3   | 0.5   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN | Com I <sub>OH</sub> = -3.2mA | 2.4 | 2.8   |       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0.4V        |     |       | -100  | μA   |
| I <sub>OZH</sub> <sup>3</sup> |                              |                       | V <sub>O</sub> = 2.4V        |     |       | 100   | μA   |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V          | -30 | -70   | -130  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX | 16R4, 16R6, 16R8, 16L8       |     | 120   | 180   | mA   |

**Switching Characteristics Over Operating Conditions**

| SYMBOL           | PARAMETER                            |                  | TEST CONDITIONS                                | COMMERCIAL |     |     | UNIT |
|------------------|--------------------------------------|------------------|--|------------|-----|-----|------|
|                  |                                      |                  |  | MIN        | TYP | MAX |      |
| t <sub>PD</sub>  | Input or feedback to output          | 16R6, 16R4, 16L8 | R <sub>1</sub> = 200Ω<br>R <sub>2</sub> = 390Ω |            | 25  | 35  | ns   |
| t <sub>CLK</sub> | Clock to output or feedback          |                  |  |            | 15  | 25  | ns   |
| t <sub>PZX</sub> | Pin 11 to output enable except 16L8  |                  |  |            | 15  | 25  | ns   |
| t <sub>PXZ</sub> | Pin 11 to output disable except 16L8 |                  |  |            | 15  | 25  | ns   |
| t <sub>PZX</sub> | Input to output enable               | 16R6, 16R4, 16L8 |  |            | 25  | 35  | ns   |
| t <sub>PXZ</sub> | Input to output disable              | 16R6, 16R4, 16L8 |  |            | 25  | 35  | ns   |
| f <sub>MAX</sub> | Maximum frequency                    |                  |  |            | 16  | 25  |      |

- The PAL20 Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 20A Series**  
**16L8A, 16R8A, 16R6A, 16R4A**

**Operating Conditions**

| SYMBOL          | PARAMETER                                   |                     | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|-----------------|---|---------------------|----------|-----|-----|------------|-----|------|------|
|                 |   |                     | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                              |                     | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                              | Low                 | 20       | 10  |     | 15         | 10  |      | ns   |
|                 |   | High                | 20       | 10  |     | 15         | 10  |      |      |
| t <sub>su</sub> | Set up time from input or feedback to clock | 16R8A, 16R6A, 16R4A | 30       | 15  |     | 25         | 15  |      | ns   |
| t <sub>h</sub>  | Hold time                                   |                     | 0        | -10 |     | 0          | -10 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature              |                     | -55      |     |     | 0          |     | 75   | °C   |
| T <sub>C</sub>  | Operating case temperature                  |                     |          |     | 125 |            |     |      | °C   |

**Electrical Characteristics** Over Operating Conditions

| SYMBOL                        | PARAMETER                    | TEST CONDITIONS       |                              | MIN | TYP   | MAX   | UNIT |
|-------------------------------|------------------------------|-----------------------|------------------------------|-----|-------|-------|------|
| V <sub>IL</sub> <sup>1</sup>  | Low-level input voltage      |                       |                              |     |       | 0.8   | V    |
| V <sub>IH</sub> <sup>1</sup>  | High-level input voltage     |                       |                              | 2   |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA       |     | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>2</sup>  | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V        |     | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>2</sup>  | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V        |     |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V        |     |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN | Mil I <sub>OL</sub> = 12mA   | 2.4 | 0.3   | 0.5   | V    |
|                               |                              |                       | Com I <sub>OL</sub> = 24mA   |     |       |       |      |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN | Mil I <sub>OH</sub> = -2mA   | 2.4 | 2.8   |       | V    |
|                               |                              |                       | Com I <sub>OH</sub> = -3.2mA |     |       |       |      |
| I <sub>OZL</sub> <sup>2</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0.4V        |     |       | -100  | μA   |
| I <sub>OZH</sub> <sup>2</sup> |                              |                       | V <sub>O</sub> = 2.4V        |     |       | 100   | μA   |
| I <sub>OS</sub> <sup>3</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V          | -30 | -70   | -130  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX |                              |     | 120   | 180   | mA   |

1. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
3. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 20A Series**  
**16L8A, 16R8A, 16R6A, 16R4A**

**Switching Characteristics** Over Operating Conditions

| SYMBOL    | PARAMETER                             |                     | TEST CONDITIONS                        | MILITARY |     |     | COMMERCIAL |      |     | UNIT |
|-----------|---------------------------------------|---------------------|--|----------|-----|-----|------------|------|-----|------|
|           |                                       |                     |  | MIN      | TYP | MAX | MIN        | TYP  | MAX |      |
| $t_{PD}$  | Input or feedback to output           | 16R6A, 16R4A, 16L8A | $R_1 = 200\Omega$<br>$R_2 = 390\Omega$ |          | 15  | 30  |            | 15   | 25  | ns   |
| $t_{CLK}$ | Clock to output or feedback           |                     |  |          | 10  | 20  |            | 10   | 15  | ns   |
| $t_{PZX}$ | Pin 11 to output enable except 16L8A  |                     |  |          | 10  | 25  |            | 10   | 20  | ns   |
| $t_{PXZ}$ | Pin 11 to output disable except 16L8A |                     |  |          | 11  | 25  |            | 11   | 20  | ns   |
| $t_{PZX}$ | Input to output enable                | 16R6A, 16R4A, 16L8A |  |          | 10  | 30  |            | 10   | 25  | ns   |
| $t_{PXZ}$ | Input to output disable               | 16R6A, 16R4A, 16L8A |  |          | 13  | 30  |            | 13   | 25  | ns   |
| $f_{MAX}$ | Maximum frequency                     | 16R8A, 16R6A, 16R4A |  |          | 20  | 40  |            | 28.5 | 40  | MHz  |

**2**

**Medium 20A-2 Series**  
**16L8A-2, 16R8A-2, 16R6A-2, 16R4A-2**

**Operating Conditions**

| SYMBOL   | PARAMETER                                   |                           | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|----------|---|---------------------------|----------|-----|-----|------------|-----|------|------|
|          |   |                           | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                              |                           | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| $t_w$    | Width of clock                              | Low                       | 25       | 10  |     | 25         | 10  |      | ns   |
|          |   | High                      | 25       | 10  |     | 25         | 10  |      |      |
| $t_{su}$ | Set up time from input or feedback to clock | 16R6A-2, 16R4A-2, 16R8A-2 | 50       | 25  |     | 35         | 25  |      | ns   |
| $t_h$    | Hold time                                   |                           | 0        | -15 |     | 0          | -15 |      | ns   |
| $T_A$    | Operating free-air temperature              |                           | -55      |     | 125 | 0          |     | 75   | °C   |

**Electrical Characteristics Over Operating Conditions**

| SYMBOL      | PARAMETER                    | TEST CONDITIONS       |                      | MIN                      | TYP   | MAX   | UNIT          |               |
|-------------|------------------------------|-----------------------|----------------------|--------------------------|-------|-------|---------------|---------------|
| $V_{IL}^1$  | Low-level input voltage      |                       |                      |                          |       | 0.8   | V             |               |
| $V_{IH}^1$  | High-level input voltage     |                       |                      | 2                        |       |       | V             |               |
| $V_{IC}$    | Input clamp voltage          | $V_{CC} = \text{MIN}$ | $I_I = -18\text{mA}$ |                          | -0.8  | -1.5  | V             |               |
| $I_{IL}^2$  | Low-level input current      | $V_{CC} = \text{MAX}$ | $V_I = 0.4\text{V}$  |                          | -0.02 | -0.25 | mA            |               |
| $I_{IH}^2$  | High-level input current     | $V_{CC} = \text{MAX}$ | $V_I = 2.4\text{V}$  |                          |       | 25    | $\mu\text{A}$ |               |
| $I_I$       | Maximum input current        | $V_{CC} = \text{MAX}$ | $V_I = 5.5\text{V}$  |                          |       | 1     | mA            |               |
| $V_{OL}$    | Low-level output voltage     | $V_{CC} = \text{MIN}$ | Mil                  | $I_{OL} = 12\text{mA}$   |       | 0.3   | 0.5           | V             |
|             |                              |                       | Com                  | $I_{OL} = 24\text{mA}$   |       |       |               |               |
| $V_{OH}$    | High-level output voltage    | $V_{CC} = \text{MIN}$ | Mil                  | $I_{OH} = -2\text{mA}$   | 2.4   | 2.8   |               | V             |
|             |                              |                       | Com                  | $I_{OH} = -3.2\text{mA}$ |       |       |               |               |
| $I_{OZL}^2$ | Off-state output current     | $V_{CC} = \text{MAX}$ |                      | $V_O = 0.4\text{V}$      |       |       | -100          | $\mu\text{A}$ |
| $I_{OZH}^2$ |                              |                       |                      | $V_O = 2.4\text{V}$      |       |       | 100           | $\mu\text{A}$ |
| $I_{OS}^3$  | Output short-circuit current | $V_{CC} = 5\text{V}$  | $V_O = 0\text{V}$    | -30                      | -70   | -130  | mA            |               |
| $I_{CC}$    | Supply current               | $V_{CC} = \text{MAX}$ |                      |                          | 60    | 90    | mA            |               |

**Switching Characteristics Over Operating Conditions**

| SYMBOL       | PARAMETER                                      |                           | TEST CONDITIONS                        | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|--------------|--|---------------------------|--|----------|-----|-----|------------|-----|-----|------|
|              |  |                           |  | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{PD}$     | Input or feedback to output                    | 16L8A-2, 16R6A-2, 16R4A-2 | $R_1 = 200\Omega$<br>$R_2 = 390\Omega$ |          | 25  | 50  |            | 25  | 35  | ns   |
| $t_{CLK}$    | Clock to output or feedback                    |                           |  |          | 15  | 25  |            | 15  | 25  | ns   |
| $t_{PXZ/ZX}$ | Pin 11 to output disable/enable except 16L8A-2 |                           |  |          | 15  | 25  |            | 15  | 25  | ns   |
| $t_{PZX}$    | Input to output enable                         | 16L8A-2, 16R6A-2, 16R4A-2 |  |          | 25  | 45  |            | 25  | 35  | ns   |
| $t_{PXZ}$    | Input to output disable                        | 16L8A-2, 16R6A-2, 16R4A-2 |  |          | 25  | 45  |            | 25  | 35  | ns   |
| $f_{MAX}$    | Maximum frequency                              |                           |  | 14       | 25  |     | 16         | 25  |     | MHz  |

1. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. I/O pin leakage is the worst case of  $I_{IL}$  and  $I_{OZL}$  (or  $I_{IH}$  and  $I_{OZH}$ ).
3. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 20A-4 Series**  
**16L8A-4, 16R8A-4, 16R6A-4, 16R4A-4**

**Operating Conditions**

| SYMBOL   | PARAMETER                                   |                           | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|----------|---|---------------------------|----------|-----|-----|------------|-----|------|------|
|          |   |                           | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                              |                           | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| $t_w$    | Width of clock                              |                           | Low      | 40  | 20  | 30         | 20  |      | ns   |
|          |   |                           | High     | 40  | 20  | 30         | 20  |      |      |
| $t_{su}$ | Set up time from input or feedback to clock | 16R8A-4, 16R6A-4, 16R4A-4 | 90       | 45  |     | 60         | 45  |      | ns   |
| $t_h$    | Hold time                                   |                           | 0        | -15 |     | 0          | -15 |      | ns   |
| $T_A$    | Operating free-air temperature              |                           | -55      |     | 125 | 0          |     | 75   | °C   |

**Electrical Characteristics** Over Operating Conditions

| SYMBOL      | PARAMETER                    | TEST CONDITIONS       |                            | MIN | TYP   | MAX   | UNIT |
|-------------|------------------------------|-----------------------|----------------------------|-----|-------|-------|------|
| $V_{IL}^1$  | Low-level input voltage      |                       |                            |     |       | 0.8   | V    |
| $V_{IH}^1$  | High-level input voltage     |                       |                            | 2   |       |       | V    |
| $V_{IC}$    | Input clamp voltage          | $V_{CC} = \text{MIN}$ | $I_I = -18\text{mA}$       |     | -0.8  | -1.5  | V    |
| $I_{IL}^2$  | Low-level input current      | $V_{CC} = \text{MAX}$ | $V_I = 0.4\text{V}$        |     | -0.02 | -0.25 | mA   |
| $I_{IH}^2$  | High-level input current     | $V_{CC} = \text{MAX}$ | $V_I = 2.4\text{V}$        |     |       | 25    | μA   |
| $I_I$       | Maximum input current        | $V_{CC} = \text{MAX}$ | $V_I = 5.5\text{V}$        |     |       | 1     | mA   |
| $V_{OL}$    | Low-level output voltage     | $V_{CC} = \text{MIN}$ | Mil $I_{OL} = 4\text{mA}$  |     | 0.3   | 0.5   | V    |
|             |                              |                       | Com $I_{OL} = 8\text{mA}$  |     |       |       |      |
| $V_{OH}$    | High-level output voltage    | $V_{CC} = \text{MIN}$ | Mil $I_{OH} = -1\text{mA}$ | 2.4 | 2.8   |       | V    |
|             |                              |                       | Com $I_{OH} = -1\text{mA}$ |     |       |       |      |
| $I_{OZL}^2$ | Off-state output current     | $V_{CC} = \text{MAX}$ | $V_O = 0.4\text{V}$        |     |       | -100  | μA   |
| $I_{OZH}^2$ |                              |                       | $V_O = 2.4\text{V}$        |     |       | 100   | μA   |
| $I_{OS}^3$  | Output short-circuit current | $V_{CC} = 5\text{V}$  | $V_O = 0\text{V}$          | -30 | -70   | -130  | mA   |
| $I_{CC}$    | Supply current               | $V_{CC} = \text{MAX}$ |                            |     | 30    | 50    | mA   |

**Switching Characteristics** Over Operating Conditions

| SYMBOL       | PARAMETER  |                           | TEST CONDITIONS                                 | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|--------------|--|---------------------------|---|----------|-----|-----|------------|-----|-----|------|
|              |  |                           |   | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{PD}$     | Input or feedback to output                      | 16R6A-4, 16R4A-4, 16L8A-4 | $R_1 = 800\Omega$<br>$R_2 = 1.56\text{k}\Omega$ |          | 35  | 75  |            | 35  | 55  | ns   |
| $t_{CLK}$    | Clock to output or feedback                      |                           |   |          | 20  | 45  |            | 20  | 35  | ns   |
| $t_{PXZ/ZX}$ | Pin 11 to output disable/enable - except 16L8A-4 |                           |   |          | 15  | 40  |            | 15  | 30  | ns   |
| $t_{PZX}$    | Input to output enable                           | 16R6A-4, 16R4A-4, 16L8A-4 |   |          | 30  | 65  |            | 30  | 50  | ns   |
| $t_{PXZ}$    | Input to output disable                          | 16R6A-4, 16R4A-4, 16L8A-4 |   |          | 30  | 65  |            | 30  | 50  | ns   |
| $f_{MAX}$    | Maximum frequency                                | 16R8A-4, 16R6A-4, 16R4A-4 |   |          | 8   | 18  |            | 11  | 18  | MHz  |

- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of  $I_{IL}$  and  $I_{OZL}$  (or  $I_{IH}$  and  $I_{OZH}$ ).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 20B Series**  
**16L8B, 16R8B, 16R6B, 16R4B**

**Operating Conditions**

| SYMBOL          | PARAMETER                                  |                         | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|-----------------|--|-------------------------|-------------------------|-----|------|------|
|                 |  |                         | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                             |                         | 4.75                    | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | Low                     | 10                      | 6   |      | ns   |
|                 |  | High                    | 10                      | 5   |      |      |
| t <sub>su</sub> | Setup time from input or feedback to clock | 16R8B<br>16R6B<br>16R4B | 15                      | 10  |      | ns   |
| t <sub>h</sub>  | Hold time                                  |                         | 0                       | -10 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature             |                         | 0                       | 25  | 75   | °C   |

**Electrical Characteristics** Over Operating Conditions

| SYMBOL                        | PARAMETER                    | TEST CONDITION        |                          | COMMERCIAL |       |       | UNIT |
|-------------------------------|------------------------------|-----------------------|--------------------------|------------|-------|-------|------|
|                               |                              |                       |                          | MIN        | TYP   | MAX   |      |
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |                       |                          |            |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |                       |                          | 2          |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA   |            | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V    |            | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V    |            |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V    |            |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN | I <sub>OL</sub> = 24mA   |            | 0.3   | 0.5   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN | I <sub>OH</sub> = -3.2mA | 2.4        | 2.8   |       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0.4V    |            |       | -100  | μA   |
|                               |                              |                       | V <sub>O</sub> = 2.4V    |            |       | 100   | μA   |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V      | -30        | -70   | -130  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX |                          |            | 120   | 180   | mA   |

**Switching Characteristics** Over Operating Conditions

| SYMBOL           | PARAMETER                                       |                         | TEST CONDITIONS  | COMMERCIAL  |     |     | UNIT |
|------------------|---|-------------------------|--|-------------|-----|-----|------|
|                  |   |                         |  | MIN         | TYP | MAX |      |
| t <sub>PD</sub>  | 16L8B, 16R4B, 16R6B input or feedback to output |                         | Commercial<br>R <sub>1</sub> = 200Ω<br>R <sub>2</sub> = 390Ω |             | 12  | 15  | ns   |
| t <sub>CLK</sub> | Clock to output or feedback except 16L8B        |                         |  |             | 8   | 12  | ns   |
| t <sub>PZX</sub> | Pin 11 to output enable except 16L8B            |                         |  |             | 10  | 15  | ns   |
| t <sub>PXZ</sub> | Pin 11 to output disable except 16L8B           |                         |  |             | 10  | 15  | ns   |
| t <sub>PZX</sub> | Input to output enable                          | 16R6B, 16R4B, and 16L8B |  |             | 12  | 22  | ns   |
| t <sub>PXZ</sub> | Input to output disable                         | 16R6B, 16R4B, and 16L8B |  |             | 12  | 15  | ns   |
| f <sub>MAX</sub> | 16R8B, 16R6B, 16R4B                             | Feedback                |  |             | 37  | 45  | MHz  |
|                  | Maximum frequency                               |                         |  | No feedback | 50  | 55  |      |

- The PAL20B Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.



**Medium 20B-2 Series**  
**16L8B-2, 16R8B-2, 16R6B-2, 16R4B-2**

**Operating Conditions**

| SYMBOL          | PARAMETER                                  |                               | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|-----------------|--|-------------------------------|-------------------------|-----|------|------|
|                 |  |                               | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                             |                               | 4.75                    | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | Low                           | 15                      | 10  |      | ns   |
|                 |  | High                          | 15                      | 10  |      |      |
| t <sub>su</sub> | Setup time from input or feedback to clock | 16R8B-2<br>16R6B-2<br>16R4B-2 | 25                      | 15  |      | ns   |
| t <sub>h</sub>  | Hold time                                  |                               | 0                       | -10 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature             |                               | 0                       | 25  | 75   | °C   |

**2**

**Electrical Characteristics** Over Operating Conditions

| SYMBOL                        | PARAMETER                    | TEST CONDITION        |                          | COMMERCIAL |       |       | UNIT |
|-------------------------------|------------------------------|-----------------------|--------------------------|------------|-------|-------|------|
|                               |                              |                       |                          | MIN        | TYP   | MAX   |      |
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |                       |                          |            |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |                       |                          | 2          |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA   |            | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V    |            | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V    |            |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V    |            |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN | I <sub>OL</sub> = 24mA   |            | 0.3   | 0.5   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN | I <sub>OH</sub> = -3.2mA | 2.4        | 2.8   |       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0.4V    |            |       | -100  | μA   |
| I <sub>OZH</sub> <sup>3</sup> |                              |                       | V <sub>O</sub> = 2.4V    |            |       |       | 100  |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V      | -30        | -100  | -250  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX |                          |            | 60    | 90    | mA   |

**Switching Characteristics** Over Operating Conditions

| SYMBOL           | PARAMETER   | TEST CONDITIONS  | COMMERCIAL |      |     | UNIT |
|------------------|---|--|------------|------|-----|------|
|                  |   |  | MIN        | TYP  | MAX |      |
| t <sub>PD</sub>  | Input or feedback to output 16L8B-2, 16R4B-2, and 16R6B-2 | Commercial<br>R <sub>1</sub> = 200Ω<br>R <sub>2</sub> = 390Ω |            | 17   | 25  | ns   |
| t <sub>CLK</sub> | Clock to output or feedback except 16L8B-2                |  |            | 10   | 15  | ns   |
| t <sub>PZX</sub> | Pin 11 to output enable except 16L8B-2                    |  |            | 10   | 20  | ns   |
| t <sub>PXZ</sub> | Pin 11 to output disable except 16L8B-2                   |  |            | 11   | 20  | ns   |
| t <sub>PZX</sub> | Input to output enable 16R6B-2, 16R4B-2, and 16L8B-2      |  |            | 10   | 25  | ns   |
| t <sub>PXZ</sub> | Input to output disable 16R6B-2, 16R4B-2, and 16L8B-2     |  |            | 13   | 25  | ns   |
| f <sub>MAX</sub> | Maximum frequency 16R8B-2, 16R6B-2, and 16R4B-2           |  |            | 28.5 | 40  |      |

- The PAL20B-2 Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 20B-4 Series**  
**16L8B-4, 16R8B-4, 16R6B-4, 16R4B-4**

**Operating Conditions**

| SYMBOL          | PARAMETER                                  |                               | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|-----------------|--|-------------------------------|-------------------------|-----|------|------|
|                 |  |                               | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                             |                               | 4.75                    | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | Low                           | 25                      | 10  |      | ns   |
|                 |  | High                          | 25                      | 10  |      |      |
| t <sub>su</sub> | Setup time from input or feedback to clock | 16R8B-4<br>16R6B-4<br>16R4B-4 | 35                      | 25  |      | ns   |
| t <sub>h</sub>  | Hold time                                  |                               | 0                       | -10 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature             |                               | 0                       | 25  | 75   | °C   |

**Electrical Characteristics** Over Operating Conditions

| SYMBOL                        | PARAMETER                    | TEST CONDITION                               | COMMERCIAL |       |       | UNIT |
|-------------------------------|------------------------------|--|------------|-------|-------|------|
|                               |                              |  | MIN        | TYP   | MAX   |      |
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |  |            |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |  | 2          |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN I <sub>I</sub> = -18mA |            | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX V <sub>I</sub> = 0.4V  |            | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX V <sub>I</sub> = 2.4V  |            |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX V <sub>I</sub> = 5.5V  |            |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN I <sub>OL</sub> = 8mA  |            | 0.3   | 0.5   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN I <sub>OH</sub> = -1mA | 2.4        | 2.8   |       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX                        |            |       | -100  | μA   |
| I <sub>OZH</sub> <sup>3</sup> |                              |  |            |       | 100   | μA   |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V V <sub>O</sub> = 0V     | -30        | -100  | -250  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX                        |            | 30    | 55    | mA   |

**Switching Characteristics** Over Operating Conditions

| SYMBOL           | PARAMETER   | TEST CONDITIONS                                  | COMMERCIAL |     |     | UNIT |
|------------------|---|--|------------|-----|-----|------|
|                  |   |  | MIN        | TYP | MAX |      |
| t <sub>PD</sub>  | Input or feedback to output 16L8B-4, 16R4B-4, and 16R6B-4 | R <sub>1</sub> = 800Ω<br>R <sub>2</sub> = 1.56KΩ |            | 25  | 35  | ns   |
| t <sub>CLK</sub> | Clock to output or feedback except 16L8B-4                |  |            | 15  | 25  | ns   |
| t <sub>PZX</sub> | Pin 11 to output enable except 16L8B-4                    |  |            | 15  | 25  | ns   |
| t <sub>PXZ</sub> | Pin 11 to output disable except 16L8B-4                   |  |            | 15  | 25  | ns   |
| t <sub>PZX</sub> | Input to output enable 16R6B-4, 16R4B-4, and 16L8B-4      |  |            | 25  | 35  | ns   |
| t <sub>PXZ</sub> | Input to output disable 16R6B-4, 16R4B-4, and 16L8B-4     |  |            | 25  | 35  | ns   |
| f <sub>MAX</sub> | Maximum frequency 16R8B-4, 16R6B-4, and 16R4B-4           |  |            | 16  | 25  |      |

1. The PAL20B-4 Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
2. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
3. I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
4. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 20D Series  
16L8D, 16R8D, 16R6D, 16R4D**

**Operating Conditions**

| SYMBOL          | PARAMETER                                  |      | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|-----------------|--|------|-------------------------|-----|------|------|
|                 |  |      | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                             |      | 4.75                    | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | Low  | 8                       | 6   |      | ns   |
|                 |  | High | 8                       | 5   |      |      |
| t <sub>su</sub> | Setup time from input or feedback to clock |      | 10                      | 8   |      | ns   |
| t <sub>h</sub>  | Hold time                                  |      | 0                       | -6  |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature             |      | 0                       | 25  | 75   | °C   |

**2**

**Electrical Characteristics**

| SYMBOL                        | PARAMETER                    | TEST CONDITION                                 | MIN                   | TYP   | MAX   | UNIT |
|-------------------------------|------------------------------|--|-----------------------|-------|-------|------|
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |  |                       |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |  | 2                     |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN I <sub>I</sub> = -18mA   |                       | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX V <sub>I</sub> = 0.4V    |                       | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX V <sub>I</sub> = 2.4V    |                       |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX V <sub>I</sub> = 5.5V    |                       |       | 200   | μA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN I <sub>OL</sub> = 24mA   |                       | 0.3   | 0.5   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN I <sub>OH</sub> = -3.2mA | 2.4                   | 3.4   |       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX V <sub>O</sub> = 0.4V    |                       |       | -100  | μA   |
| I <sub>OZH</sub> <sup>3</sup> |                              |  | V <sub>O</sub> = 2.4V |       |       |      |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V V <sub>O</sub> = 0V       | -30                   | -70   | -130  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX                          |                       | 120   | 180   | mA   |
| C <sub>IN</sub>               | Input Capacitance            | V <sub>IN</sub> = 2.0V@f = 1MHz                |                       | 2     |       | pF   |
| C <sub>OUT</sub>              | Output Capacitance           | V <sub>OUT</sub> = 2.0V@f = 1MHz               |                       | 4     |       |      |
| C <sub>CLK, EN</sub>          | Clock/Enable Capacitance     | V <sub>CLK, EN</sub> = 2.0V@f = 1MHz           |                       | 9     |       |      |

**Medium 20D Series**  
**16L8D, 16R8D, 16R6D, 16R4D**

**Switching Characteristics** Over Operating Conditions

| SYMBOL    | PARAMETER                                       |             | TEST CONDITIONS                        | COMMERCIAL |     |     | UNIT |
|-----------|---|-------------|--|------------|-----|-----|------|
|           |   |             |  | MIN        | TYP | MAX |      |
| $t_{PD}$  | Input or feedback to output 16L8D, 16R6D, 16R4D |             | $R_1 = 200\Omega$<br>$R_2 = 390\Omega$ | 3          | 8   | 10  | ns   |
| $t_{CLK}$ | Clock to output or feedback except 16L8D        |             |  | 2          | 6   | 8   | ns   |
| $t_{PZX}$ | Pin 11 to output enable except 16L8D            |             |  | 3          | 8   | 10  | ns   |
| $t_{PXZ}$ | Pin 11 to output disable except 16L8D           |             |  | 3          | 8   | 10  | ns   |
| $t_{PZX}$ | Input to output enable 16L8D, 16R6D, 16R4D      |             |  | 1          | 8   | 10  | ns   |
| $t_{PXZ}$ | Input to output disable 16L8D, 16R6D, 16R4D     |             |  | 1          | 8   | 10  | ns   |
| $f_{MAX}$ | Maximum frequency<br>16R8D, 16R6D, 16R4D        | Feedback    |  | 55.5       | 70  |     | MHz  |
|           |   | No feedback |  | 62.5       | 75  |     |      |

1. The PAL20D Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
2. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
3. I/O pin leakage is the worst case of  $I_{IL}$  and  $I_{OZL}$  (or  $I_{IH}$  and  $I_{OZH}$ ).
4. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 20D Series**  
**16L8D, 16R8D, 16R6D, 16R4D**

**Metastability**

Metastability is a condition which can occur in any latch or flip-flop if the minimum setup or hold times are violated. In most cases, the flip-flop will either react to the input or remain in its current state, both of which are stable results. The flip-flop can also reach an "in-between" condition called the metastable state, which is stable only if there is no noise in the system and the flip-flop is perfectly balanced. This metastable condi-

tion lasts until the flip-flop falls into one of its two stable states, which can take longer than the normal response time. The PAL20D Series exhibits better metastability characteristics than most other registered devices. It is less likely to enter the metastable state and recovers faster to a stable state. As a result, the PAL20D Series can make an excellent synchronizer circuit, and the metastability characteristics have been specified for designs in which the setup and hold times may not always be met.

**Metastability Characteristics Over Operating Conditions**

| SYMBOL           | PARAMETER                                  | TEST CONDITIONS                                  | COMMERCIAL |      |     | UNIT             |
|------------------|--|--|------------|------|-----|------------------|
|                  |  |  | MIN        | TYP  | MAX |                  |
| p                | Poisson process rate                       |  | 0.85       | 1.05 |     | ns <sup>-1</sup> |
| k                | MTBF constant                              |  |            | 0.8  | 1.0 | μs <sup>-1</sup> |
| t <sub>MET</sub> | Minimum recovery time in asynchronous mode | MTBF = 10 years<br>f <sub>d</sub> = (1/3)f d = 3 |            | 20   | 30  | ns               |
| f <sub>MET</sub> | Maximum frequency in asynchronous mode     | MTBF = 10 years<br>f <sub>d</sub> = (1/3)f d = 3 | 21         | 26   |     | MHz              |

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**Definition of Variables**

**MTBF (Mean Time Between Failures):** the average time between metastable occurrences that cause a violation of the device specifications. Metastability characteristics are calculated at an arbitrary MTBF of 10 years for the convenience of the user.

**p (Poisson process rate):** experimentally calculated factor which determines the slope of the curve of probability of failure.

**k (MTBF constant):** experimentally calculated factor which determines the magnitude of the curve of probability of failure.

**tsu (setup time):** the specified minimum time interval allowed between the application of a data signal at a specified device input pin (pin 9 on the device under test) and a subsequent clock transition. For the PAL20D Series, tsu is 10 nanoseconds.

**tCLK (clock to output time):** the specified maximum time interval between a clock transition and the availability of valid signals at an output pin. For the PAL20D Series, tCLK is 8 nanoseconds.

**fMAX (maximum frequency):** specified maximum frequency for the device under test. Calculated as 1/(tsu + tCLK). For the PAL20D Series, this calculates to 55.5 Megahertz.

**f (clock frequency):** actual clock frequency for the device under test.

**f<sub>d</sub> (data frequency):** actual data frequency for a specified input to the device under test.

**d (data ratio):** the ratio of the clock frequency to the data frequency (f/f<sub>d</sub>).

**t (time delay):** the additional time allowed per period beyond that required by the specifications. t is the actual time between clock transitions beyond the required period of (tsu + tCLK).

**tMET (metastability recovery time):** minimum t required to guarantee recovery from metastability, with specified test conditions.

**fMET (metastability frequency):** maximum f clock frequency to limit metastability failures, with specified test conditions.

**Metastability Equations**

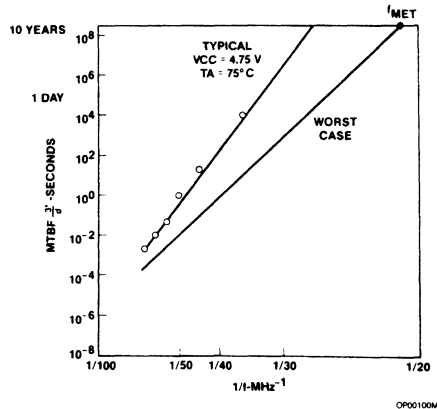
$$MTBF = k (d/3) (1/f)^2 e^{(p/f)}$$

$$f_{MAX} = 1/(tsu + tCLK)$$

$$f = 1/(tsu + tCLK + t)$$

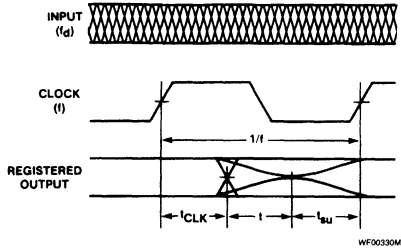
$$f = d (f_d)$$

**Metastability vs. Clock Frequency**

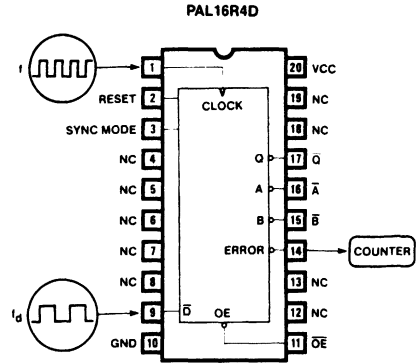


\*Normalized to d = 3; multiply by 3/d for other data frequencies.

### Metastability Waveforms



### Metastability Test Circuit



### Metastability Test Pattern File

CHIP Metastability\_Test PAL16R4

CLOCK RESET SYNC MODE NC NC NC NC NC /D GND  
/OE NC NC /ERROR /B /A /Q NC NC VCC

#### EQUATIONS

```

Q      := /Q* SYNC_MODE      ;TOGGLE SYNCHRONOUS INPUT (TESTS f MAX)
      + D*/SYNC_MODE        ;TOGGLE ASYNCHRONOUS INPUT (TESTS META.)

A      := A*/Q              ;HOLD A (IF NOT ERROR)
      + /A* Q              ;TOGGLE A (IF NOT ERROR)
      + ERROR              ;SET A IF ERROR

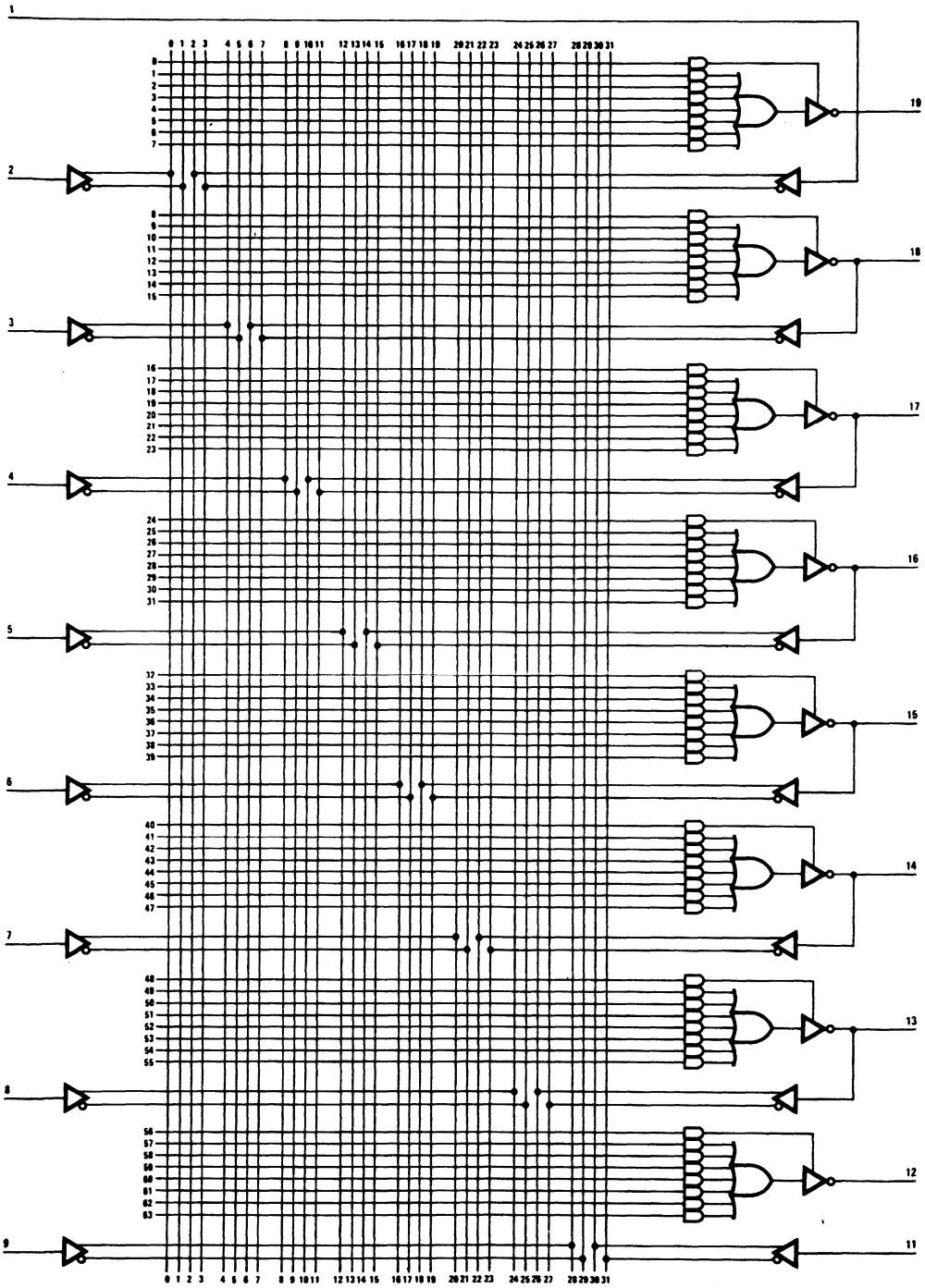
B      := B*/Q*/ERROR       ;HOLD B IF NOT ERROR, OR RESET
      + /B* Q*/ERROR       ;TOGGLE B IF NOT ERROR, OR RESET

ERROR := /A*/B             ;COMPARE A AND B,
      + A* B              ; ERROR GOES HIGH IF A EQUALS B
      + RESET             ;INITIALIZE A AND B TO OPPOSITE PHASES
    
```

TB002030M

Medium 20 Series  
16L8 Logic Diagram

16L8

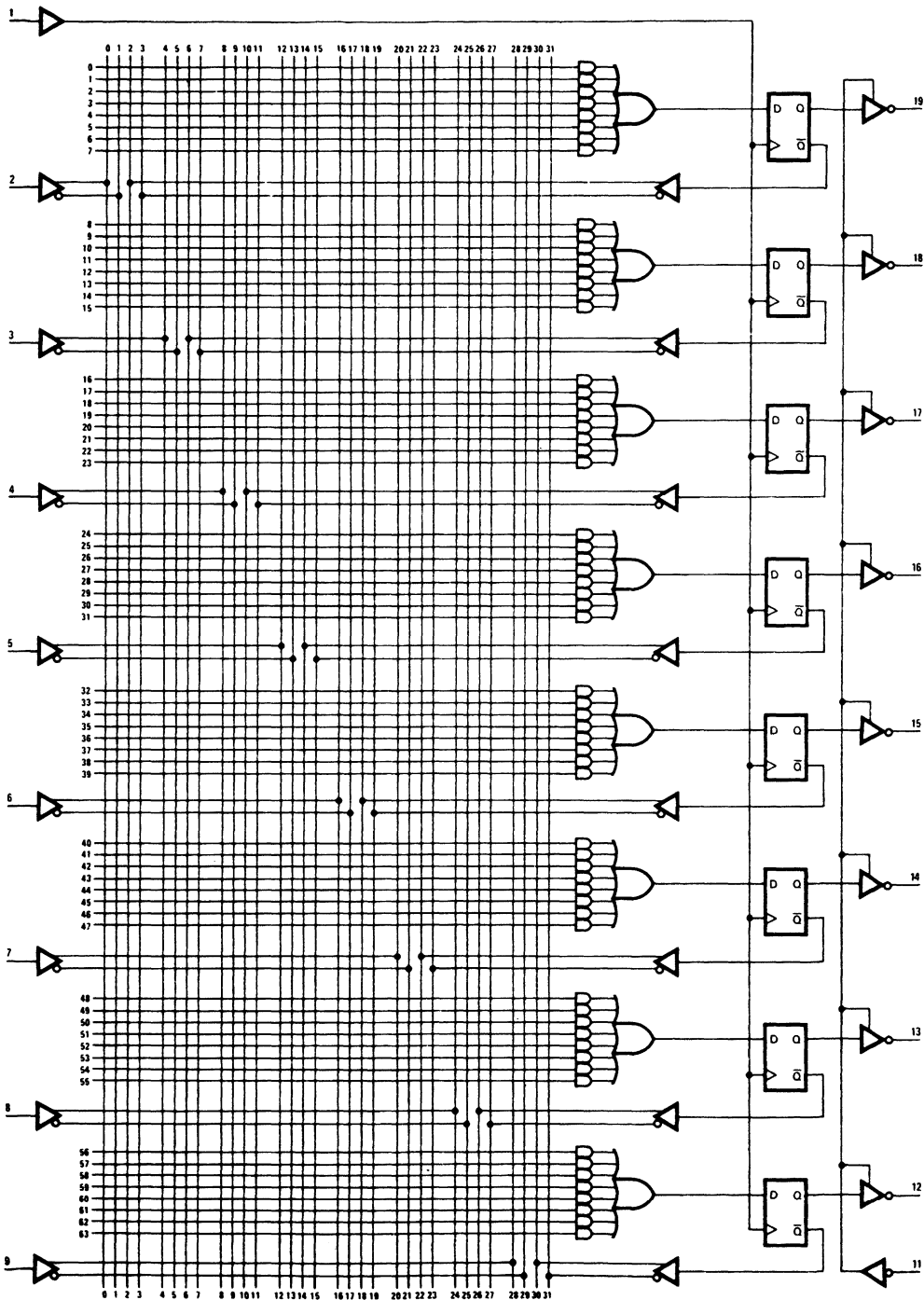


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LD00410M

**Medium 20 Series  
16R8 Logic Diagram**

**16R8**

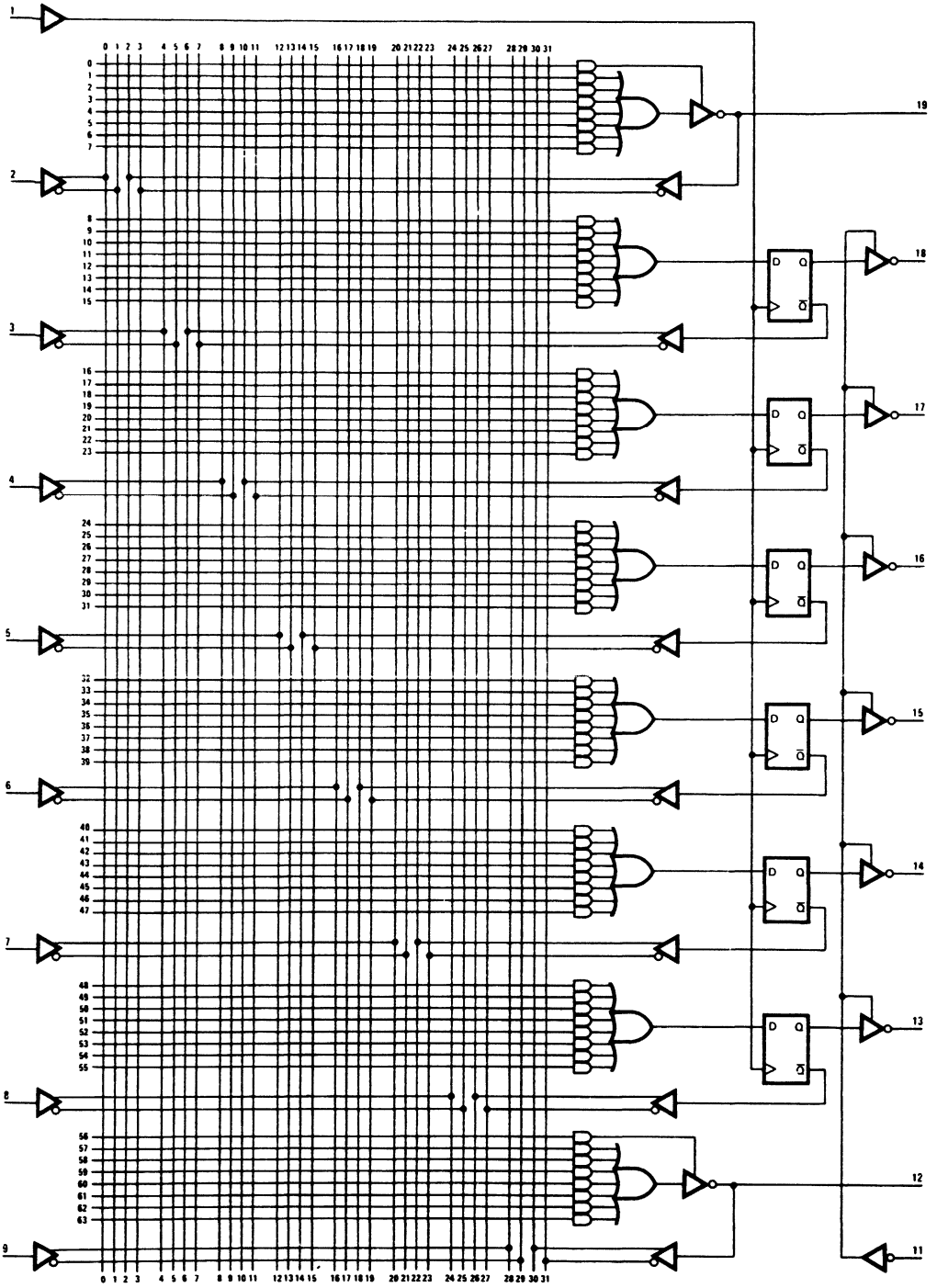


LD00420M



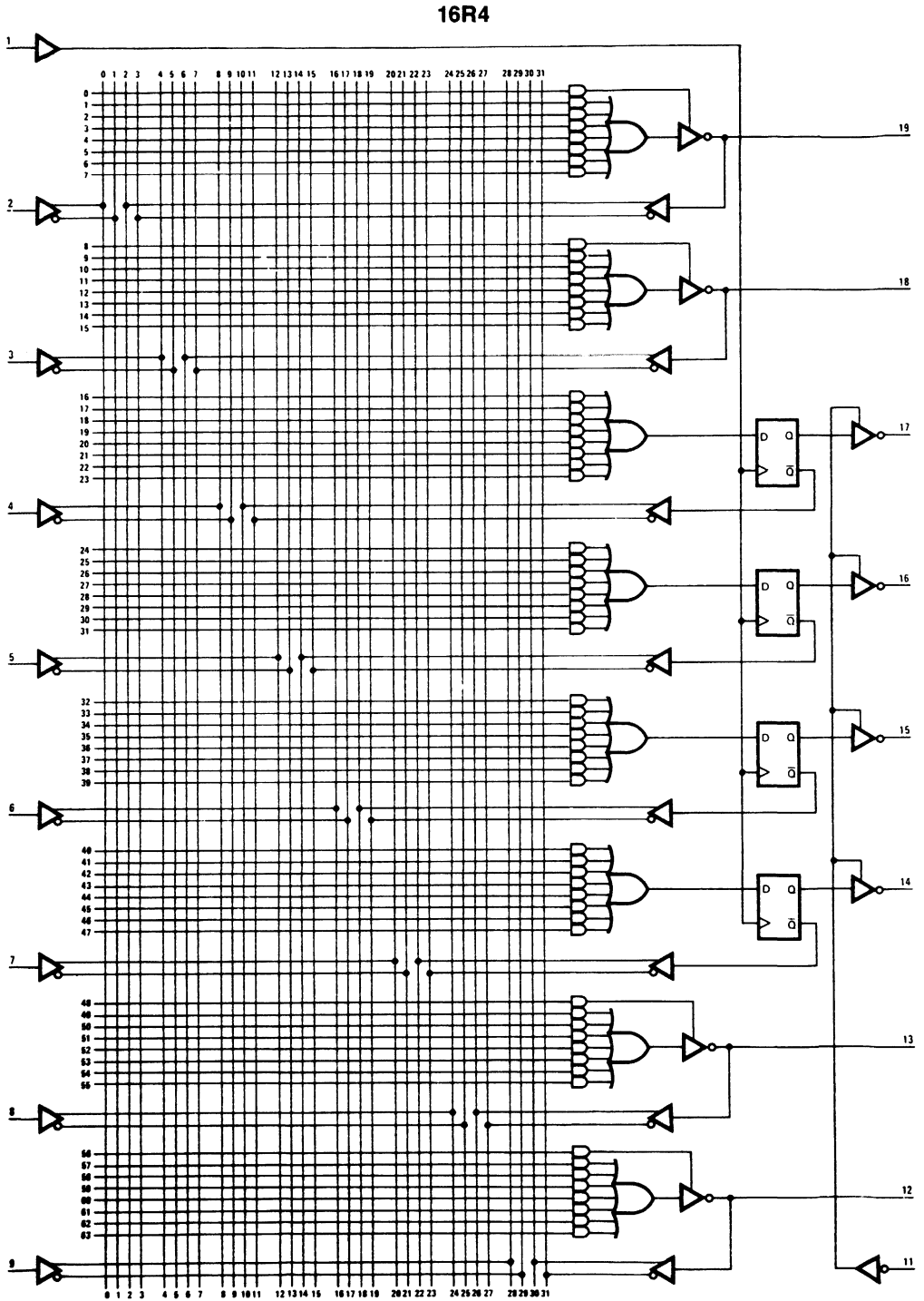
**Medium 20 Series  
16R6 Logic Diagram**

**16R6**



**2**

**Medium 20 Series  
16R4 Logic Diagram**



L000440M

**Medium 20PA Series  
16P8A, 16RP8A, 16RP6A, 16RP4A**

**Medium 20PA Series**

|           | ARRAY INPUTS | OUTPUTS       |            | t <sub>PD</sub> *<br>(ns) | I <sub>CC</sub><br>(mA) |
|-----------|--------------|---------------|------------|---------------------------|-------------------------|
|           |              | COMBINATORIAL | REGISTERED |                           |                         |
| PAL16P8A  | 16           | 8             | 0          | 25/30                     | 180                     |
| PAL16RP8A | 16           | 0             | 8          | 25/30                     | 180                     |
| PAL16RP6A | 16           | 6             | 2          | 25/30                     | 180                     |
| PAL16RP4A | 16           | 4             | 4          | 25/30                     | 180                     |

\* 25ns active low, 30ns active high

**Description**

The Medium 20PA Series is equivalent to the Medium 20 Series, with the addition of programmable polarity. With programmable polarity unused, these devices are equivalent to the Medium 20A Series.

**Polarity**

Each of these devices offers programmable polarity on each output. If the polarity fuse is unused, the output is active low. If the polarity fuse is programmed, the output is inverted to active high.

**Preload and Power-up Reset**

Each device also offers register preload for device testability. The registers can be preloaded from the outputs by using supervoltages (see waveforms at end of section) in order to simplify functional testing. This series also offers Power-up Reset, whereby the registers power up to a logic LOW, setting the active-low outputs to a logic HIGH.

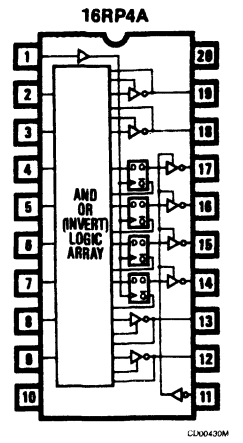
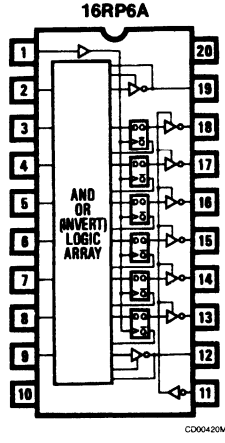
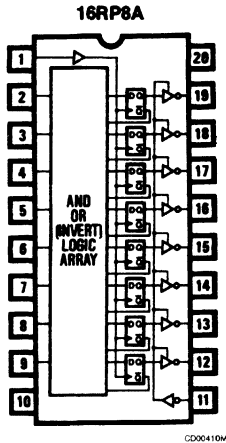
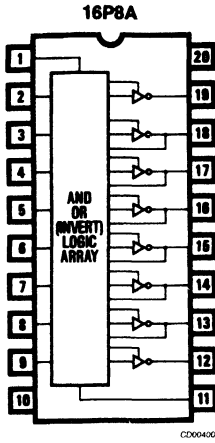
**Performance**

Performance varies according to the use of the programmable polarity. Active low outputs have a t<sub>pd</sub> of 25ns, while active high outputs have a t<sub>pd</sub> of 30ns due to the extra inversion. All devices consume 180mA maximum ICC.

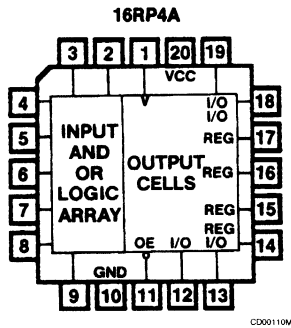
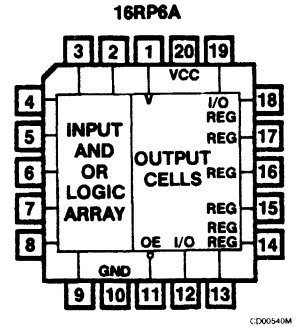
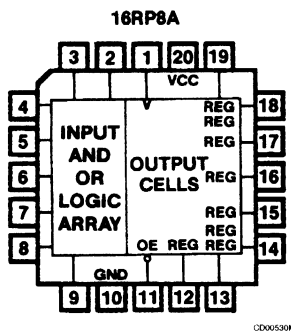
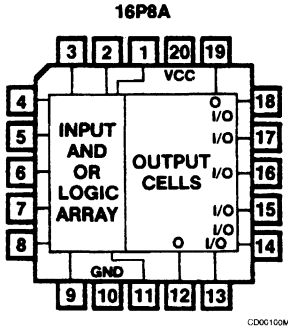
**2**

**Medium 20PA Series**  
**16P8A, 16RP8A, 16RP6A, 16RP4A**

**DIP Pinouts**



**PLCC Pinouts**



**Medium 20PA Series**  
**16P8A, 16RP8A, 16RP6A, 16RP4A**

**Operating Conditions**

| SYMBOL          | PARAMETER                                  |                            | COMMERCIAL <sup>1</sup> |                     |      | UNIT |
|-----------------|--|----------------------------|-------------------------|---------------------|------|------|
|                 |  |                            | MIN                     | TYP                 | MAX  |      |
| V <sub>CC</sub> | Supply voltage                             |                            | 4.75                    | 5                   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | Low                        | 20                      | 14                  |      | ns   |
|                 |  | High                       | 10                      | 6                   |      |      |
| t <sub>SU</sub> | Setup time from input or feedback to clock | 16RP8A<br>16RP6A<br>16RP4A | Polarity fuse intact    | 25                  | 15   | ns   |
|                 |  |                            |                         | Polarity fuse blown | 30   |      |
| t <sub>h</sub>  | Hold time                                  |                            | 0                       |                     | -10  |      |
| T <sub>A</sub>  | Operating free-air temperature             |                            | 0                       |                     | 75   | °C   |

2

**Electrical Characteristics** Over Operating Conditions

| SYMBOL                        | PARAMETER                    | TEST CONDITION                                    | COMMERCIAL |       |       | UNIT |
|-------------------------------|------------------------------|---|------------|-------|-------|------|
|                               |                              |   | MIN        | TYP   | MAX   |      |
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |   |            |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |   | 2          |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN    I <sub>I</sub> = -18mA   |            | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX    V <sub>I</sub> = 0.4V    |            | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX    V <sub>I</sub> = 2.4V    |            |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX    V <sub>I</sub> = 5.5V    |            |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN    I <sub>OL</sub> = 24mA   |            | 0.3   | 0.5   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN    I <sub>OH</sub> = -3.2mA | 2.4        | 2.8   |       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX                             |            |       | -100  | μA   |
| I <sub>OZH</sub> <sup>3</sup> |                              |   |            |       | 100   | μA   |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V    V <sub>O</sub> = 0V       | -30        | -70   | -130  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX                             |            | 120   | 180   | mA   |

1. The PAL20PA Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
2. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
3. I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
4. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

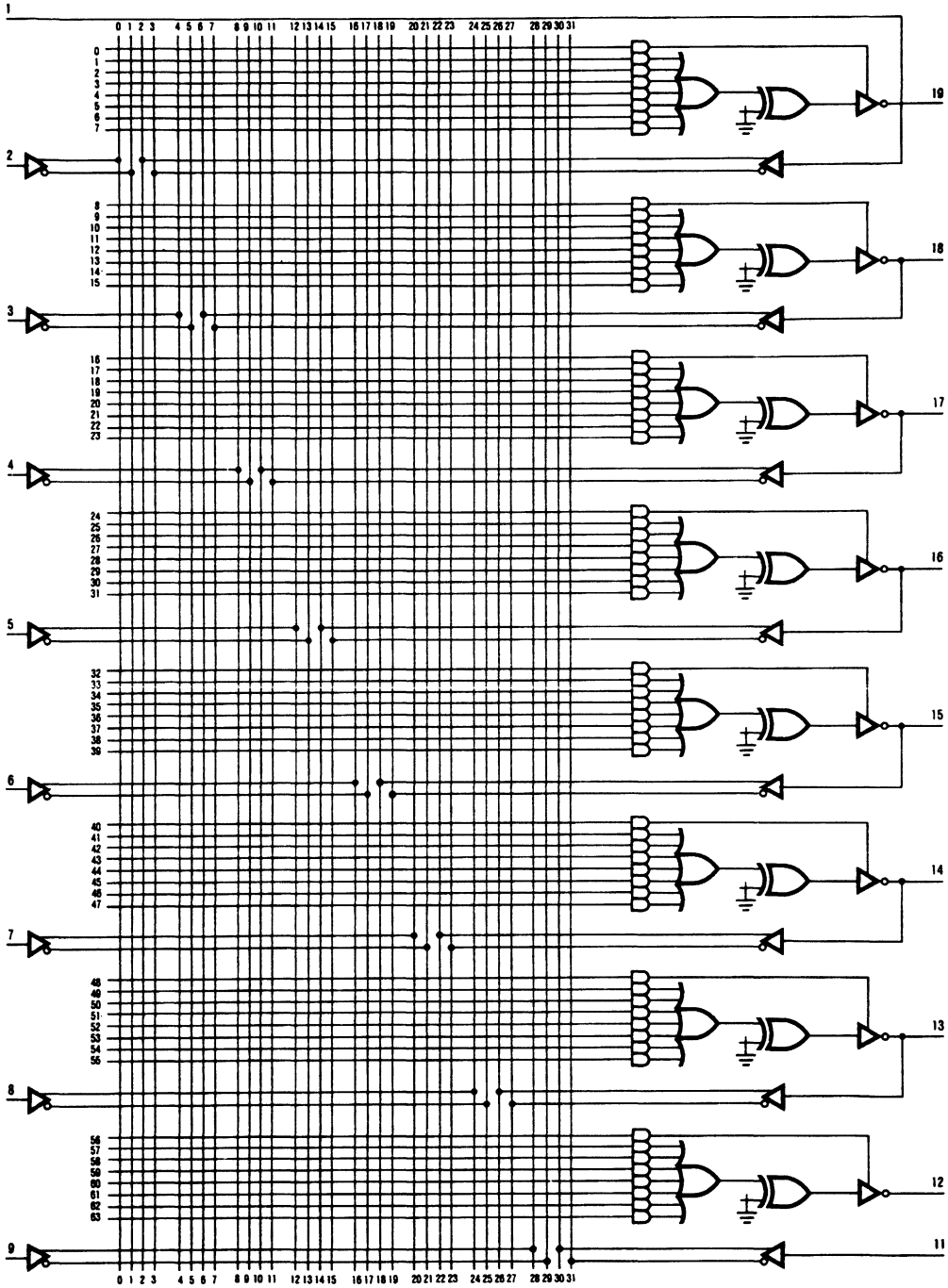
**Medium 20PA Series**  
**16P8A, 16RP8A, 16RP6A, 16RP4A**

**Switching Characteristics** Over Operating Conditions

| SYMBOL           | PARAMETER   |                           | TEST CONDITIONS                                 | COMMERCIAL |     |     | UNIT |
|------------------|---|---------------------------|---|------------|-----|-----|------|
|                  |   |                           |   | MIN        | TYP | MAX |      |
| t <sub>PD</sub>  | Input or feedback to output 16P8A, 16RP6A, 16RP4A | Polarity fuse intact      | R <sub>1</sub> = 200Ω<br>R <sub>2</sub> = 390KΩ |            | 15  | 25  | ns   |
|                  |   | Polarity fuse blown       |   |            | 20  | 30  |      |
| t <sub>CLK</sub> | Clock to output or feedback                       |                           |   | 10         | 15  | ns  |      |
| t <sub>PZX</sub> | Pin 11 to output enable except 16P8A              |                           |   | 10         | 20  | ns  |      |
| t <sub>PXZ</sub> | Pin 11 to output disable except 16P8A             |                           |   | 11         | 20  | ns  |      |
| t <sub>PZX</sub> | Input to output enable                            | 16RP6A, 16RP4A, and 16P8A |   |            | 10  | 25  | ns   |
| t <sub>PXZ</sub> | Input to output disable                           | 16RP6A, 16RP4A, and 16P8A |   |            | 13  | 25  | ns   |
| f <sub>MAX</sub> | Maximum frequency 16RP8A, 16RP6A, 16RP4A          | Polarity fuse intact      |   | 28.5       | 40  |     | MHz  |
|                  |   | Polarity fuse blown       |   | 25         | 33  |     |      |

Medium 20PA Series  
16P8A Logic Diagram

16P8A

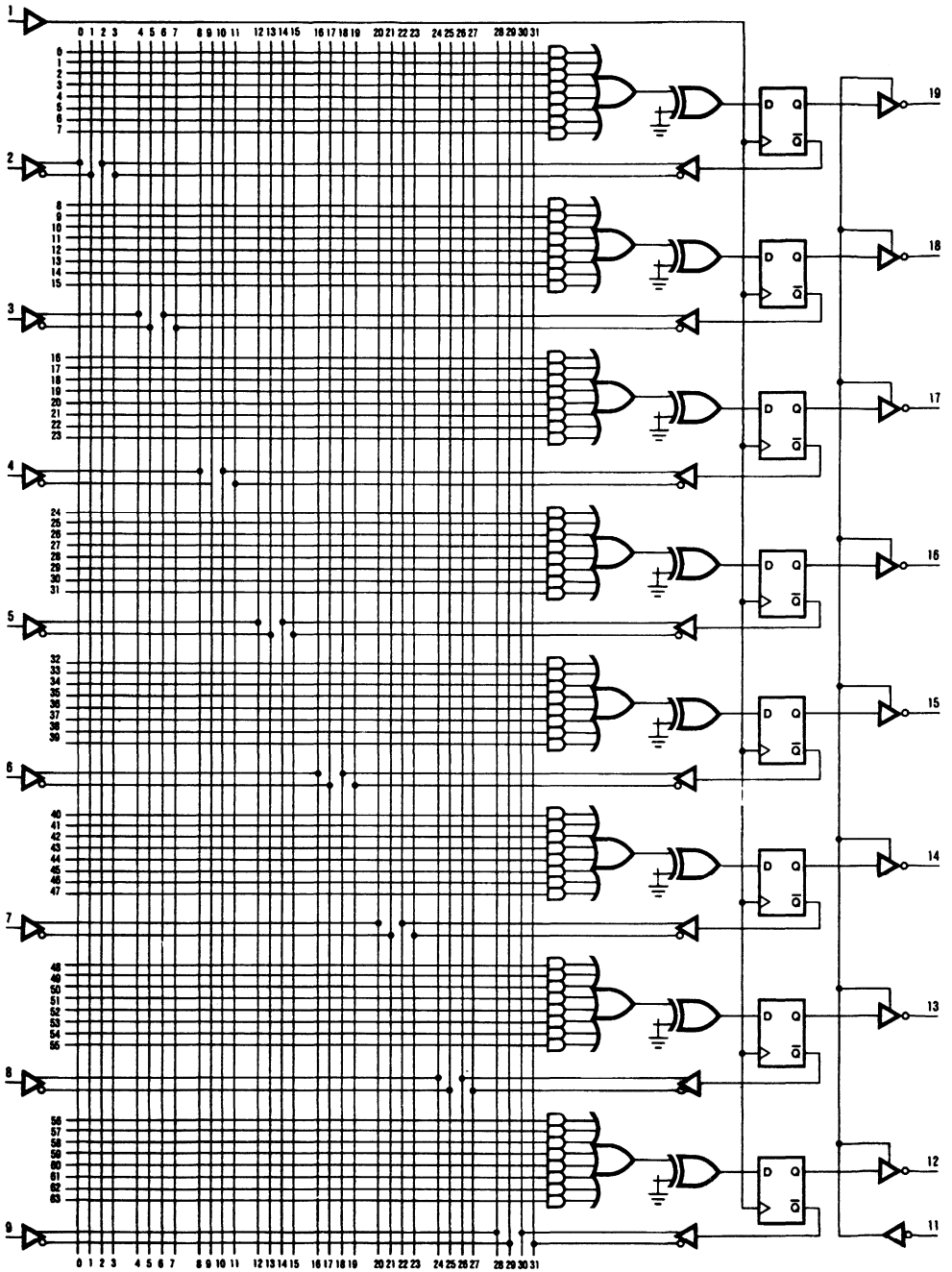


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LD00450M

**Medium 20PA Series  
16RP8A Logic Diagram**

**16RP8A**

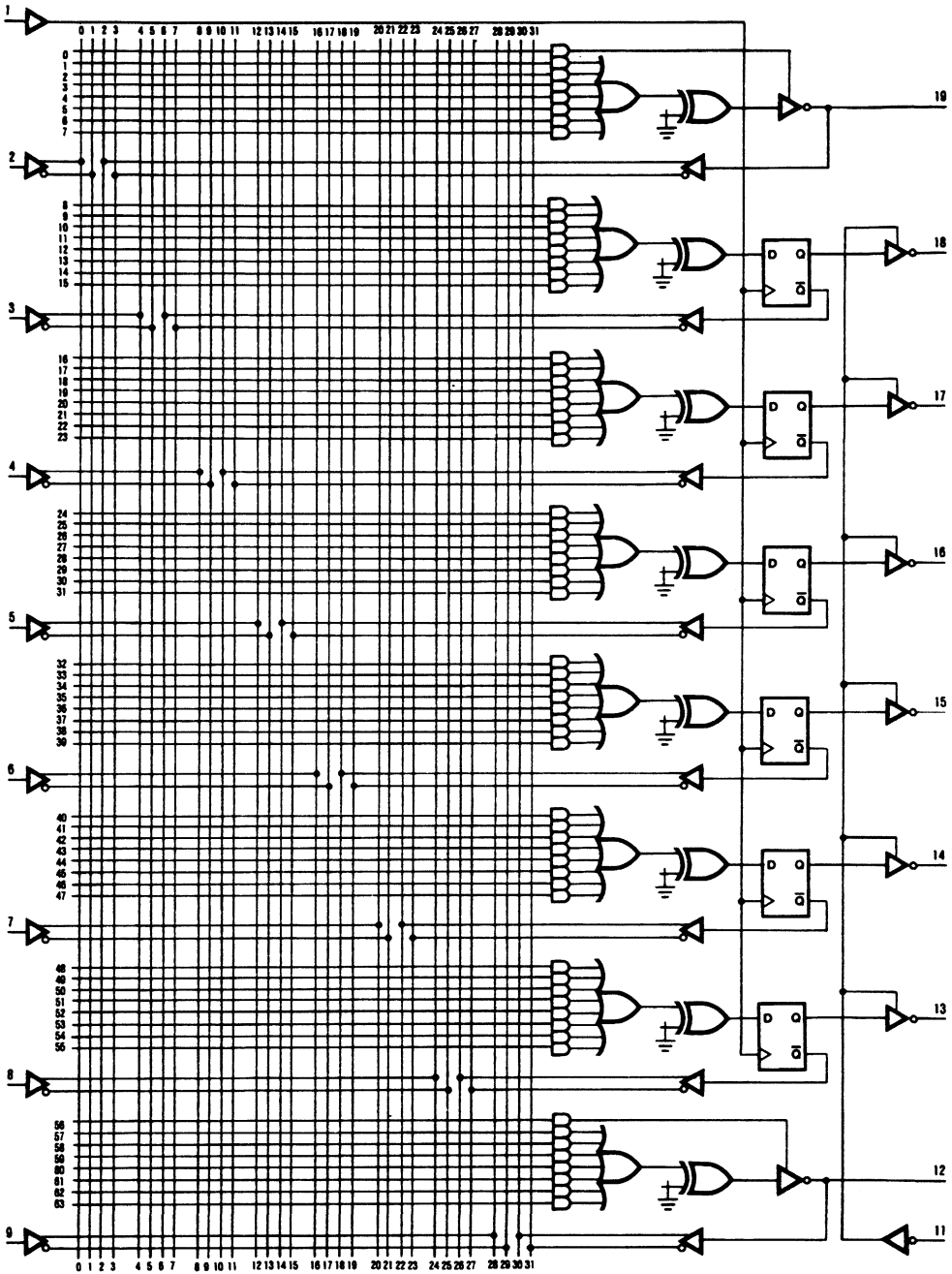


L000460M



**Medium 20PA Series  
16RP6A Logic Diagram**

**16RP6A**

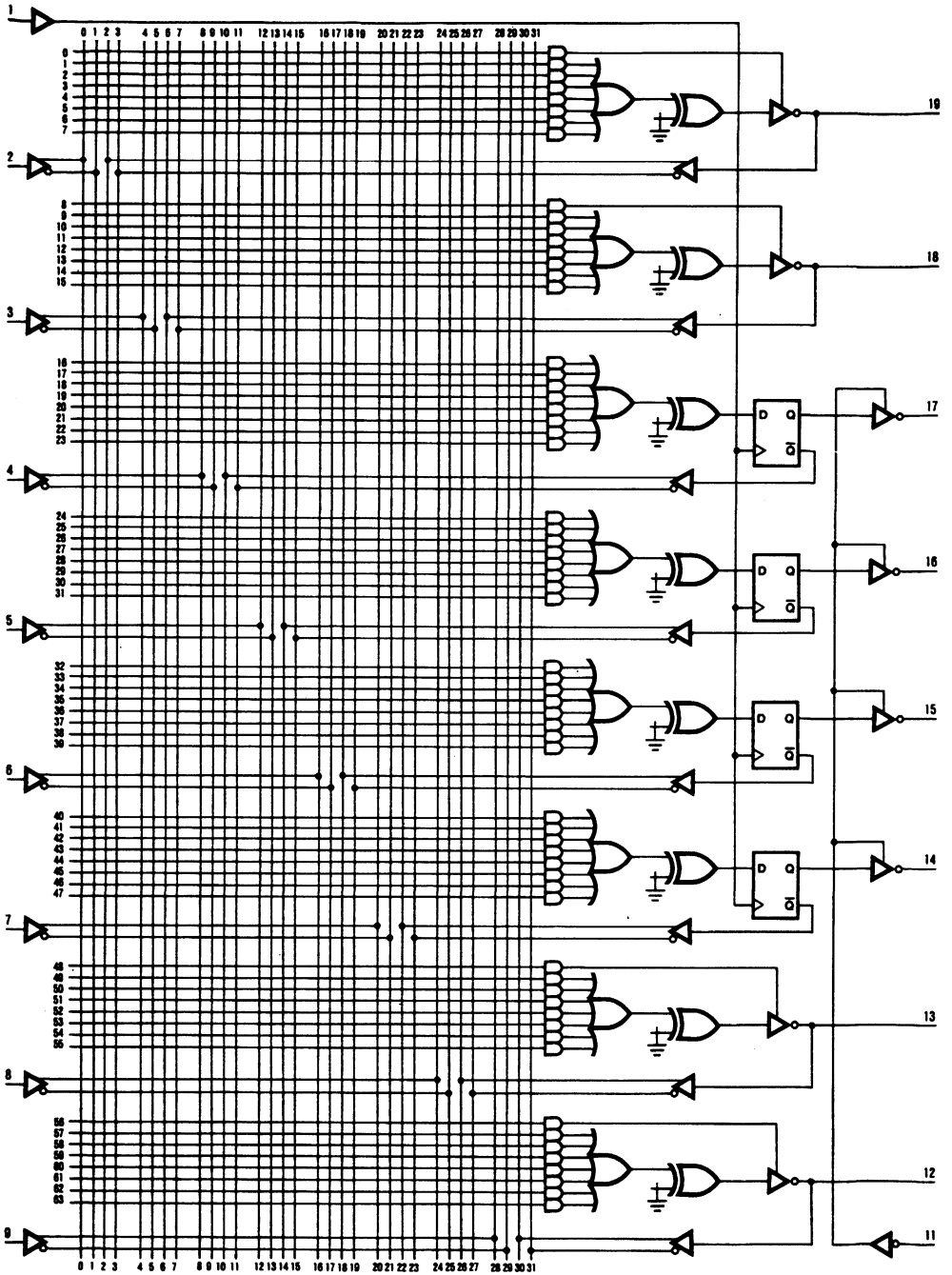


**2**

L000470M

Medium 20PA Series  
16RP4A Logic Diagram

16RP4A



L000480M

**Large 20 Arithmetic Series  
16X4, 16A4**

**Large 20 Arithmetic Series**

|         | ARRAY INPUTS | OUTPUTS       |            | PRODUCT TERMS |
|---------|--------------|---------------|------------|---------------|
|         |              | COMBINATORIAL | REGISTERED |               |
| PAL16X4 | 16           | 4             | 4          | 64            |
| PAL16A4 | 16           | 4             | 4          | 74            |

**Description**

The PAL16X4 and PAL16A4 have arithmetic gated feedback. These are specialized devices for arithmetic applications.

**Arithmetic Gated Feedback**

The arithmetic functions (add, subtract, greater than, and less than) are implemented by addition of gated feedback to the features of the XOR PAL device. The XOR at the input of the D-type flip-flop allows carries from previous operations to be

XORed with two variable sums generated by the PAL device array. The flip-flop Q output is fed back to be gated with input terms A (Figure 13). This gated feedback provides any one of the sixteen possible Boolean combinations which are mapped in the Karnaugh map (Figure 14). Figure 15 shows how the PAL device array can be programmed to perform these sixteen operations. These features provide for versatile operations on two variables and facilitate the parallel generation of carries necessary for fast arithmetic operations.

**2**

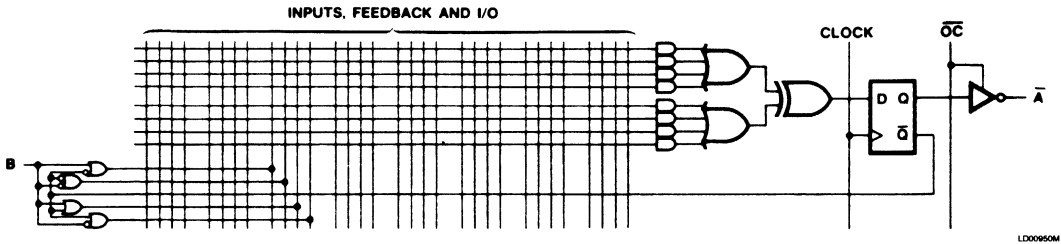


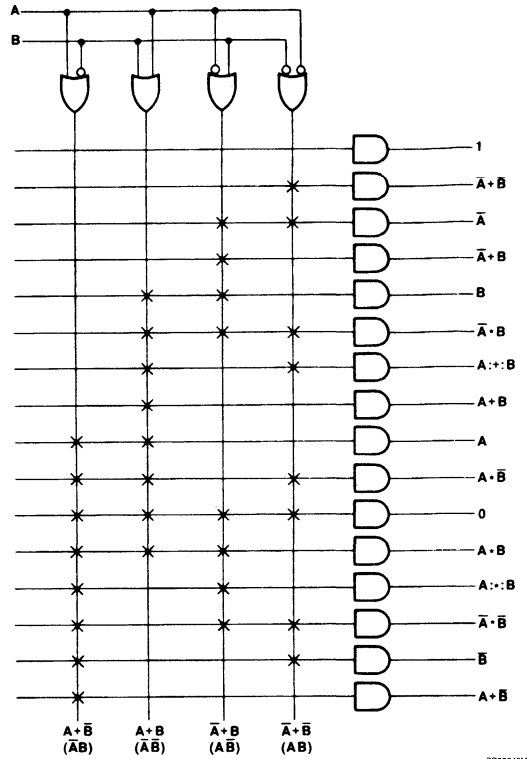
Figure 13

Large 20 Arithmetic Series  
16X4, 16A4

|    |               |                     |                     |               |
|----|---------------|---------------------|---------------------|---------------|
|    | --            | -x                  | xx                  | x-            |
| -- | 1             | $\bar{A} + \bar{B}$ | $\bar{A}$           | $\bar{A} + B$ |
| -x | $A + B$       | $A + B$             | $\bar{A} + B$       | $B$           |
| xx | $A$           | $A + \bar{B}$       | 0                   | $A + B$       |
| x- | $A + \bar{B}$ | $\bar{B}$           | $\bar{A} + \bar{B}$ | $A + \bar{B}$ |

T801630M

Figure 14

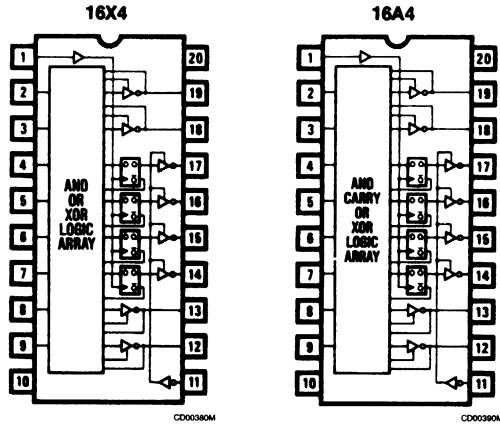


9D00240M

Figure 15

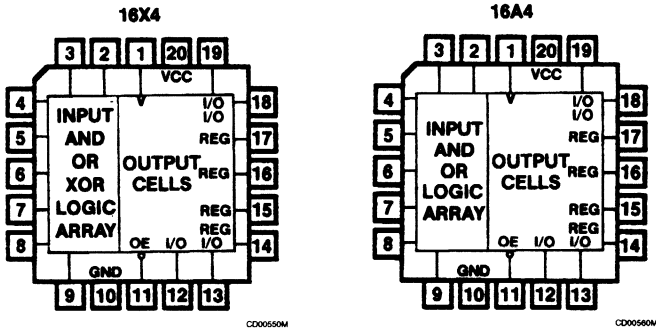
**Large 20 Arithmetic Series  
16X4, 16A4**

**DIP Pinouts**



**2**

**PLCC Pinouts**



**Large 20 Arithmetic Series**  
**16X4, 16A4**

**Operating Conditions**

| SYMBOL          | PARAMETER                                   | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|-----------------|---|----------|-----|-----|------------|-----|------|------|
|                 |   | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                              | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                              | Low      | 25  | 10  |            | 25  | 10   | ns   |
|                 |   | High     | 25  | 10  |            | 25  | 10   |      |
| t <sub>su</sub> | Set up time from input or feedback to clock | 55       | 30  |     | 45         | 30  |      | ns   |
| t <sub>h</sub>  | Hold time                                   | 0        | -15 |     | 0          | -15 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature              | -55      |     |     | 0          |     | 75   | °C   |
| T <sub>C</sub>  | Operating case temperature                  |          |     | 125 |            |     |      | °C   |

**Electrical Characteristics**

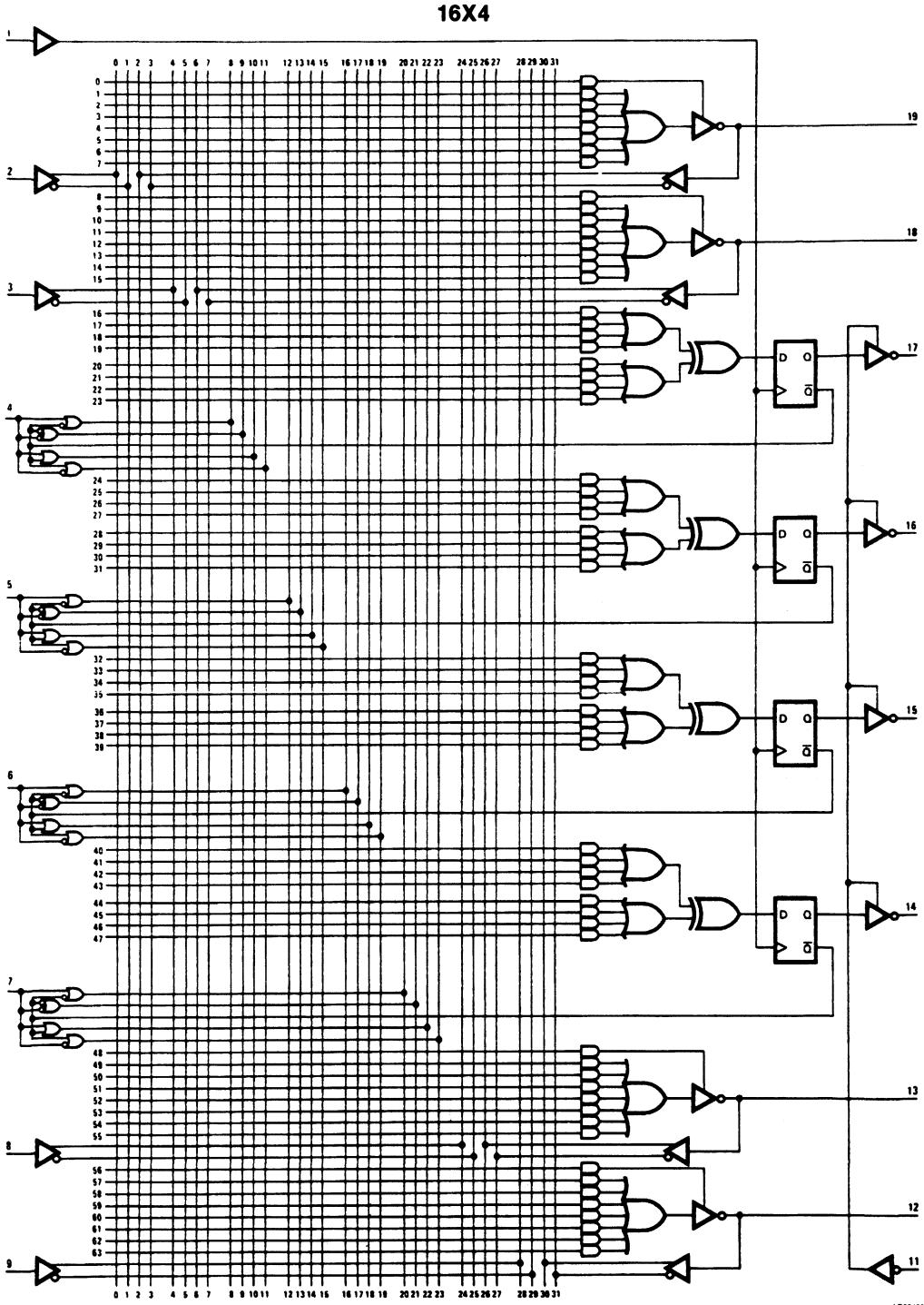
| SYMBOL                        | PARAMETER                    | TEST CONDITIONS       |                              | MIN | TYP   | MAX   | UNIT |
|-------------------------------|------------------------------|-----------------------|------------------------------|-----|-------|-------|------|
| V <sub>IL</sub> <sup>1</sup>  | Low-level input voltage      |                       |                              |     |       | 0.8   | V    |
| V <sub>IH</sub> <sup>1</sup>  | High-level input voltage     |                       |                              | 2   |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA       |     | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>2</sup>  | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V        |     | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>2</sup>  | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V        |     |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V        |     |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN | Mil I <sub>OL</sub> = 12mA   |     | 0.3   | 0.5   | V    |
|                               |                              |                       | Com I <sub>OL</sub> = 24mA   |     |       |       |      |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN | Mil I <sub>OL</sub> = -2mA   | 2.4 | 2.8   |       | V    |
|                               |                              |                       | Com I <sub>OL</sub> = -3.2mA |     |       |       |      |
| I <sub>OZL</sub> <sup>2</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0.4V        |     |       | -100  | μA   |
| I <sub>OZH</sub> <sup>2</sup> |                              |                       | V <sub>O</sub> = 2.4V        |     |       | 100   | μA   |
| I <sub>OS</sub> <sup>3</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V          | -30 | -70   | -130  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX | 16X4                         |     | 160   | 225   | mA   |
|                               |                              |                       | 16A4                         |     | 170   | 240   |      |

**Switching Characteristics** Over Operating Conditions

| SYMBOL           | PARAMETER                   | TEST CONDITIONS                                | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|------------------|-----------------------------|--|----------|-----|-----|------------|-----|-----|------|
|                  |                             |  | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| t <sub>PD</sub>  | Input or feedback to output | R <sub>1</sub> = 200Ω<br>R <sub>2</sub> = 390Ω |          | 30  | 45  |            | 30  | 40  | ns   |
| t <sub>CLK</sub> | Clock to output or feedback |  |          | 15  | 25  |            | 15  | 25  | ns   |
| t <sub>PZX</sub> | Pin 11 to output enable     |  |          | 15  | 25  |            | 15  | 25  | ns   |
| t <sub>PXZ</sub> | Pin 11 to output disable    |  |          | 15  | 25  |            | 15  | 25  | ns   |
| t <sub>PZX</sub> | Input to output enable      |  |          | 30  | 45  |            | 30  | 40  | ns   |
| t <sub>PXZ</sub> | Input to output disable     |  |          | 30  | 45  |            | 30  | 40  | ns   |
| f <sub>MAX</sub> | Maximum frequency           |  |          | 12  | 22  |            | 14  | 22  | MHz  |

1. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
3. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Large 20 Arithmetic Series  
16X4 Logic Diagram**

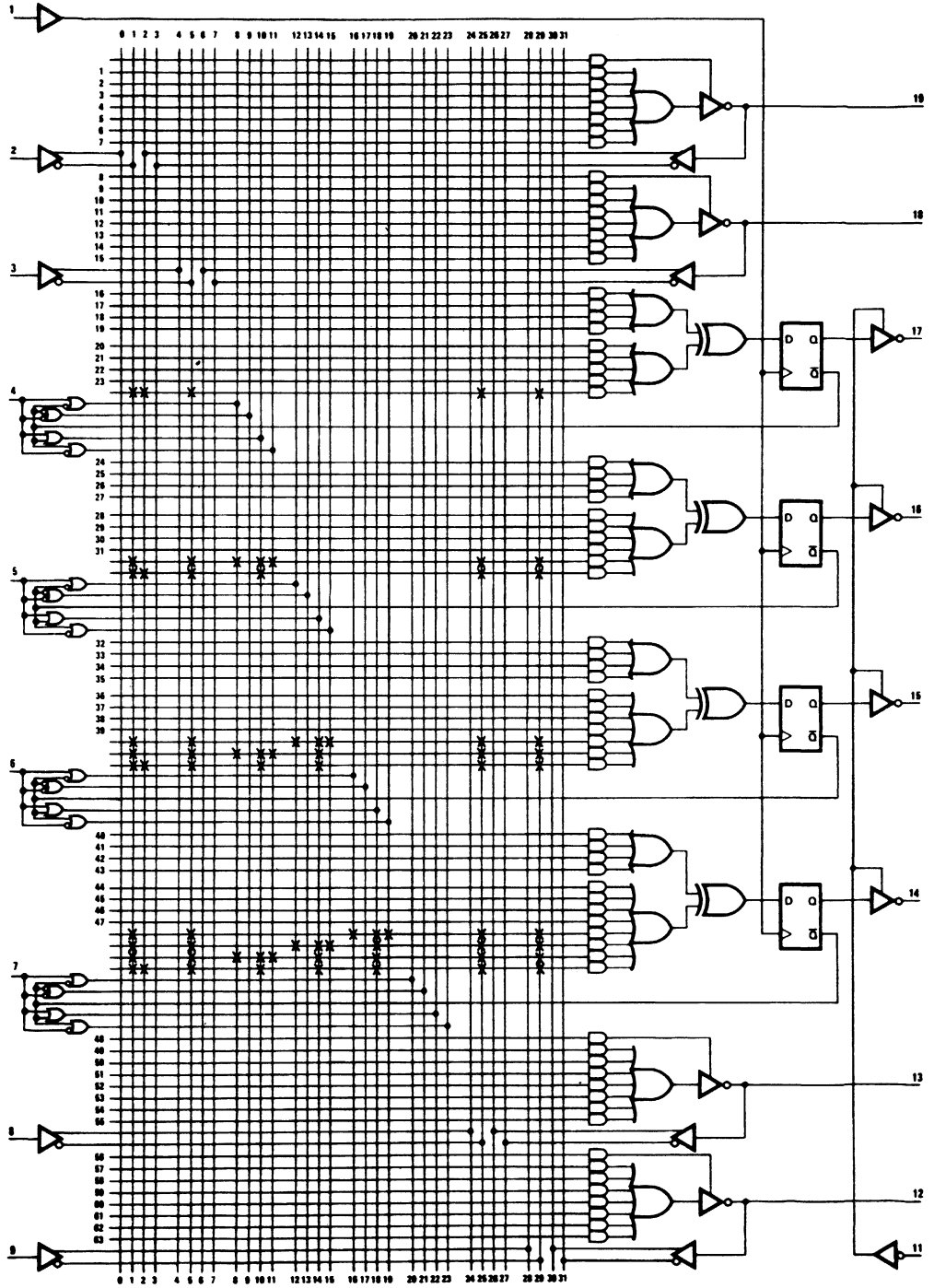


**2**

LD00490M

Large 20 Arithmetic Series  
16A4 Logic Diagram

16A4



LD00500M



## Large 20RA Series 16RA8

---

### Large 20RA (PAL16RA8)

#### Description

The PAL16RA8 is a 20-pin registered asynchronous PAL device. It is a 20-pin version of the original asynchronous PAL device, the PAL20RA10. This versatile device features programmable clock, enable, set, and reset, all of which can operate asynchronously to other flip-flops in the same device. It also has individual flop-flop bypass, allowing this one device to provide any combination of registered and combinatorial outputs.

#### Programmable Clock

The clock input to each flip-flop comes from the programmable array, allowing the flip-flops to be clocked independently if desired.

#### Programmable Set and Reset

Each flip-flop has a product line for asynchronous set and one product for asynchronous reset. If the chosen product line is high, the flip-flop will set (become a logic HIGH), or reset (become a logic LOW). The sense of the output pin is inverted if the output is active low.

#### Programmable Polarity

Each flip-flop has individually programmable polarity. The unprogrammed state is active low.

#### Programmable Flip-flop Bypass

If both the set and reset product lines are high, the flip-flop is bypassed and the output becomes combinatorial. Thus each output can be configured to be registered or combinatorial.

#### Programmable and Hard-Wired Three-State Outputs

The PAL16RA8 provides a product term dedicated to output control. There is also an output control pin (pin 11). The output is enabled if both the output control pin is low and the output control product term is high. If the output control pin is high all outputs will be disabled. If an output control product term is low, then that output will be disabled.

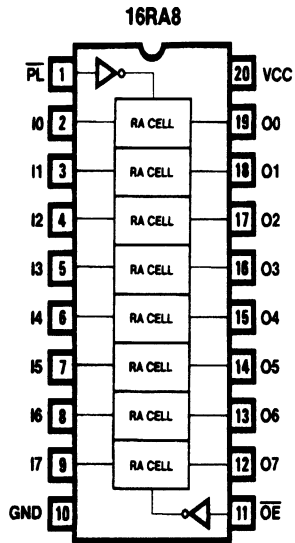
#### Register Preload and Power-up Reset

Each device also offers register preload for device testability. The registers can be preloaded from the outputs by using TTL level signals in order to simplify functional testing. This series also offers Power-up Reset, whereby the registers power up to a logic LOW, setting the active-low outputs to a logic HIGH.

2

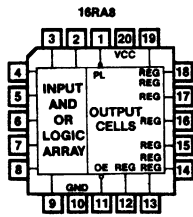
**Large 20RA Series  
16RA8**

**DIP Pinout**



C000050M

**PLCC Pinout**



C000121M

**Large 20RA Series  
16RA8**

**Operating Conditions**

| SYMBOL           | PARAMETER                                 | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|------------------|---|-------------------------|-----|------|------|
|                  |   | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub>  | Supply voltage                            | 4.75                    | 5   | 5.25 | V    |
| t <sub>w</sub>   | Width of clock                            | 20                      | 13  |      | ns   |
| t <sub>wp</sub>  | Preload pulse width                       | 35                      | 15  |      | ns   |
| t <sub>su</sub>  | Setup time for input or feedback to clock | 20                      | 10  |      | ns   |
| t <sub>sup</sub> | Preload setup time                        | 25                      | 5   |      | ns   |
| t <sub>h</sub>   | Hold time                                 | Polarity fuse intact    | 10  | -2   | ns   |
|                  |   | Polarity fuse blown     | 0   | -6   |      |
| t <sub>hp</sub>  | Preload hold time                         | 25                      | 5   |      | ns   |
| T <sub>A</sub>   | Operating free-air temperature            | 0                       |     | 75   | °C   |
| T <sub>C</sub>   | Operating case temperature                |                         |     |      | °C   |

**2**

**Electrical Characteristics Over Operating Conditions**

| SYMBOL                       | PARAMETER                    | TEST CONDITION        |   | MIN  | TYP   | MAX   | UNIT |
|------------------------------|------------------------------|-----------------------|---|------|-------|-------|------|
| V <sub>IL</sub> <sup>2</sup> | Low-level input voltage      |                       |   |      |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup> | High-level input voltage     |                       |   | 2    |       |       | V    |
| V <sub>IC</sub>              | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA                      |      | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>3</sup> | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V                       |      | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>3</sup> | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V                       |      |       | 25    | μA   |
| I <sub>I</sub>               | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V                       |      |       | 1     | mA   |
| V <sub>OL</sub>              | Low-level output voltage     | V <sub>CC</sub> = MIN | I <sub>OL</sub> = 8mA                       |      | 0.3   | 0.5   | V    |
| V <sub>OH</sub>              | High-level output voltage    | V <sub>CC</sub> = MIN | I <sub>OH</sub> = -3.2mA                    | 2.4  | 2.8   |       | V    |
| I <sub>OZ</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 2.4V/V <sub>O</sub> = 0.4V | -100 |       | 100   | μA   |
| I <sub>OS</sub> <sup>4</sup> | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V                         | -30  | -70   | -130  | mA   |
| I <sub>CC</sub>              | Supply current               | V <sub>CC</sub> = MAX |   |      | 135   | 170   | mA   |

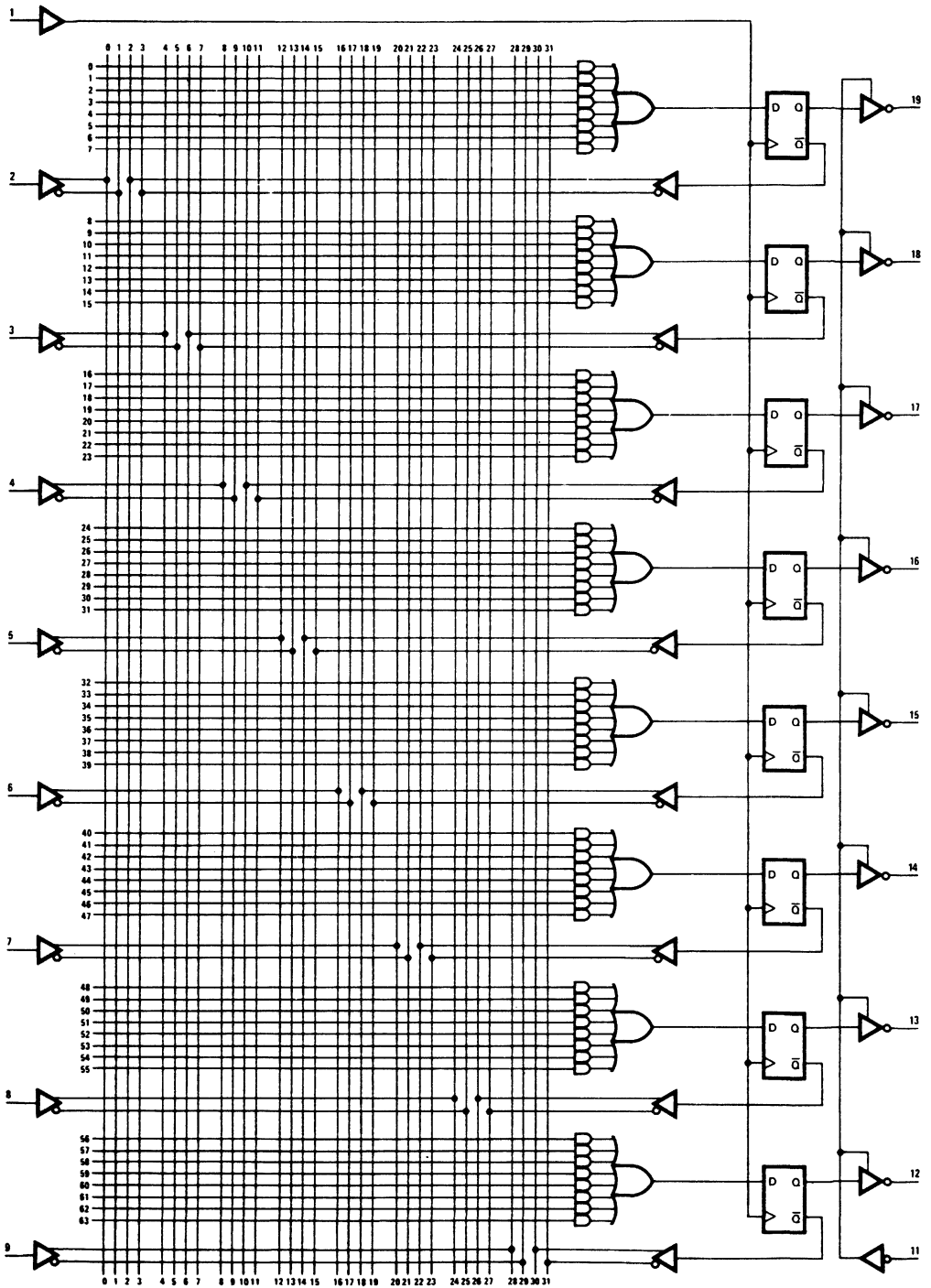
**Switching Characteristics Over Operating Conditions**

| SYMBOL           | PARAMETER                   | TEST CONDITIONS                                 | COMMERCIAL |     |     | UNIT |
|------------------|-----------------------------|---|------------|-----|-----|------|
|                  |                             |   | MIN        | TYP | MAX |      |
| t <sub>PD</sub>  | Input or feedback to output | Polarity fuse intact                            |            | 20  | 30  | ns   |
|                  |                             | Polarity fuse blown                             |            | 25  | 35  |      |
| t <sub>CLK</sub> | Clock to output or feedback | R <sub>1</sub> = 560Ω<br>R <sub>2</sub> = 1.1KΩ | 10         | 17  | 30  | ns   |
| t <sub>S</sub>   | Input to asynchronous set   |   |            | 22  | 35  | ns   |
| t <sub>R</sub>   | Input to asynchronous reset |   |            | 27  | 40  | ns   |
| t <sub>PZX</sub> | Pin 11 to output enable     |   |            | 10  | 20  | ns   |
| t <sub>PXZ</sub> | Pin 11 to output disable    |   |            | 10  | 20  | ns   |
| t <sub>PZX</sub> | Input to output enable      |   |            | 18  | 30  | ns   |
| t <sub>PXZ</sub> | Input to output disable     |   |            | 15  | 30  | ns   |
| f <sub>MAX</sub> | Maximum frequency           |   |            | 20  | 35  | MHz  |

- The PAL20RA Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Large 20RA Series  
16RA8 Logic Diagram**

**16RA8**



LD00420M

**Small 24 Series**  
**12L10, 14L8, 16L6, 18L4, 20L2, 20C1**

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**Small 24 Series**

|          | INPUTS | OUTPUTS | POLARITY | T <sub>PD</sub><br>(ns) | I <sub>CC</sub><br>(mA) |
|----------|--------|---------|----------|-------------------------|-------------------------|
| PAL12L10 | 12     | 10      | LOW      | 40                      | 100                     |
| PAL14L8  | 14     | 8       | LOW      | 40                      | 100                     |
| PAL16L6  | 16     | 6       | LOW      | 40                      | 100                     |
| PAL18L4  | 18     | 4       | LOW      | 40                      | 100                     |
| PAL20L2  | 20     | 2       | LOW      | 40                      | 100                     |
| PAL20C1  | 20     | 2       | LOW      | 40                      | 100                     |

**Description**

The Small 24 Series is made up of six combinatorial 24-pin PAL devices. They implement simple combinatorial logic, with no feedback.

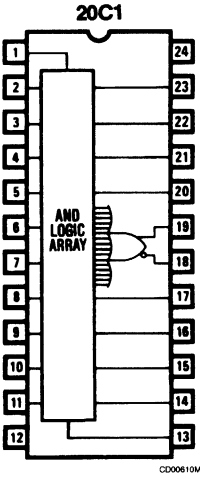
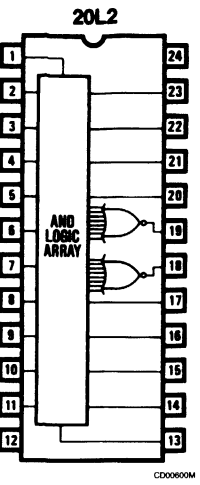
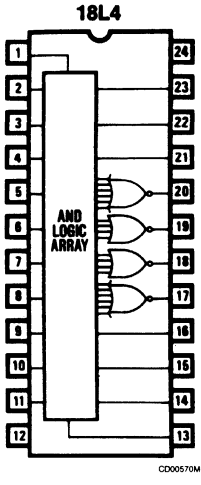
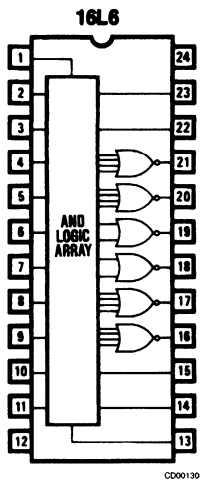
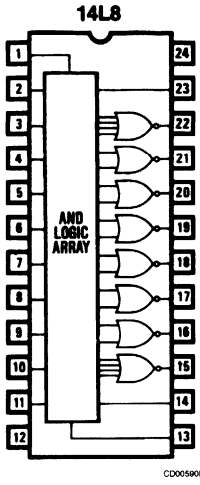
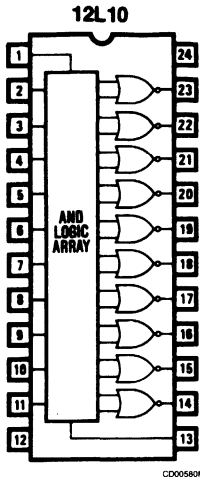
**Performance**

The standard series has a propagation delay (tpd) of 40 nanoseconds (ns). Standard supply current is 100 milliamps (mA).

**2**

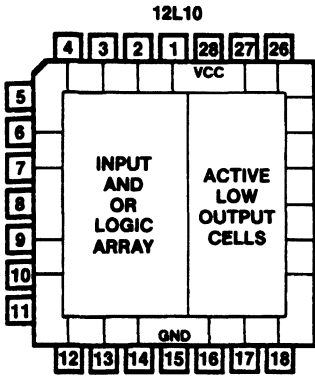
**Small 24 Series**  
**12L10, 14L8, 16L6, 18L4, 20L2, 20C1**

**DIP Pinouts**

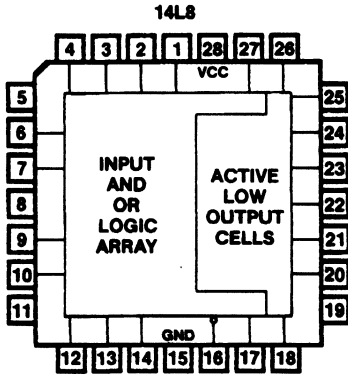


**Small 24 Series**  
**12L10, 14L8, 16L6, 18L4, 20L2, 20C1**

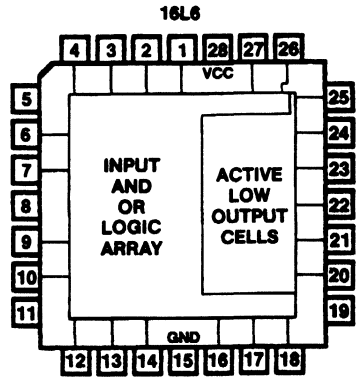
**PLCC Pinouts**



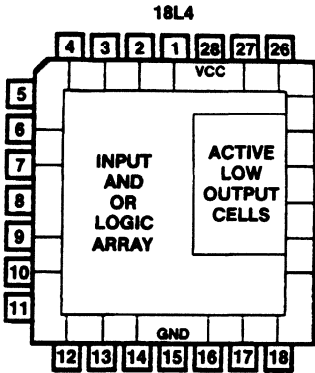
CD00730M



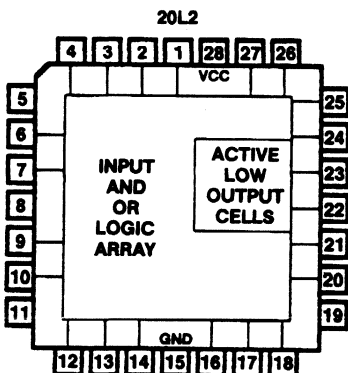
CD00180M



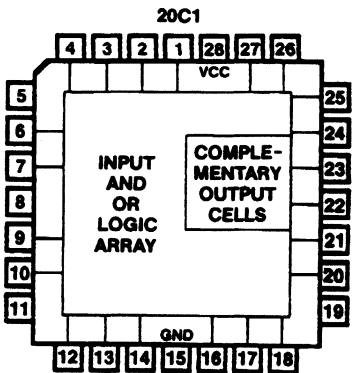
CD00740M



CD00750M



CD00180M



CD00780M

**2**

**Small 24 Series**  
**12L10, 14L8, 16L6, 18L4, 20L2, 20C1**

**Operating Conditions**

| SYMBOL   | PARAMETER                      | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|----------|--------------------------------|----------|-----|-----|------------|-----|------|------|
|          |                                | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                 | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| $T_A$    | Operating free-air temperature | -55      |     |     | 0          |     | 75   | °C   |
| $T_C$    | Operating case temperature     |          |     | 125 |            |     |      | °C   |

**Electrical Characteristics** Over Operating Conditions

| SYMBOL     | PARAMETER                    | TEST CONDITIONS       |                              | MIN | TYP   | MAX   | UNIT          |
|------------|------------------------------|-----------------------|------------------------------|-----|-------|-------|---------------|
| $V_{IL}^1$ | Low-level input voltage      |                       |                              |     |       | 0.8   | V             |
| $V_{IH}^1$ | High-level input voltage     |                       |                              | 2   |       |       | V             |
| $V_{IC}$   | Input clamp voltage          | $V_{CC} = \text{MIN}$ | $I_I = -18\text{mA}$         |     | -0.8  | -1.5  | V             |
| $I_{IL}$   | Low-level input current      | $V_{CC} = \text{MAX}$ | $V_I = 0.4\text{V}$          |     | -0.02 | -0.25 | mA            |
| $I_{IH}$   | High-level input current     | $V_{CC} = \text{MAX}$ | $V_I = 2.4\text{V}$          |     |       | 25    | $\mu\text{A}$ |
| $I_I$      | Maximum input current        | $V_{CC} = \text{MAX}$ | $V_I = 5.5\text{V}$          |     |       | 1     | mA            |
| $V_{OL}$   | Low-level output voltage     | $V_{CC} = \text{MIN}$ | MIL $I_{OL} = 8\text{mA}$    |     | 0.3   | 0.5   | V             |
|            |                              |                       | COM $I_{OL} = 8\text{mA}$    |     |       |       |               |
| $V_{OH}$   | High-level output voltage    | $V_{CC} = \text{MIN}$ | MIL $I_{OH} = -2\text{mA}$   | 2.4 | 2.8   |       | V             |
|            |                              |                       | COM $I_{OH} = -3.2\text{mA}$ |     |       |       |               |
| $I_{OS}^2$ | Output short-circuit current | $V_{CC} = 5\text{V}$  | $V_O = 0\text{V}$            | -30 | -70   | -130  | mA            |
| $I_{CC}$   | Supply current               | $V_{CC} = \text{MAX}$ |                              |     | 60    | 100   | mA            |

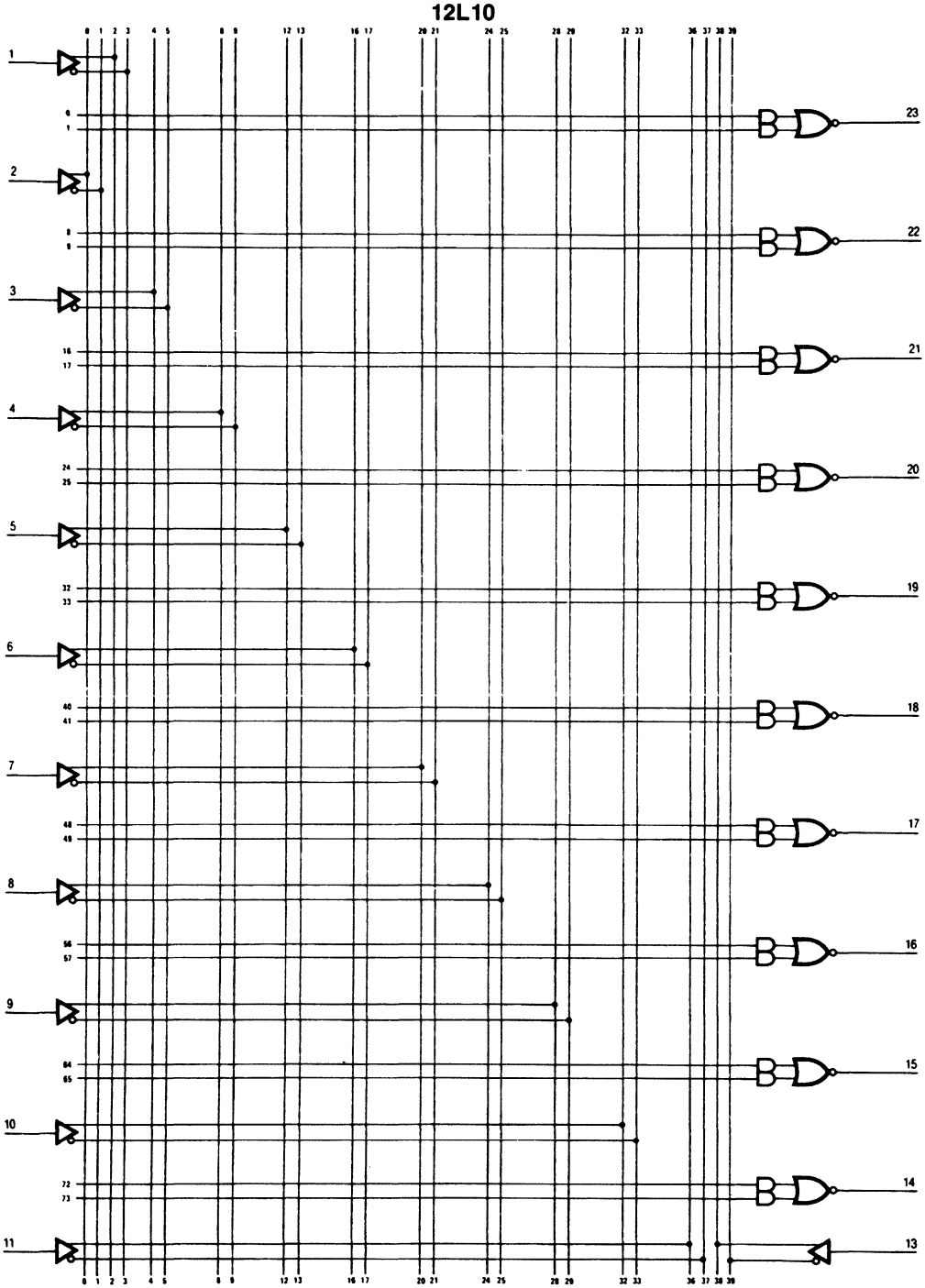
**Switching Characteristics** Over Operating Conditions

| SYMBOL   | PARAMETER                   | TEST CONDITIONS                              | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|----------|-----------------------------|--|----------|-----|-----|------------|-----|-----|------|
|          |                             |  | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{PD}$ | Input or feedback to output | $R1 = 560\Omega$<br>$R2 = 1.1\text{k}\Omega$ |          | 25  | 45  |            | 25  | 40  | ns   |

1. These are absolute values with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.



**Small 24 Series  
12L10 Logic Diagram**

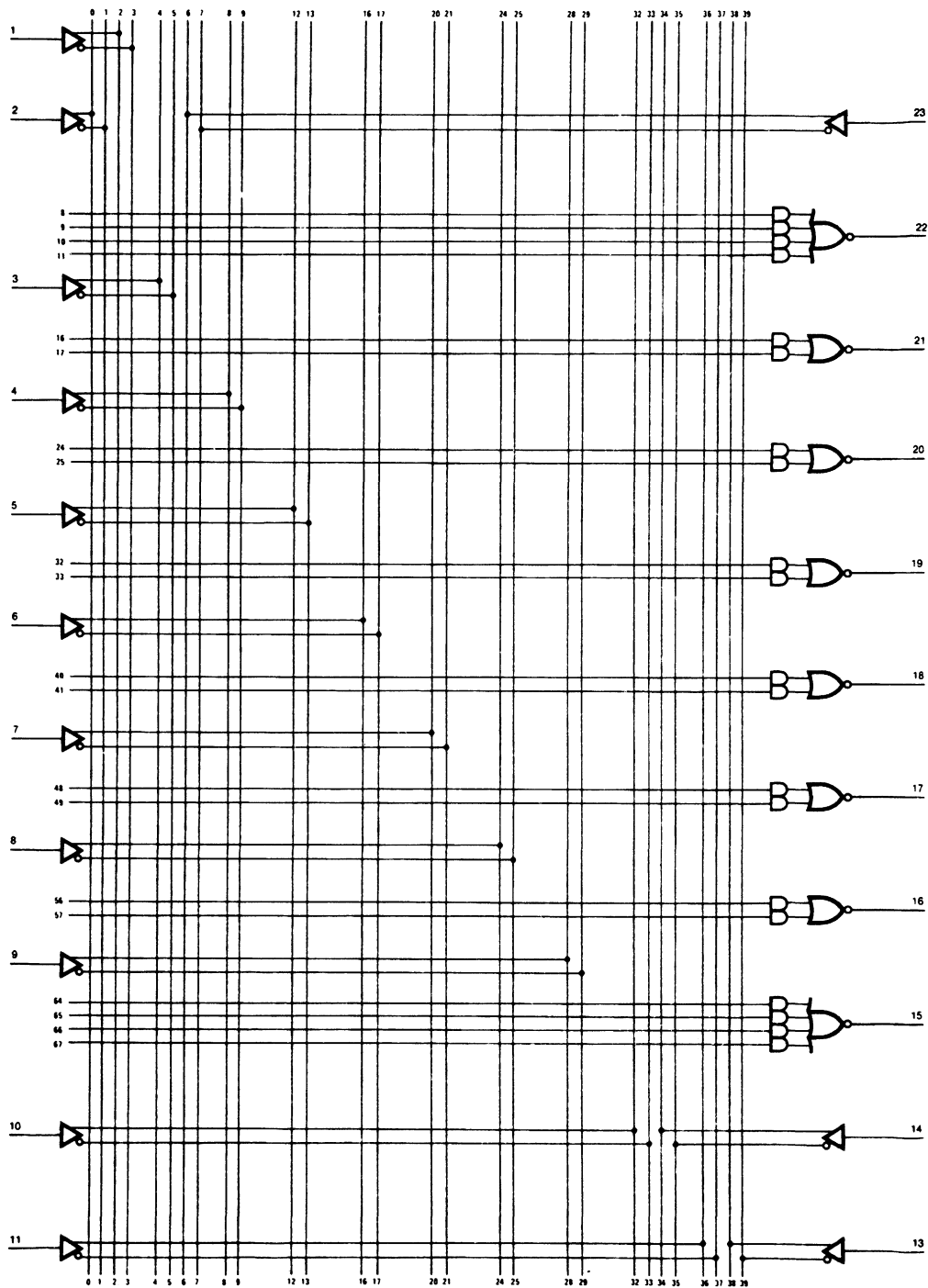


**2**

LD00510M

**Small 24 Series  
14L8 Logic Diagram**

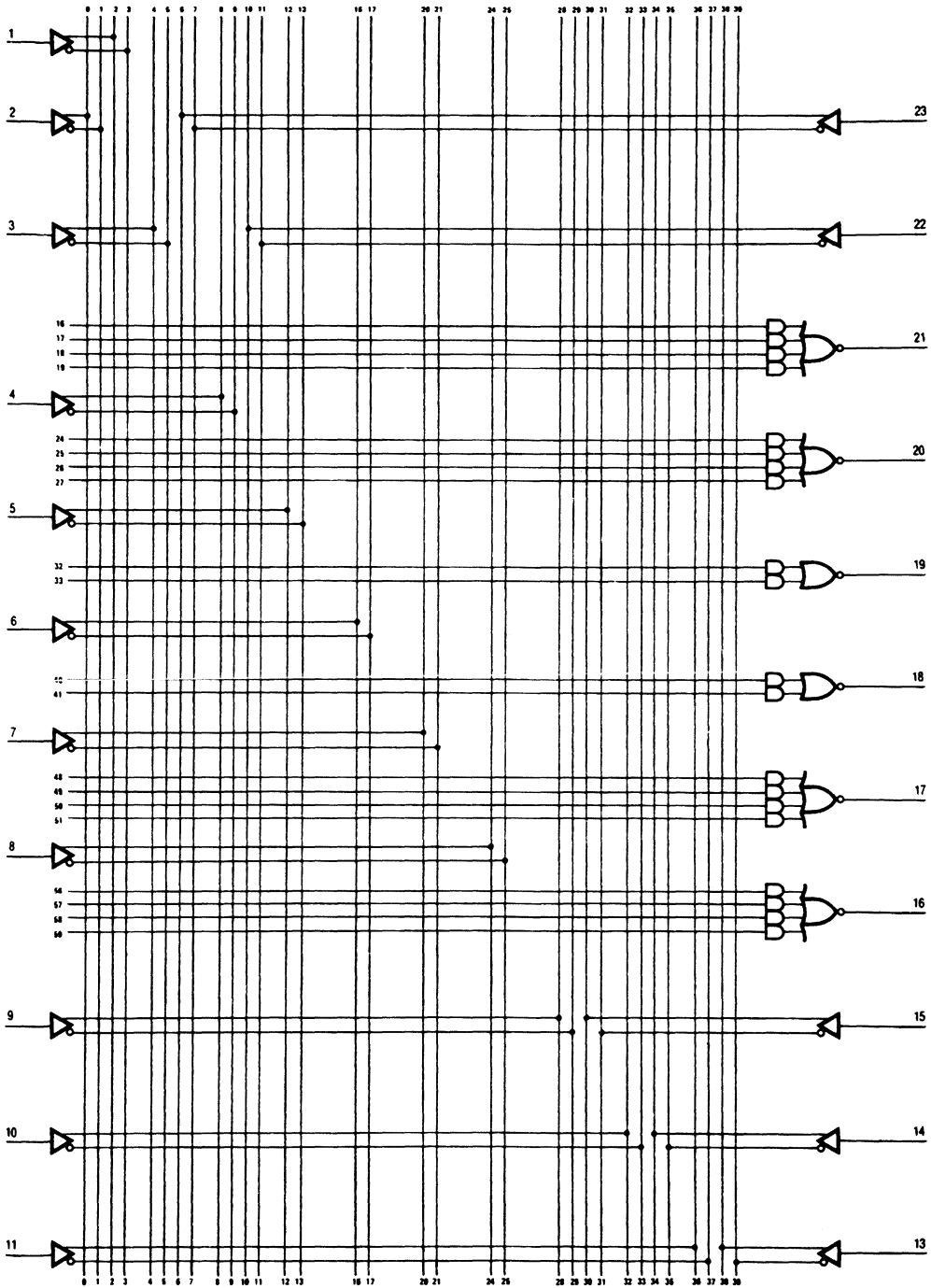
**14L8**



L70X20M

**Small 24 Series  
16L6 Logic Diagram**

**16L6**

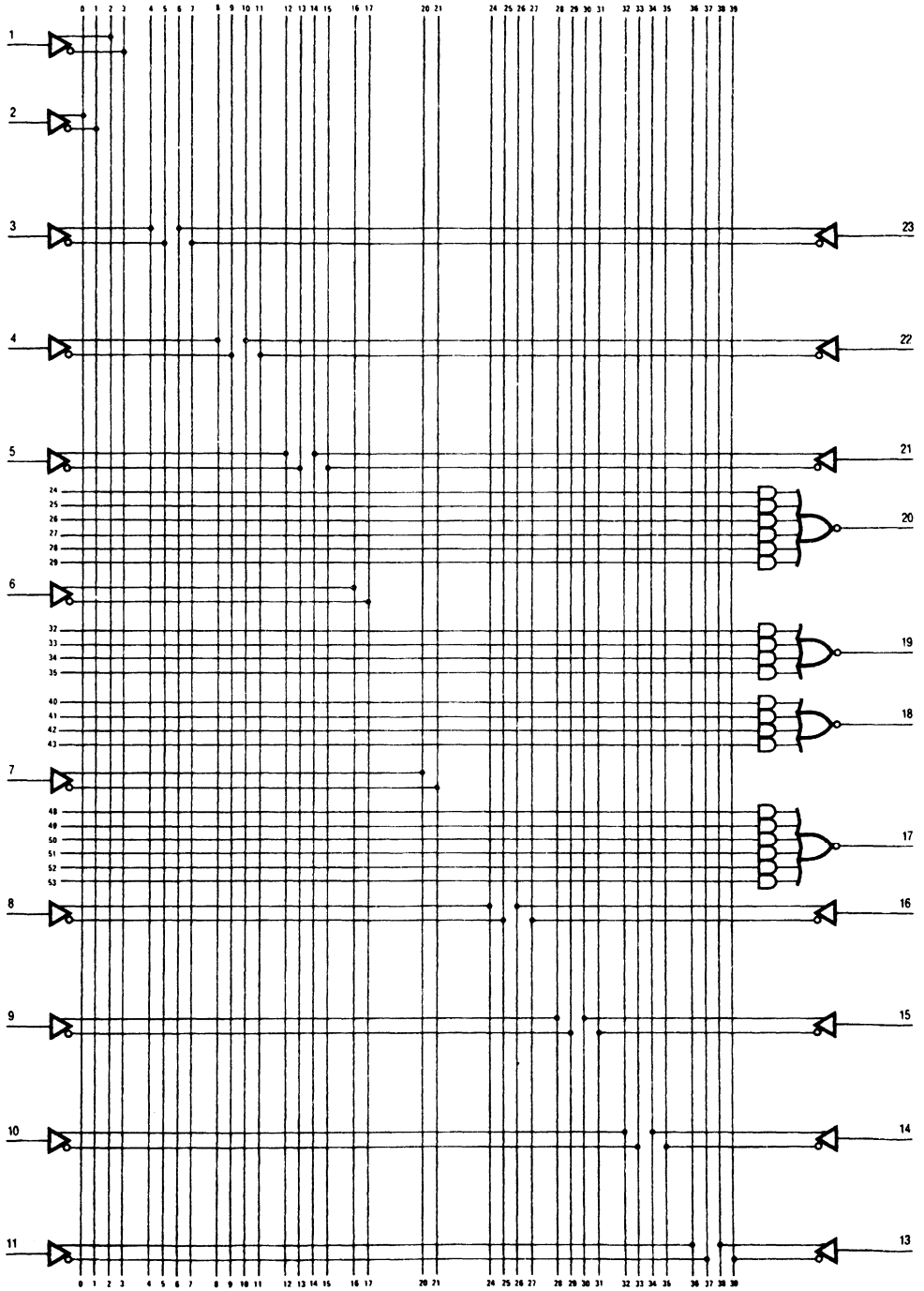


**2**

L000530M

**Small 24 Series  
18L4 Logic Diagram**

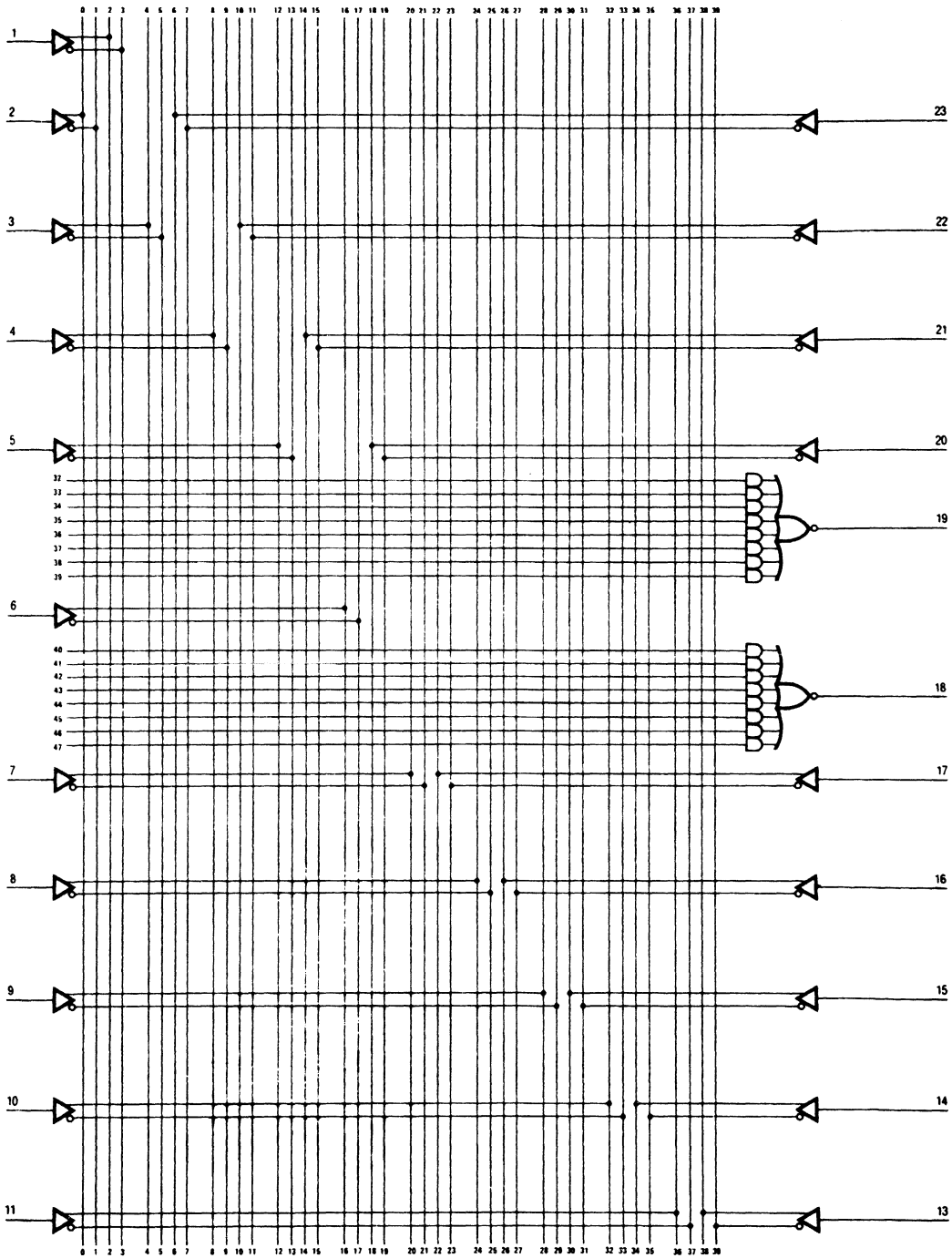
**18L4**



LD00540M

**Small 24 Series  
20L2 Logic Diagram**

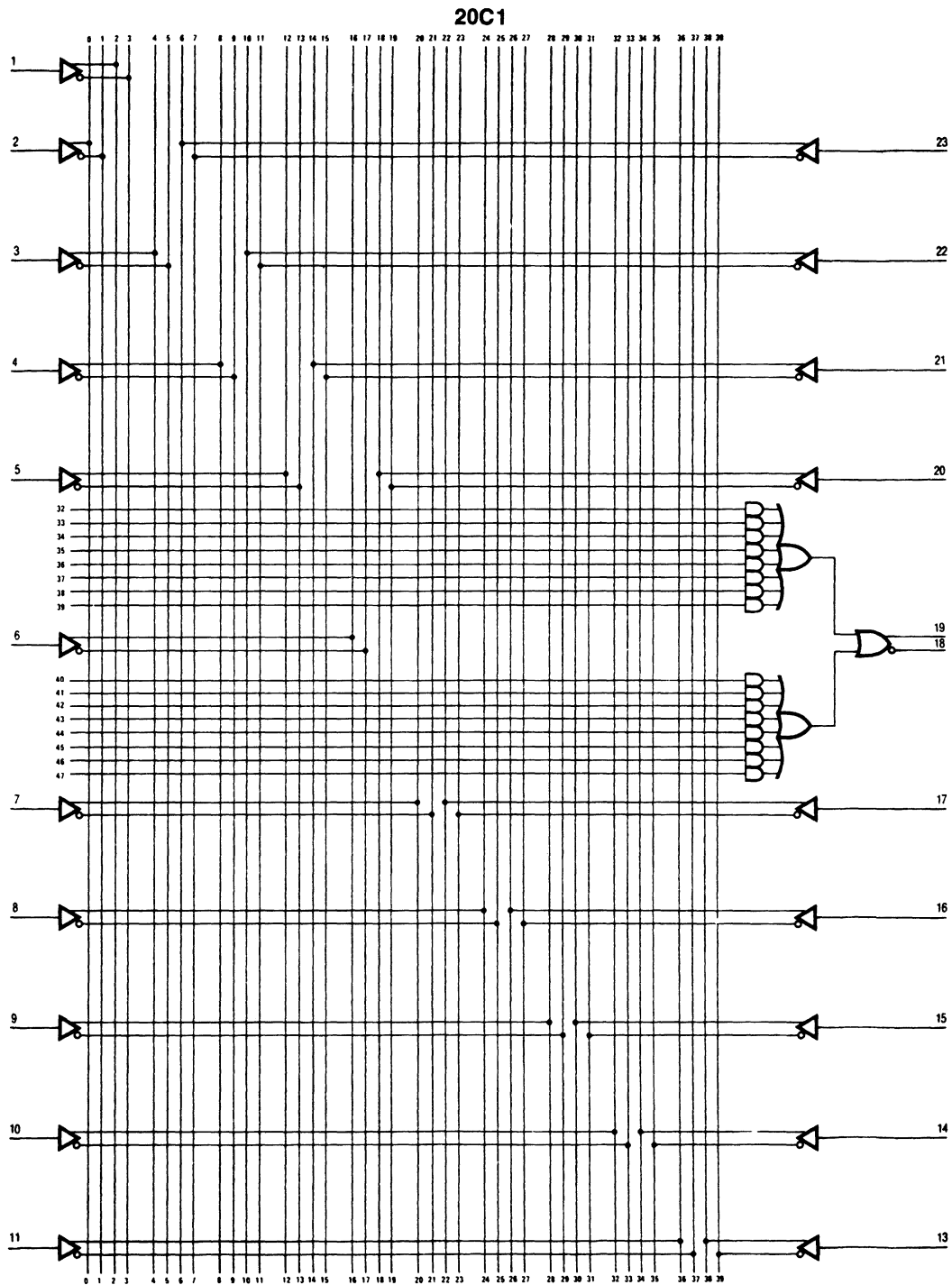
**20L2**



**2**

L000550M

**Small 24 Series  
20C1 Logic Diagram**



LD00560M

**Small 24A Decoder Series**  
**6L16A, 8L14A**

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**Small 24A Decoder Series**

|          | INPUTS | OUTPUTS | $t_{PD}$<br>(ns) | $I_{CC}$<br>(mA) |
|----------|--------|---------|------------------|------------------|
| PAL6L16A | 6      | 16      | 25               | 90               |
| PAL8L14A | 8      | 14      | 25               | 90               |

**Description**

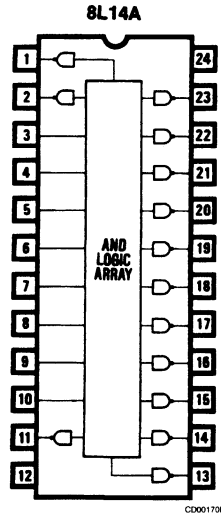
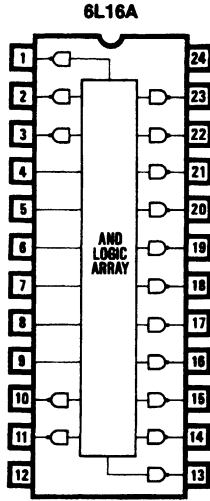
The Small 24A Decoder Series provides a wide number of outputs, especially useful in decoding applications. These two parts implement simple combinatorial logic.

**Performance**

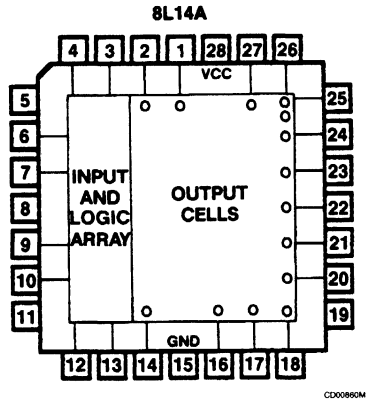
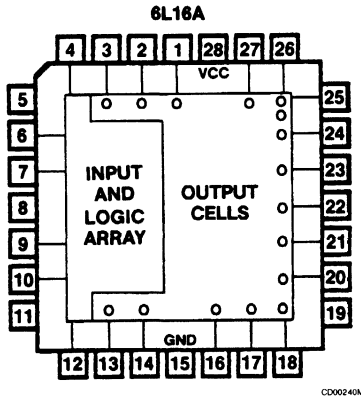
These devices offer 25ns speed at only 90mA supply current.

**Small 24A Decoder Series  
6L16A, 8L14A**

**DIP Pinouts**



**PLCC Pinouts**





**Small 24A Decoder Series**  
**6L16A, 8L14A**

**Operating Conditions**

| SYMBOL          | PARAMETER                      | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|-----------------|--------------------------------|-------------------------|-----|------|------|
|                 |                                | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                 | 4.75                    | 5   | 5.25 | V    |
| T <sub>A</sub>  | Operating free-air temperature | 0                       | 25  | 75   | °C   |

**Electrical Characteristics** Over Operating Conditions

| SYMBOL                       | PARAMETER                    | TEST CONDITION                                    | MIN | TYP   | MAX   | UNIT |
|------------------------------|------------------------------|---|-----|-------|-------|------|
| V <sub>IL</sub> <sup>2</sup> | Low-level input voltage      |   |     |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup> | High-level input voltage     |   | 2   |       |       | V    |
| V <sub>IC</sub>              | Input clamp voltage          | V <sub>CC</sub> = MIN<br>I <sub>I</sub> = -18mA   |     | -0.8  | -1.5  | V    |
| I <sub>IL</sub>              | Low-level input current      | V <sub>CC</sub> = MAX<br>V <sub>I</sub> = 0.4V    |     | -0.02 | -0.25 | mA   |
| I <sub>IH</sub>              | High-level input current     | V <sub>CC</sub> = MAX<br>V <sub>I</sub> = 2.4V    |     |       | 25    | μA   |
| I <sub>I</sub>               | Maximum input current        | V <sub>CC</sub> = MAX<br>V <sub>I</sub> = 5.5V    |     |       | 1     | mA   |
| V <sub>OL</sub>              | Low-level output voltage     | V <sub>CC</sub> = MIN<br>I <sub>OL</sub> = 8mA    |     | 0.3   | 0.5   | V    |
| V <sub>OH</sub>              | High-level output voltage    | V <sub>CC</sub> = MIN<br>I <sub>OH</sub> = -3.2mA | 2.4 | 2.8   |       | V    |
| I <sub>OS</sub> <sup>3</sup> | Output short-circuit current | V <sub>CC</sub> = 5V<br>V <sub>O</sub> = 0V       | -30 | -70   | -130  | mA   |
| I <sub>CC</sub>              | Supply current               | V <sub>CC</sub> = MAX                             |     | 60    | 90    | mA   |

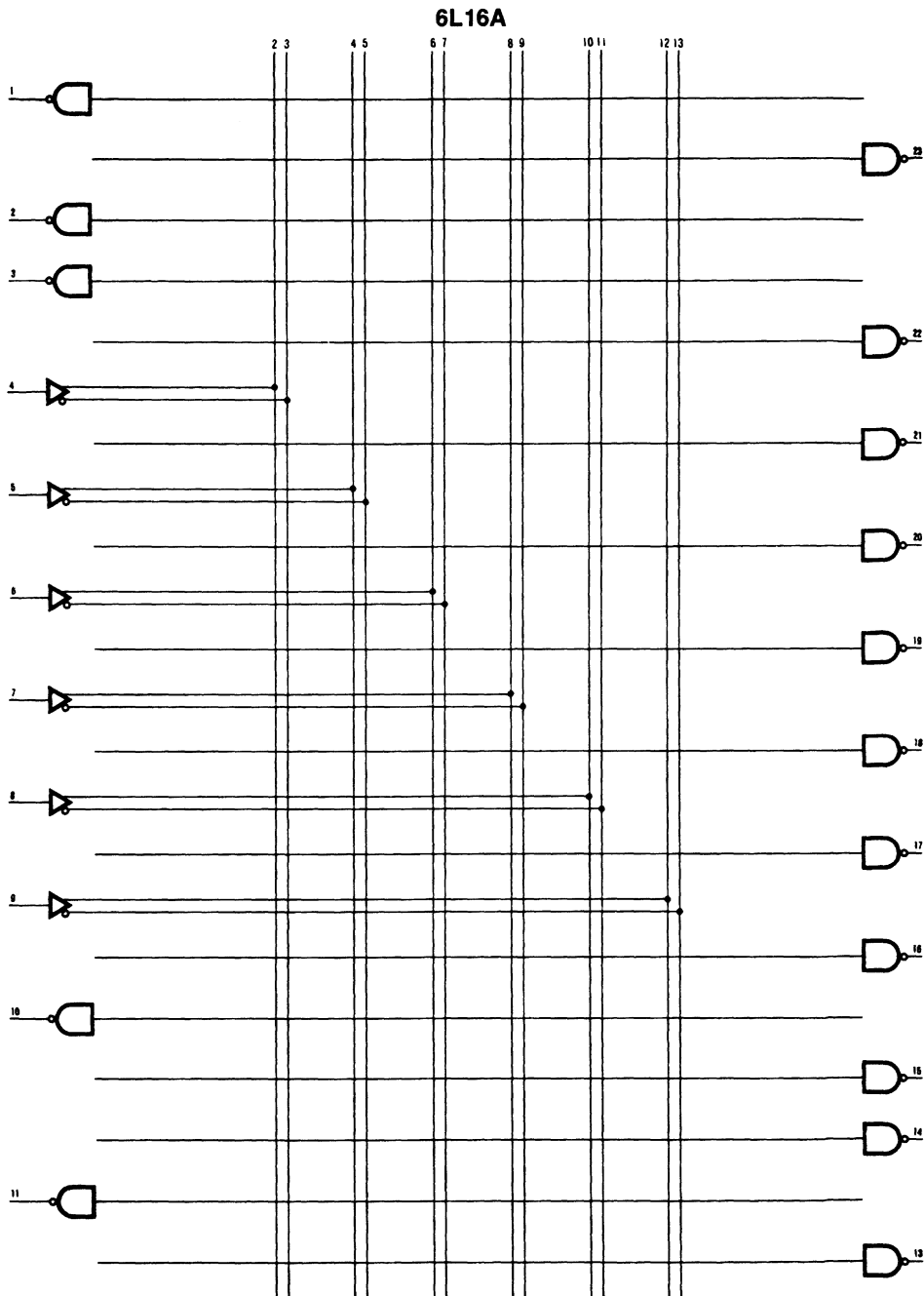
**2**

**Switching Characteristics** Over Operating Conditions

| SYMBOL          | PARAMETER                         | TEST CONDITIONS                                 | COMMERCIAL |     |     | UNIT |
|-----------------|-----------------------------------|---|------------|-----|-----|------|
|                 |                                   |   | MIN        | TYP | MAX |      |
| t <sub>PD</sub> | Input to output propagation delay | R <sub>1</sub> = 560Ω<br>R <sub>2</sub> = 1.1KΩ |            | 15  | 25  | ns   |

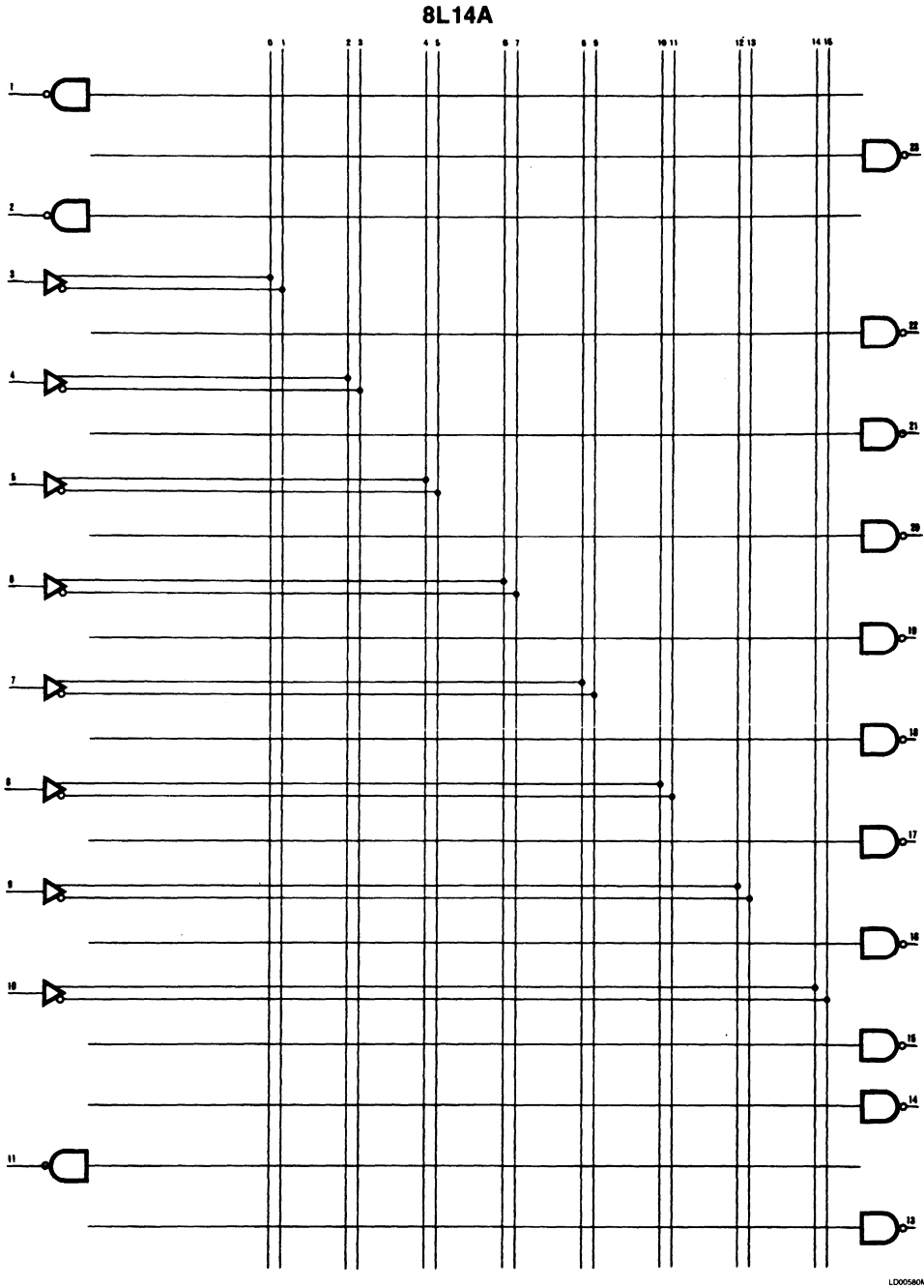
1. The PAL24A Decoder Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
2. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
3. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Small 24A Decoder Series  
6L16A Logic Diagram**



L009704

**Small 24A Decoder Series  
8L14A Logic Diagram**



**2**

**Medium 24 Series**  
**20L8, 20R8, 20R6, 20R4**

**Medium 24 Series**

|         | DEDICATED INPUTS | OUTPUTS       |            |
|---------|------------------|---------------|------------|
|         |                  | COMBINATORIAL | REGISTERED |
| PAL20L8 | 12               | 8 (6 I/O)     | 0          |
| PAL20R8 | 10               | 0             | 8          |
| PAL20R6 | 10               | 2 I/O         | 6          |
| PAL20R4 | 10               | 4 I/O         | 4          |

**Description**

The Medium 24 Series consists of four devices, each with twenty array inputs and eight outputs. The devices have either 0, 4, 6, or 8 registered outputs, with the remaining being combinatorial. Each of the registered outputs feeds back into the array, for sequential designs. The combinatorial outputs also feed back into the array, except for two of the outputs on the 20L8. This feedback allows the output to also operate as an input if the output is disabled.

**Enable**

The combinatorial outputs are enabled by a product term. The registered outputs are enabled by a common enable pin.

**Polarity**

All outputs are active low.

**Performance**

Several speed/power versions are available:

| Suffix | $t_{PD}$<br>(ns) | $I_{CC}$<br>(mA) |
|--------|------------------|------------------|
| A      | 25               | 210              |
| A-2    | 35               | 105              |
| B      | 15               | 210              |
| B-2 *  | 25               | 105              |

\* contact Monolithic Memories for datasheet

**Preload and Power-up Reset**

The B-2 Series offers register preload for device testability. The registers can be preloaded from the outputs by using supervoltages (see waveforms at end of section) in order to simplify functional testing. The B-2 Series also offers Power-up Reset, whereby the registers power up to a logic LOW, setting the active-low outputs to a logic HIGH.

**Medium 24 Series**  
**20L8, 20R8, 20R6, 20R4**

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## CMOS ZPAL™ 24 Series

### Features/Benefits

- CMOS technology provides zero standby power
- Lowest power 24-pin PAL® device family; consumes only 3mA/MHz
- 35ns maximum propagation delay
- Programmable replacement for CMOS/TTL logic
- Reduces chip count by greater than six to one
- Instant prototyping and easier board layout
- HC/HCT compatible for use in CMOS or TTL systems
- Offered over both the Commercial and Industrial temperature ranges
- Low-cost, one-time programmable SKINNYDIP® and PLCC packages save board space

### Description

The CMOS ZPAL24 Series offers the first family of PAL devices with true CMOS power consumption. Under standby conditions (inputs and clock not changing), the devices consume a maximum current of 100µA, less than 1% that of the quarter-power PAL devices. This low power consumption allows the devices to be powered by a battery almost indefinitely.

While operating, the devices consume additional power only when the inputs or clock change. Power consumption is directly proportional to the frequency of changes to the inputs.  $I_{CC}$  is therefore specified as 3mA per 1MHz of operating frequency, starting from 5mA at 1MHz. Thus, the maximum current at 8MHz would be 5mA + 7x3mA, or 26mA.

The devices have HC and HCT compatible inputs and outputs for use in CMOS and TTL systems. This feature allows the ZPAL circuits to be used for direct replacement of discrete CMOS as well as TTL logic.

### Areas of Application

- Portable computers
- Battery-operated instrumentation
- Low-power industrial equipment
- Standard CMOS/TTL logic replacement

### Features

The CMOS ZPAL24 Series includes the four standard 24-pin PAL device architectures. All four devices have twenty array inputs and eight outputs, with varying numbers of registers: zero (20L8), four (20R4), six (20R6), and eight (20R8). The combinatorial outputs on the registered devices, and six of the outputs on the 20L8, are I/O pins that can be individually programmed as inputs or outputs. Each output register, a D-type flip-flop, also feeds back into the array, for implementation of synchronous state machine designs. Registered outputs are enabled by an external input, while the combinatorial outputs use a product term to control the enable function.

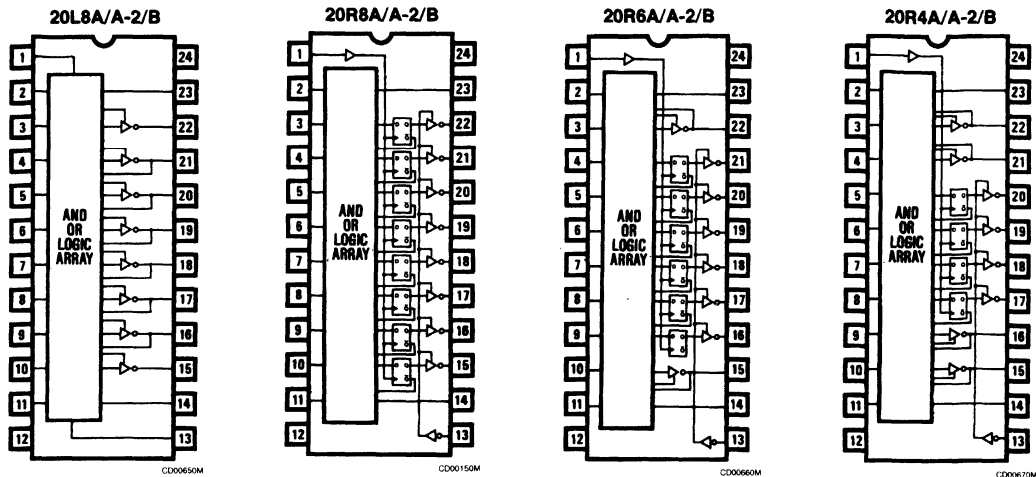
The basic PAL device architecture is a programmable AND array feeding a fixed OR array. The programmable AND array consists of a set of cells similar to those used in EPROMs. Erasable by UV light, the cells can be programmed and erased in the factory to ensure 100% programming and functional yields.

Windowed packages will be made available in the future, allowing erasure in the field. Windowed packages allow easy prototype testing and reconfiguration.

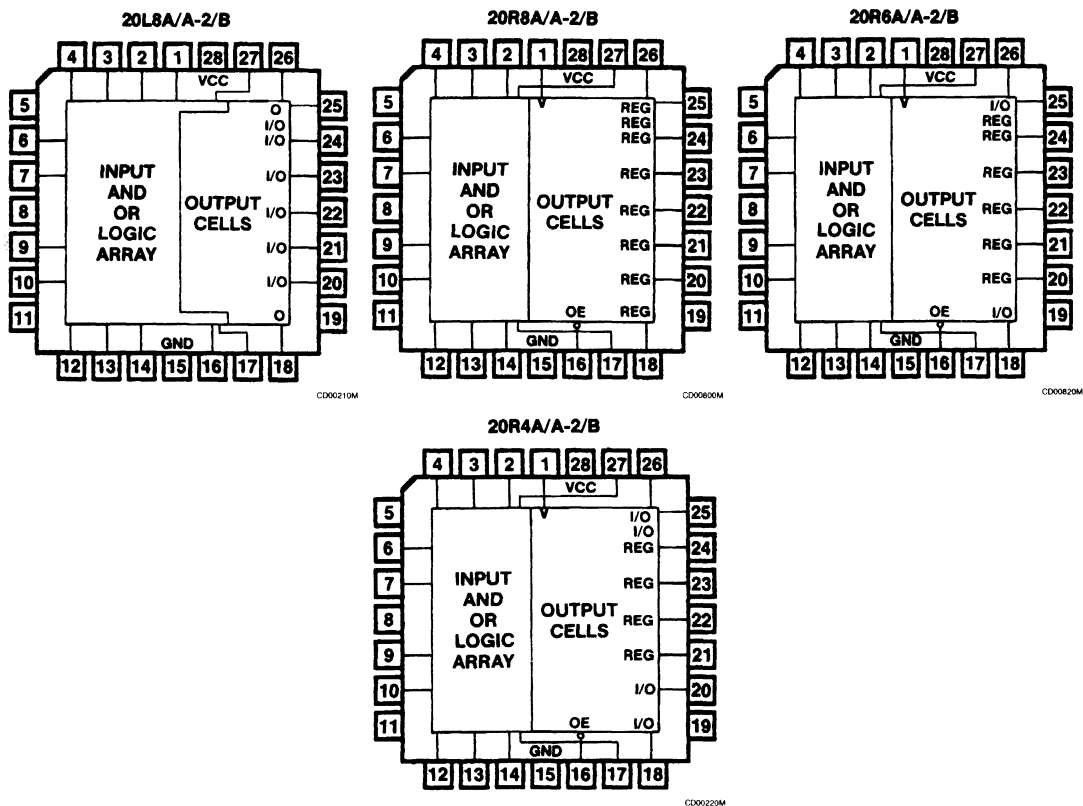
2

**Medium 24 Series**  
**20L8, 20R8, 20R6, 20R4**

**DIP Pinouts**



**PLCC Pinouts**



**Medium 24A Series**  
**20L8A, 20R8A, 20R6A, 20R4A**

**Operating Conditions**

| SYMBOL   | PARAMETER                                   |                   | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|----------|---|-------------------|----------|-----|-----|------------|-----|------|------|
|          |   |                   | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                              |                   | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| $t_w$    | Width of clock                              | Low               | 20       | 7   |     | 15         | 7   |      | ns   |
|          |   | High              | 20       | 7   |     | 15         | 7   |      |      |
| $t_{su}$ | Set up time from input or feedback to clock | 20R8A 20R6A 20R4A | 30       | 15  |     | 25         | 15  |      | ns   |
| $t_h$    | Hold time                                   |                   | 0        | -10 |     | 0          | -10 |      | ns   |
| $T_A$    | Operating free-air temperature              |                   | -55      |     |     | 0          |     | 75   | °C   |
| $T_C$    | Operating case temperature                  |                   |          |     | 125 |            |     |      | °C   |

2

**Electrical Characteristics** Over Operating Conditions

| SYMBOL      | PARAMETER                    | TEST CONDITIONS       |                              | MIN | TYP   | MAX   | UNIT          |
|-------------|------------------------------|-----------------------|------------------------------|-----|-------|-------|---------------|
| $V_{IL}^1$  | Low-level input voltage      |                       |                              |     |       | 0.8   | V             |
| $V_{IH}^1$  | High-level input voltage     |                       |                              | 2   |       |       | V             |
| $V_{IC}$    | Input clamp voltage          | $V_{CC} = \text{MIN}$ | $I_I = -18\text{mA}$         |     | -0.8  | -1.5  | V             |
| $I_{IL}^2$  | Low-level input current      | $V_{CC} = \text{MAX}$ | $V_I = 0.4\text{V}$          |     | -0.02 | -0.25 | mA            |
| $I_{IH}^2$  | High-level input current     | $V_{CC} = \text{MAX}$ | $V_I = 2.4\text{V}$          |     |       | 25    | $\mu\text{A}$ |
| $I_I$       | Maximum input current        | $V_{CC} = \text{MAX}$ | $V_I = 5.5\text{V}$          |     |       | 1     | mA            |
| $V_{OL}$    | Low-level output voltage     | $V_{CC} = \text{MIN}$ | Mil $I_{OL} = 12\text{mA}$   |     | 0.3   | 0.5   | V             |
|             |                              |                       | Com $I_{OL} = 24\text{mA}$   |     |       |       |               |
| $V_{OH}$    | High-level output voltage    | $V_{CC} = \text{MIN}$ | Mil $I_{OH} = -2\text{mA}$   | 2.4 | 2.8   |       | V             |
|             |                              |                       | Com $I_{OH} = -3.2\text{mA}$ |     |       |       |               |
| $I_{OZL}^2$ | Off-state output current     | $V_{CC} = \text{MAX}$ | $V_O = 0.4\text{V}$          |     |       | -100  | $\mu\text{A}$ |
| $I_{OZH}^2$ |                              |                       | $V_O = 2.4\text{V}$          |     |       | 100   | $\mu\text{A}$ |
| $I_{OS}^3$  | Output short-circuit current | $V_{CC} = 5\text{V}$  | $V_O = 0\text{V}$            | -30 | -90   | -130  | mA            |
| $I_{CC}$    | Supply current               | $V_{CC} = \text{MAX}$ |                              |     | 160   | 210   | mA            |

1. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.

2. I/O pin leakage is the worst case of  $I_{IL}$  and  $I_{OZL}$  (or  $I_{IH}$  and  $I_{OZH}$ ).

3. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 24A Series**  
**20L8A, 20R8A, 20R6A, 20R4A**

**Switching Characteristics** Over Operating Conditions

| SYMBOL    | PARAMETER                             |                      | TEST CONDITIONS                        | MILITARY |     |     | COMMERCIAL |      |     | UNIT |
|-----------|---------------------------------------|----------------------|--|----------|-----|-----|------------|------|-----|------|
|           |                                       |                      |  | MIN      | TYP | MAX | MIN        | TYP  | MAX |      |
| $t_{PD}$  | Input or feedback to output           | 20R6A 20R4A<br>20L8A | $R_1 = 200\Omega$<br>$R_2 = 390\Omega$ |          | 15  | 30  |            | 15   | 25  | ns   |
| $t_{CLK}$ | Clock to output or feedback           |                      |  |          | 10  | 20  |            | 10   | 15  | ns   |
| $t_{PZX}$ | Pin 13 to output enable except 20L8A  |                      |  |          | 10  | 25  |            | 10   | 20  | ns   |
| $t_{PXZ}$ | Pin 13 to output disable except 20L8A |                      |  |          | 11  | 25  |            | 11   | 20  | ns   |
| $t_{PZX}$ | Input to output enable                | 20R6A 20R4A<br>20L8A |  |          | 10  | 30  |            | 10   | 25  | ns   |
| $t_{PXZ}$ | Input to output disable               | 20R6A 20R4A<br>20L8A |  |          | 13  | 30  |            | 13   | 25  | ns   |
| $f_{MAX}$ | Maximum frequency                     | 20R8A 20R6A<br>20R4A |  |          | 20  | 40  |            | 28.5 | 40  | MHz  |



**Medium 24A-2 Series**  
**20L8A-2, 20R8A-2, 20R6A-2, 20R4A-2**

**Operating Conditions**

| SYMBOL          | PARAMETER                                  | COMMERCIAL <sup>1</sup>   |     |      | UNIT |
|-----------------|--|---------------------------|-----|------|------|
|                 |  | MIN                       | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                             | 4.75                      | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | Low                       | 25  | 10   | ns   |
|                 |  | High                      | 25  | 10   |      |
| t <sub>su</sub> | Setup time from input or feedback to clock | 20R8A-2, 20R6A-2, 20R4A-2 |     |      | ns   |
| t <sub>h</sub>  | Hold time                                  | 0                         | -15 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature             | 0                         | 25  | 75   | °C   |

**Electrical Characteristics** Over Operating Conditions

| SYMBOL                        | PARAMETER                    | TEST CONDITION                                 | MIN | TYP   | MAX                   | UNIT |
|-------------------------------|------------------------------|--|-----|-------|-----------------------|------|
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |  |     |       | 0.8                   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |  | 2   |       |                       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN I <sub>I</sub> = -18mA   |     | -0.8  | -1.5                  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX V <sub>I</sub> = 0.4V    |     | -0.02 | -0.25                 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX V <sub>I</sub> = 2.4V    |     |       | 25                    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX V <sub>I</sub> = 5.5V    |     |       | 1                     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN I <sub>OL</sub> = 24mA   |     | 0.3   | 0.5                   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN I <sub>OH</sub> = -3.2mA | 2.4 | 2.8   |                       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX                          |     |       | -100                  | μA   |
| I <sub>OZH</sub> <sup>3</sup> |                              |  |     |       | V <sub>O</sub> = 2.4V | 100  |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V V <sub>O</sub> = 0V       | -30 | -70   | -130                  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX                          |     | 80    | 105                   | mA   |

**Switching Characteristics** Over Operating Conditions

| SYMBOL              | PARAMETER  | TEST CONDITIONS  | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|---------------------|--|--|----------|-----|-----|------------|-----|-----|------|
|                     |  |  | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| t <sub>PD</sub>     | Input or feedback to output<br>20L8A-2 20R6A-2 20R4A-2 | Commercial<br>R <sub>1</sub> = 200Ω<br>R <sub>2</sub> = 390Ω |          | 25  | 50  |            | 25  | 35  | ns   |
| t <sub>CLK</sub>    | Clock to output or feedback<br>except 20L8A-2          |  |          | 15  | 25  |            | 15  | 25  | ns   |
| t <sub>PXZ/ZX</sub> | Pin 13 to output disable/enable<br>except 20L8A-2      |  |          | 15  | 25  |            | 15  | 25  | ns   |
| t <sub>PZX</sub>    | Input to output enable 20L8A-2<br>20R6A-2 20R4A-2      |  |          | 25  | 45  |            | 25  | 35  | ns   |
| t <sub>PXZ</sub>    | Input to output disable 20L8A-2<br>20R6A-2 20R4A-2     |  |          | 25  | 45  |            | 25  | 35  | ns   |
| f <sub>MAX</sub>    | Maximum frequency 20R8A-2<br>20R6A-2 20R4A-2           |  |          | 14  | 19  |            | 16  | 19  | MHz  |

- The PAL24A-2 Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**2**

**Medium 24B Series**  
**20L8B, 20R8B, 20R6B, 20R4B**

**Operating Conditions**

| SYMBOL          | PARAMETER                                  |      | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|-----------------|--|------|-------------------------|-----|------|------|
|                 |  |      | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                             |      | 4.75                    | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | Low  | 10                      | 6   |      | ns   |
|                 |  | High |                         |     |      |      |
| t <sub>su</sub> | Setup time from input or feedback to clock |      | 15                      | 10  |      | ns   |
| t <sub>h</sub>  | Hold time                                  |      | 0                       | -10 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature             |      | 0                       | 25  | 75   | °C   |

**Electrical Characteristics** Over Operating Conditions

| SYMBOL                        | PARAMETER                    | TEST CONDITION                                 | COMMERCIAL |       |                       | UNIT |
|-------------------------------|------------------------------|--|------------|-------|-----------------------|------|
|                               |                              |  | MIN        | TYP   | MAX                   |      |
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |  |            |       | 0.8                   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |  | 2          |       |                       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN I <sub>I</sub> = -18mA   |            | -0.8  | -1.5                  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX V <sub>I</sub> = 0.4V    |            | -0.02 | -0.25                 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX V <sub>I</sub> = 2.4V    |            |       | 25                    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX V <sub>I</sub> = 5.5V    |            |       | 1                     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN I <sub>OL</sub> = 24mA   |            | 0.3   | 0.5                   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN I <sub>OH</sub> = -3.2mA | 2.4        | 2.8   |                       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX                          |            |       | -100                  | μA   |
| I <sub>OZH</sub> <sup>3</sup> |                              |  |            |       | V <sub>O</sub> = 2.4V | 100  |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V V <sub>O</sub> = 0V       | -30        | -70   | -130                  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX                          |            | 140   | 210                   | mA   |

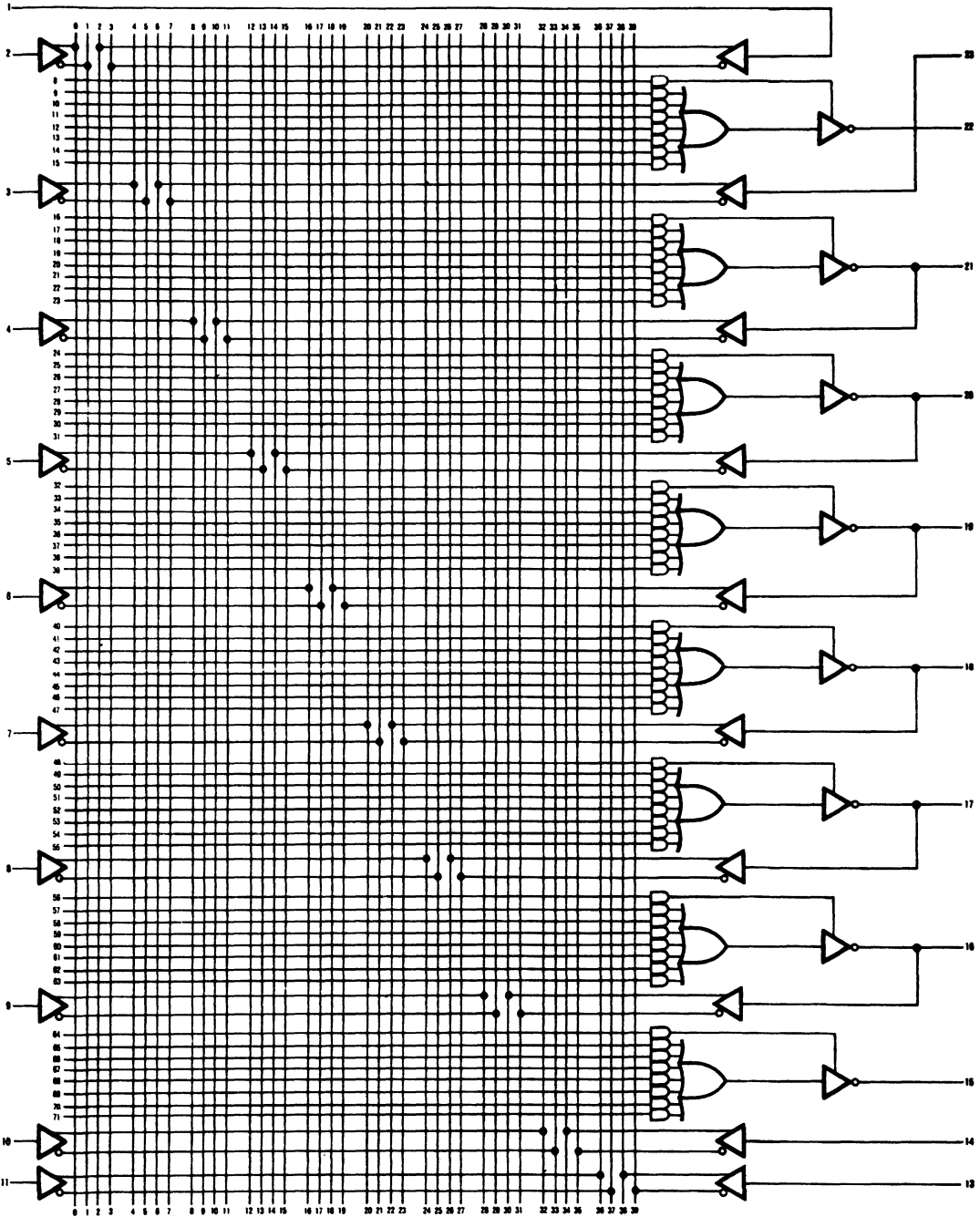
**Switching Characteristics** Over Operating Conditions

| SYMBOL           | PARAMETER                                       | TEST CONDITIONS  | COMMERCIAL |     |     | UNIT |
|------------------|---|--|------------|-----|-----|------|
|                  |   |  | MIN        | TYP | MAX |      |
| t <sub>PD</sub>  | Input or feedback to output 20L8B, 20R6B, 20R4B | Commercial<br>R <sub>1</sub> = 200Ω<br>R <sub>2</sub> = 390Ω |            | 12  | 15  | ns   |
| t <sub>CLK</sub> | Clock to output or feedback except 20L8B        |  |            | 8   | 12  | ns   |
| t <sub>PZX</sub> | Pin 13 to output enable except 20L8B            |  |            | 10  | 15  | ns   |
| t <sub>PXZ</sub> | Pin 13 to output disable except 20L8B           |  |            | 8   | 12  | ns   |
| t <sub>PZX</sub> | Input to output enable<br>20R6B, 20R4B, 20L8B   |  |            | 12  | 18  | ns   |
| t <sub>PXZ</sub> | Input to output disable<br>20R6B, 20R4B, 20L8B  |  |            | 12  | 15  | ns   |
| f <sub>MAX</sub> | Maximum frequency<br>20R8B, 20R6B, 20R4B        | Feedback   | 37         | 40  |     | MHz  |
|                  |   | No feedback  | 45         | 50  |     |      |

- The PAL24B Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 24 Series  
20L8 Logic Diagram**

20L8

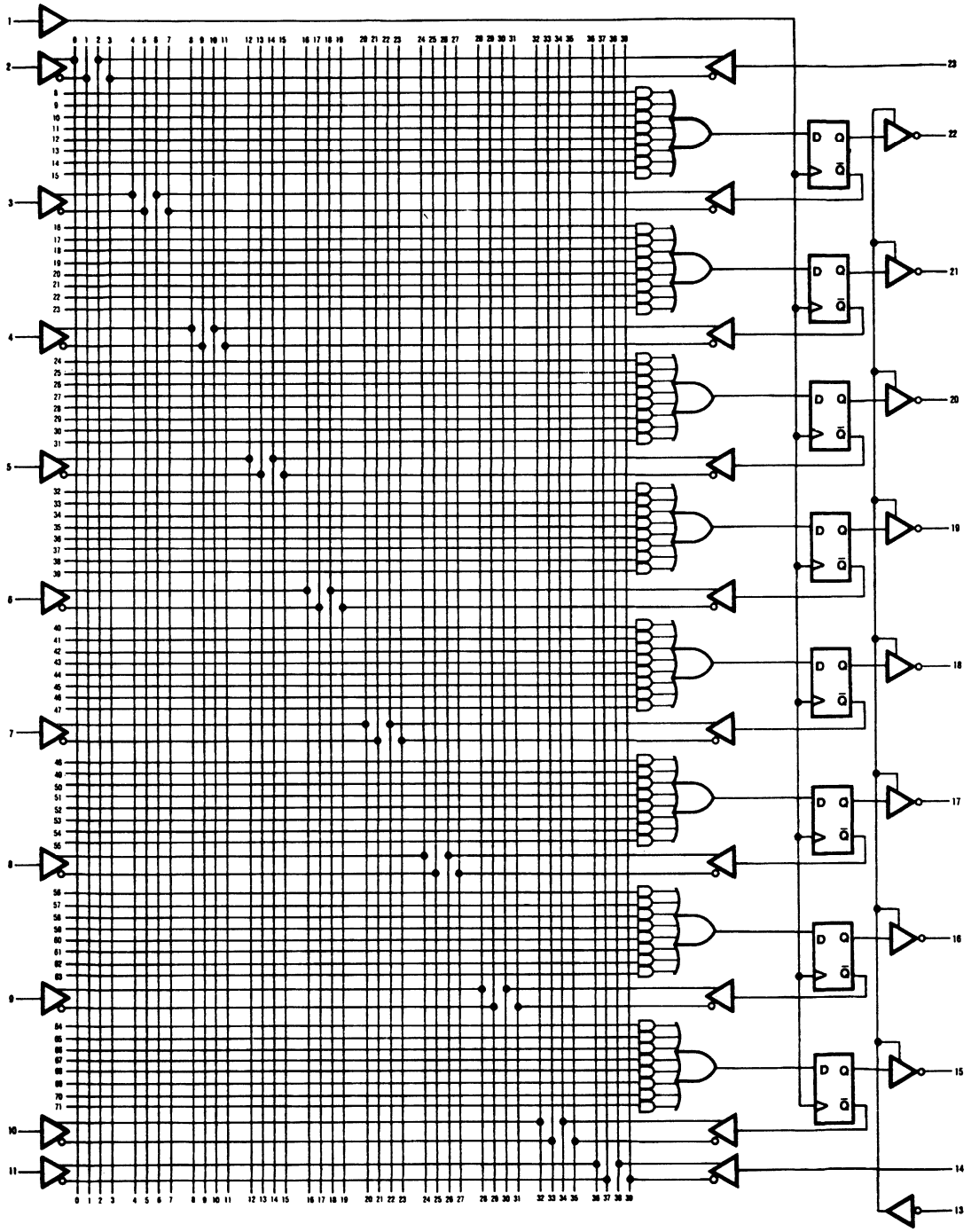


**2**

L000590M

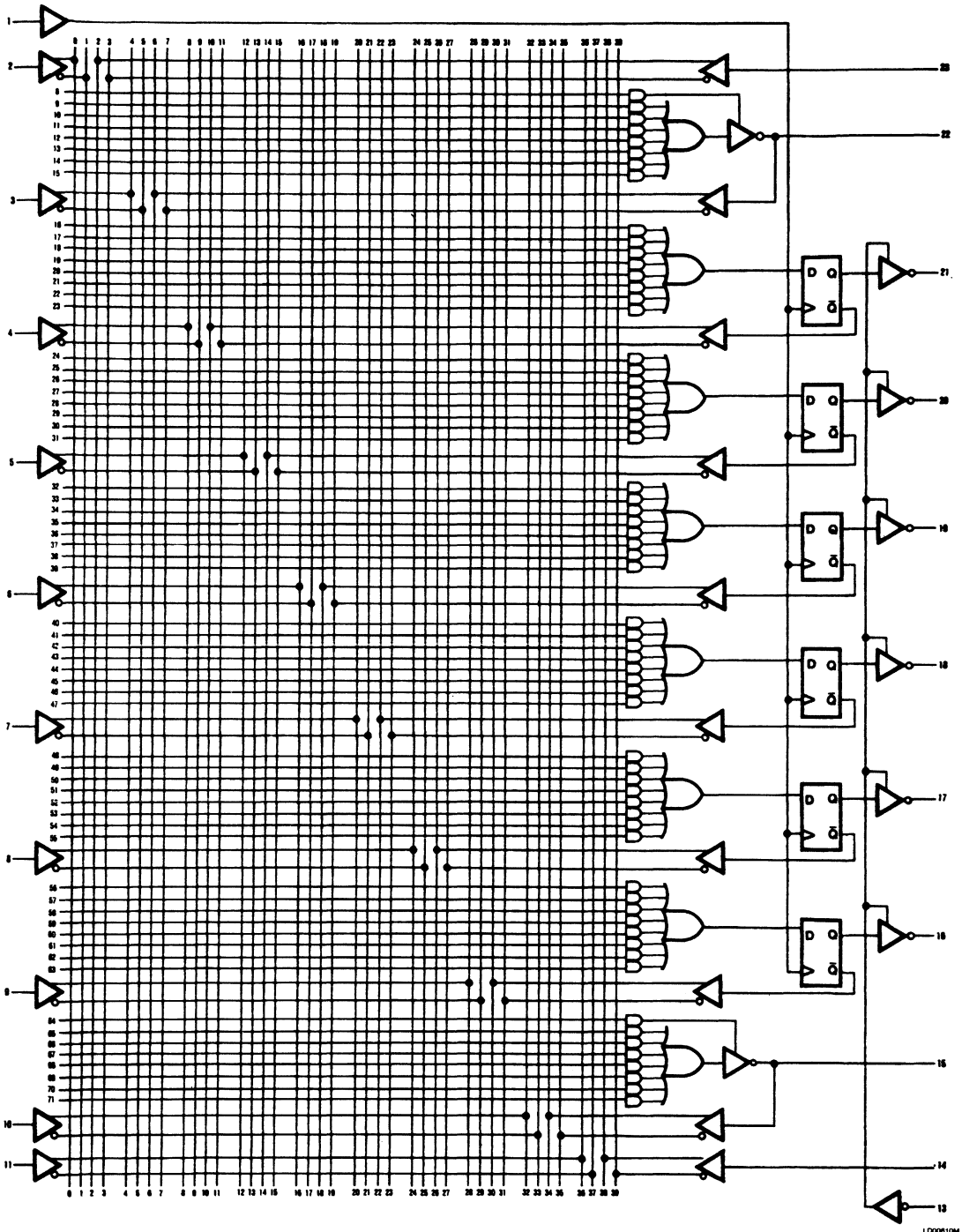
**Medium 24 Series  
20R8 Logic Diagram**

**20R8**



**Medium 24 Series  
20R6 Logic Diagram**

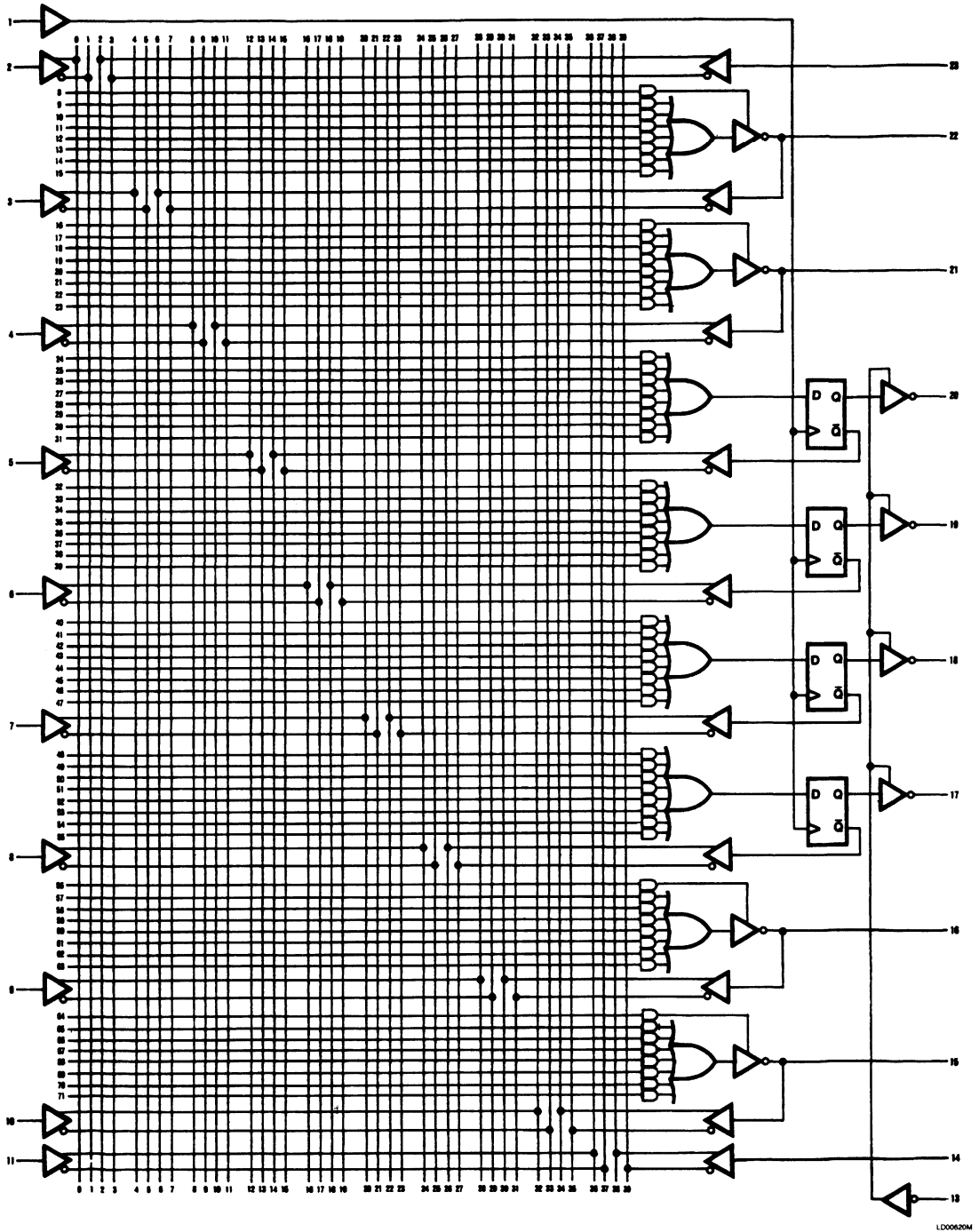
20R6



**2**

Medium 24 Series  
2OR4 Logic Diagram

2OR4



L000820M

**Medium 24X Series**  
**20L10, 20X10, 20X8, 20X4**

**Medium 24X Series**

|          | ARRAY INPUTS | OUTPUTS       |            | STANDARD                |                         | HIGH SPEED              |                         |
|----------|--------------|---------------|------------|-------------------------|-------------------------|-------------------------|-------------------------|
|          |              | COMBINATORIAL | REGISTERED | t <sub>PD</sub><br>(ns) | I <sub>CC</sub><br>(mA) | t <sub>PD</sub><br>(ns) | I <sub>CC</sub><br>(mA) |
| PAL20L10 | 20           | 10            | 0          | 50                      | 165                     | 30                      | 165                     |
| PAL20X10 | 20           | 0             | 10         | 50                      | 180                     | 30                      | 180                     |
| PAL20X8  | 20           | 2             | 8          | 50                      | 180                     | 30                      | 180                     |
| PAL20X4  | 20           | 6             | 4          | 50                      | 180                     | 30                      | 180                     |

**Description**

The PAL24X Series offers Exclusive-OR (XOR) gates preceding each register. The XOR gate has as its inputs two sums, each of two product terms. The XOR gate is very efficient for counting applications.

**Enable**

The combinatorial outputs are enabled by a product term. The registered outputs are enabled by a common enable pin.

**Polarity**

All outputs are active low.

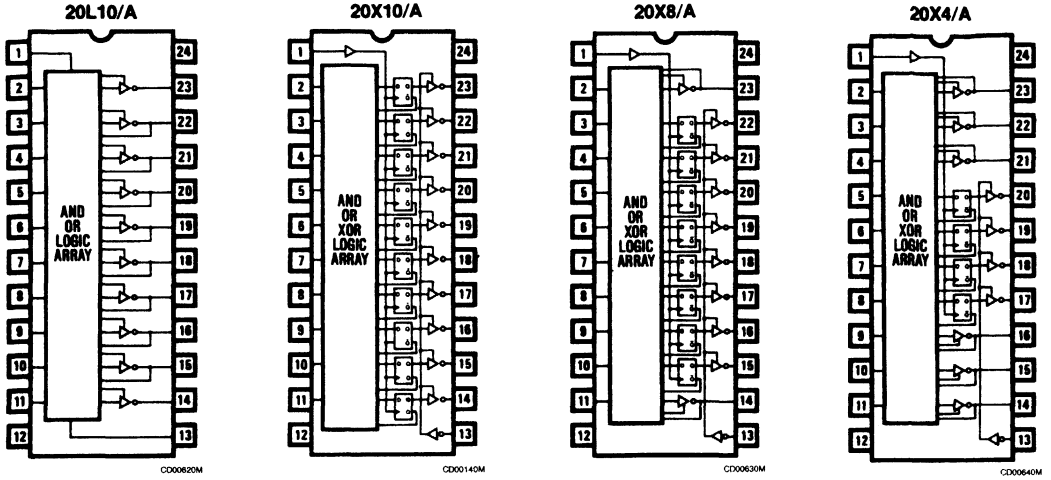
**Preload and Power-up Reset**

The 24XA Series offers register preload for device testability. The registers can be preloaded from the outputs by using supervoltages (see waveforms at end of section) in order to simplify functional testing. The 24XA Series also offers Power-up Reset, whereby the registers power up to a logic LOW, setting the active-low outputs to a logic HIGH.

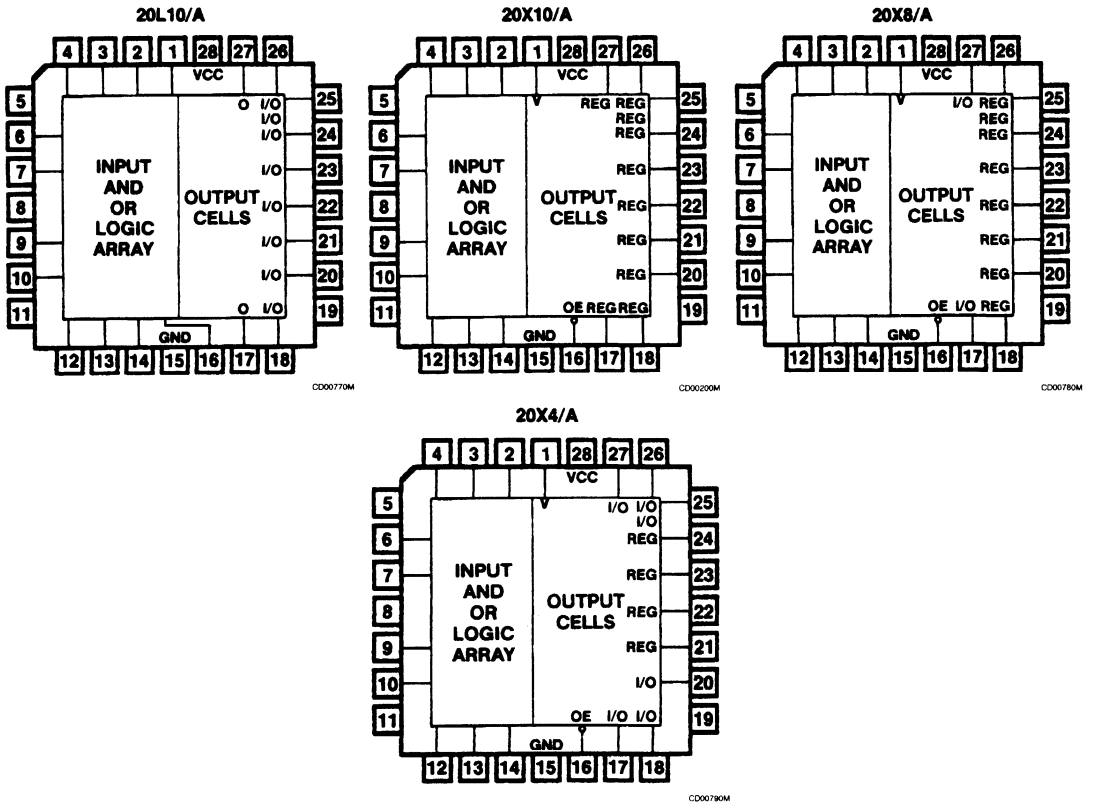
**2**

**Medium 24X Series**  
**20L10, 20X10, 20X8, 20X4**

**DIP Pinouts**



**PLCC Pinouts**





**Medium 24X Series**  
**20L10, 20X10, 20X8, 20X4**

**Operating Conditions**

| SYMBOL          | PARAMETER                                  |                   | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|-----------------|--|-------------------|----------|-----|-----|------------|-----|------|------|
|                 |  |                   | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                             |                   | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | Low               | 40       | 20  |     | 35         | 20  |      | ns   |
|                 |  | High              | 30       | 10  |     | 25         | 10  |      |      |
| t <sub>su</sub> | Setup time from input or feedback to clock | 20X10, 20X8, 20X4 | 60       | 38  |     | 50         | 38  |      | ns   |
| t <sub>h</sub>  | Hold time                                  |                   | 0        | -15 |     | 0          | -15 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature             |                   | -55      |     |     | 0          |     | 75   | °C   |
| T <sub>C</sub>  | Operating case temperature                 |                   |          |     | 125 |            |     |      | °C   |

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**Electrical Characteristics (Over Operating Conditions)**

| SYMBOL                        | PARAMETER                    | TEST CONDITIONS       |                        |                          | MIN  | TYP   | MAX   | UNIT |    |
|-------------------------------|------------------------------|-----------------------|------------------------|--------------------------|------|-------|-------|------|----|
| V <sub>IL</sub> <sup>1</sup>  | Low-level input voltage      |                       |                        |                          |      |       | 0.8   | V    |    |
| V <sub>IH</sub> <sup>1</sup>  | High-level input voltage     |                       |                        |                          | 2    |       |       | V    |    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA |                          |      | -0.8  | -1.5  | V    |    |
| I <sub>IL</sub> <sup>2</sup>  | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V  |                          |      | -0.02 | -0.25 | mA   |    |
| I <sub>IH</sub> <sup>2</sup>  | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V  |                          |      |       | 25    | μA   |    |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V  |                          |      |       | 1     | mA   |    |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN | Mil                    | I <sub>OL</sub> = 12mA   |      | 0.3   | 0.5   | V    |    |
|                               |                              |                       | Com                    | I <sub>OL</sub> = 24mA   |      |       |       |      |    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN | Mil                    | I <sub>OH</sub> = -2mA   | 2.4  | 2.8   |       | V    |    |
|                               |                              |                       | Com                    | I <sub>OH</sub> = -3.2mA |      |       |       |      |    |
| I <sub>OZL</sub> <sup>2</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0.4V  |                          |      |       | -100  | μA   |    |
| I <sub>OZH</sub> <sup>2</sup> |                              |                       | V <sub>O</sub> = 2.4V  |                          |      |       |       |      |    |
| I <sub>OS</sub> <sup>3</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V    |                          | -30  | -70   | -130  | mA   |    |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX | 20X10                  | 20X8                     | 20X4 |       | 120   | 180  | mA |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX | 20L10                  |                          |      |       | 90    | 165  | mA |

1. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
3. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Medium 24X Series**  
**20L10, 20X10, 20X8, 20X4**

**Switching Characteristics** (Over Operating Conditions)

| SYMBOL              | PARAMETER  | TEST CONDITIONS                                    | MILITARY |      |     | COMMERCIAL |      |     | UNIT |
|---------------------|--|--|----------|------|-----|------------|------|-----|------|
|                     |  |  | MIN      | TYP  | MAX | MIN        | TYP  | MAX |      |
| t <sub>PD</sub>     | Input or feedback to output<br>20X8, 20X4, 20L10 | R <sub>1</sub> = 200Ω<br><br>R <sub>2</sub> = 390Ω |          | 35   | 60  |            | 35   | 50  | ns   |
| t <sub>CLK</sub>    | Clock to output or feedback<br>except 20L10      |  |          | 20   | 35  |            | 20   | 30  | ns   |
| t <sub>PXZ/ZX</sub> | Pin 13 to output disable/enable<br>except 20L10  |  |          | 20   | 45  |            | 20   | 35  | ns   |
| t <sub>PZX</sub>    | Input to output enable except<br>20X10           |  |          | 35   | 55  |            | 35   | 45  | ns   |
| t <sub>PXZ</sub>    | Input to output disable except<br>20X10          |  |          | 35   | 55  |            | 35   | 45  | ns   |
| f <sub>MAX</sub>    | Maximum frequency<br>20X10, 20X8, 20X4           |  |          | 10.5 | 16  |            | 12.5 | 16  | MHz  |

**Medium 24XA Series**  
**20L10A, 20X10A, 20X8A, 20X4A**

**Operating Conditions**

| SYMBOL          | PARAMETER                                  |                      | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|-----------------|--|----------------------|-------------------------|-----|------|------|
|                 |  |                      | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                             |                      | 4.75                    | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | Low                  | 25                      | 15  |      | ns   |
|                 |  | High                 | 15                      | 7   |      |      |
| t <sub>su</sub> | Setup time from input or feedback to clock | 20X10A, 20X8A, 20X4A | 30                      | 20  |      | ns   |
| t <sub>h</sub>  | Hold time                                  |                      | 0                       | -15 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature             |                      | 0                       | 25  | 75   | °C   |

**Electrical Characteristics (Over Operating Conditions)**

| SYMBOL                        | PARAMETER                    | TEST CONDITION        |                          | MIN | TYP   | MAX   | UNIT |
|-------------------------------|------------------------------|-----------------------|--------------------------|-----|-------|-------|------|
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |                       |                          |     |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |                       |                          | 2   |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA   |     | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V    |     | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V    |     |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V    |     |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN | I <sub>OL</sub> = 24mA   |     | 0.3   | 0.5   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN | I <sub>OH</sub> = -3.2mA | 2.4 | 2.8   |       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0.4V    |     |       | -100  | μA   |
| I <sub>OZH</sub> <sup>3</sup> |                              |                       | V <sub>O</sub> = 2.4V    |     |       | 100   | μA   |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V      | -30 | -70   | -130  | mA   |
| I <sub>CC</sub>               | Supply Current               | V <sub>CC</sub> = MAX | 20X10A, 20X8A, 20X4A     |     | 140   | 180   | mA   |
|                               |                              |                       | 20L10A                   |     | 115   | 165   |      |

**Switching Characteristics (Over Operating Conditions)**

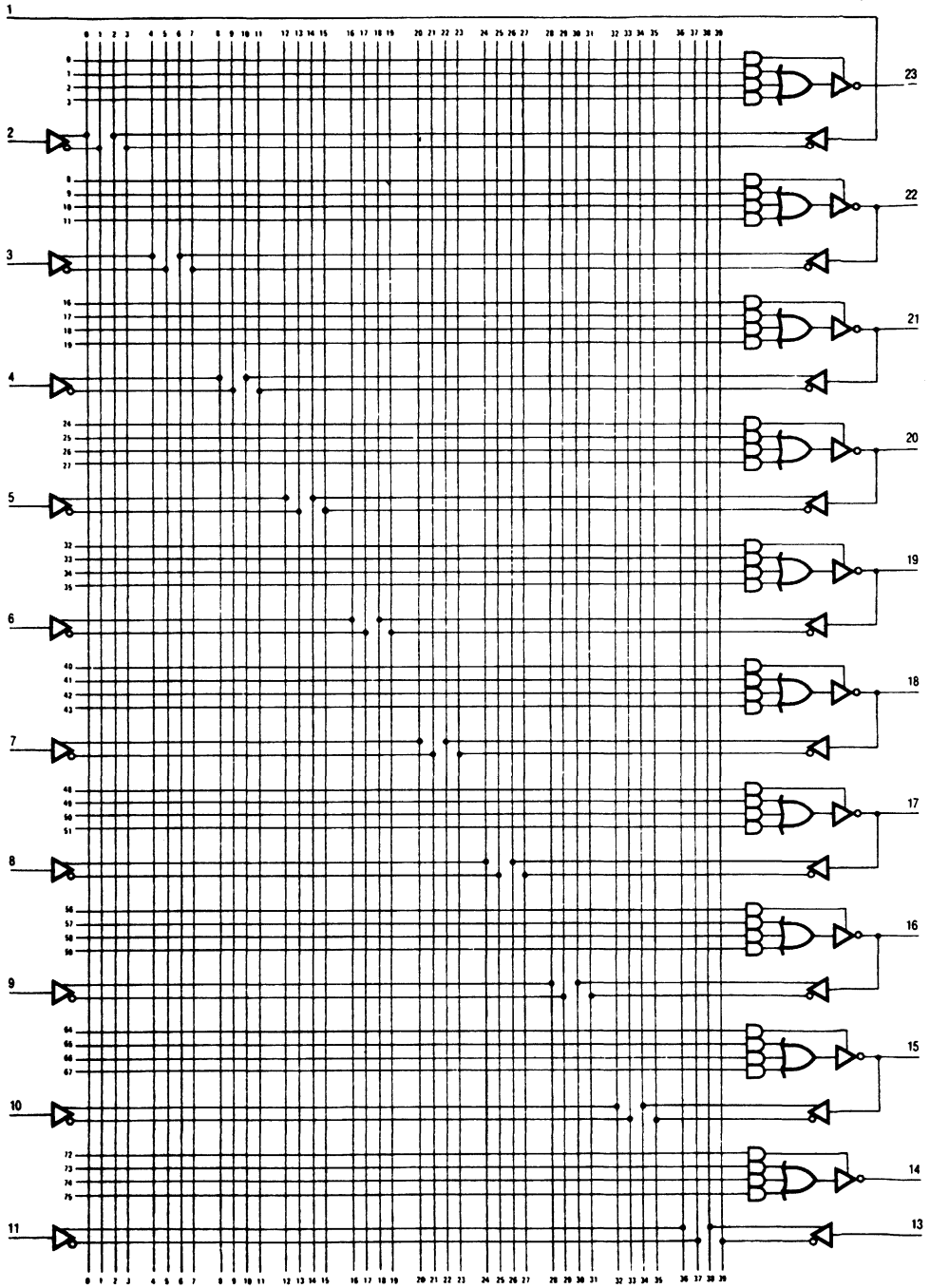
| SYMBOL           | PARAMETER  |                          | TEST CONDITIONS  | COMMERCIAL |      |     | UNIT |
|------------------|--|--------------------------|--|------------|------|-----|------|
|                  |  |                          |  | MIN        | TYP  | MAX |      |
| t <sub>PD</sub>  | Input or feedback to output 20L10A, 20X8A, and 20X4A |                          | Commercial<br>R <sub>1</sub> = 200Ω<br>R <sub>2</sub> = 360Ω |            | 23   | 30  | ns   |
| t <sub>CLK</sub> | Clock to output or feedback                          |                          |  |            | 10   | 15  | ns   |
| t <sub>PZX</sub> | Pin 13 to output enable except 20L10A                |                          |  |            | 11   | 20  | ns   |
| t <sub>PXZ</sub> | Pin 13 to output disable except 20L10A               |                          |  |            | 10   | 20  | ns   |
| t <sub>PZX</sub> | Input to output enable                               | 20X8A, 20X4A, and 20L10A |  |            | 19   | 30  | ns   |
| t <sub>PXZ</sub> | Input to output disable                              | 20X8A, 20X4A, and 20L10A |  |            | 15   | 30  | ns   |
| f <sub>MAX</sub> | Maximum frequency                                    |                          |  |            | 22.2 | 32  |      |

- The PAL24XA Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**2**

**Medium 24X Series  
20L10 Logic Diagram**

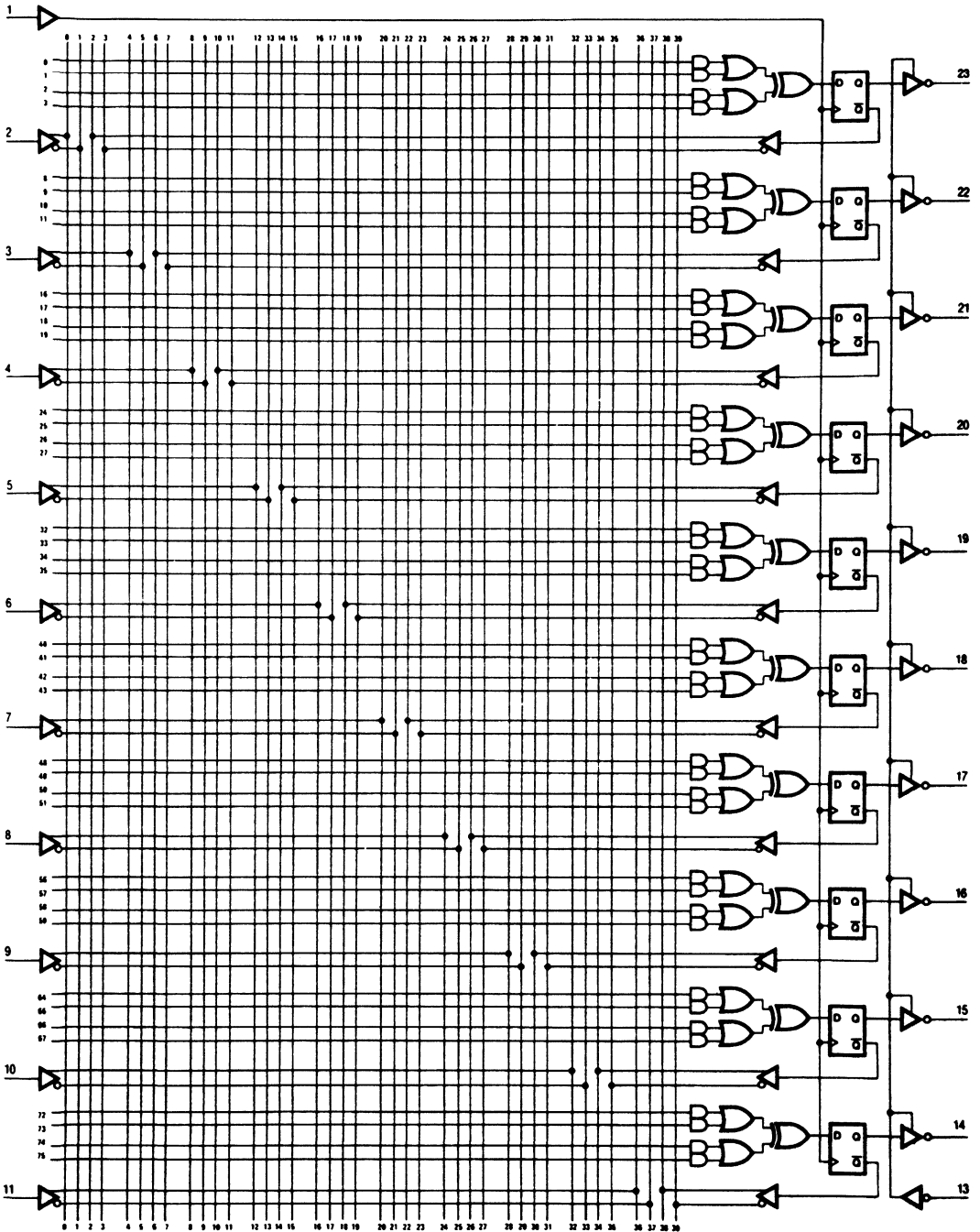
**20L10**



L000030M

**Medium 24X Series  
20X10 Logic Diagram**

**20X10**

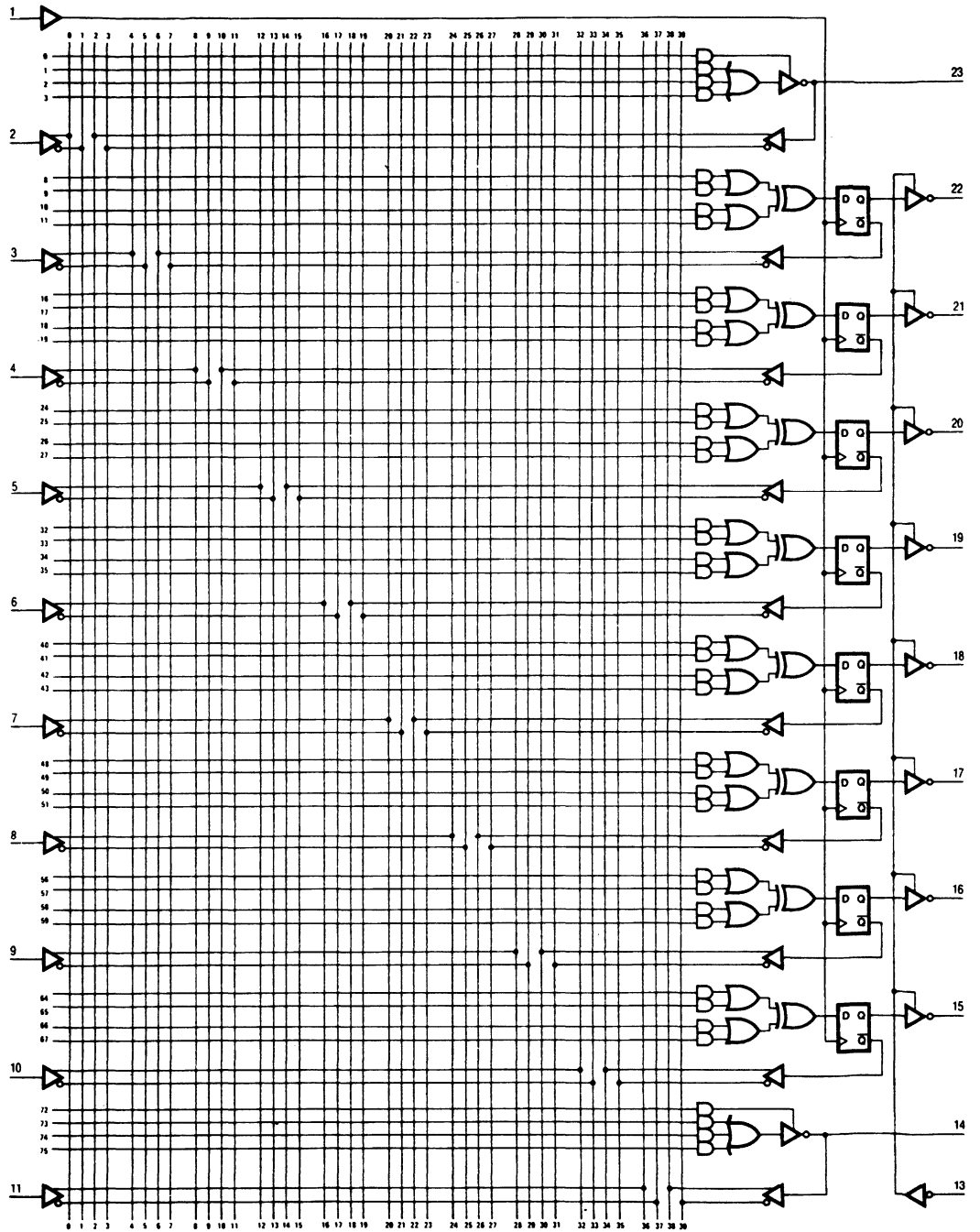


**2**

LD00840M

**Medium 24X Series  
20X8 Logic Diagram**

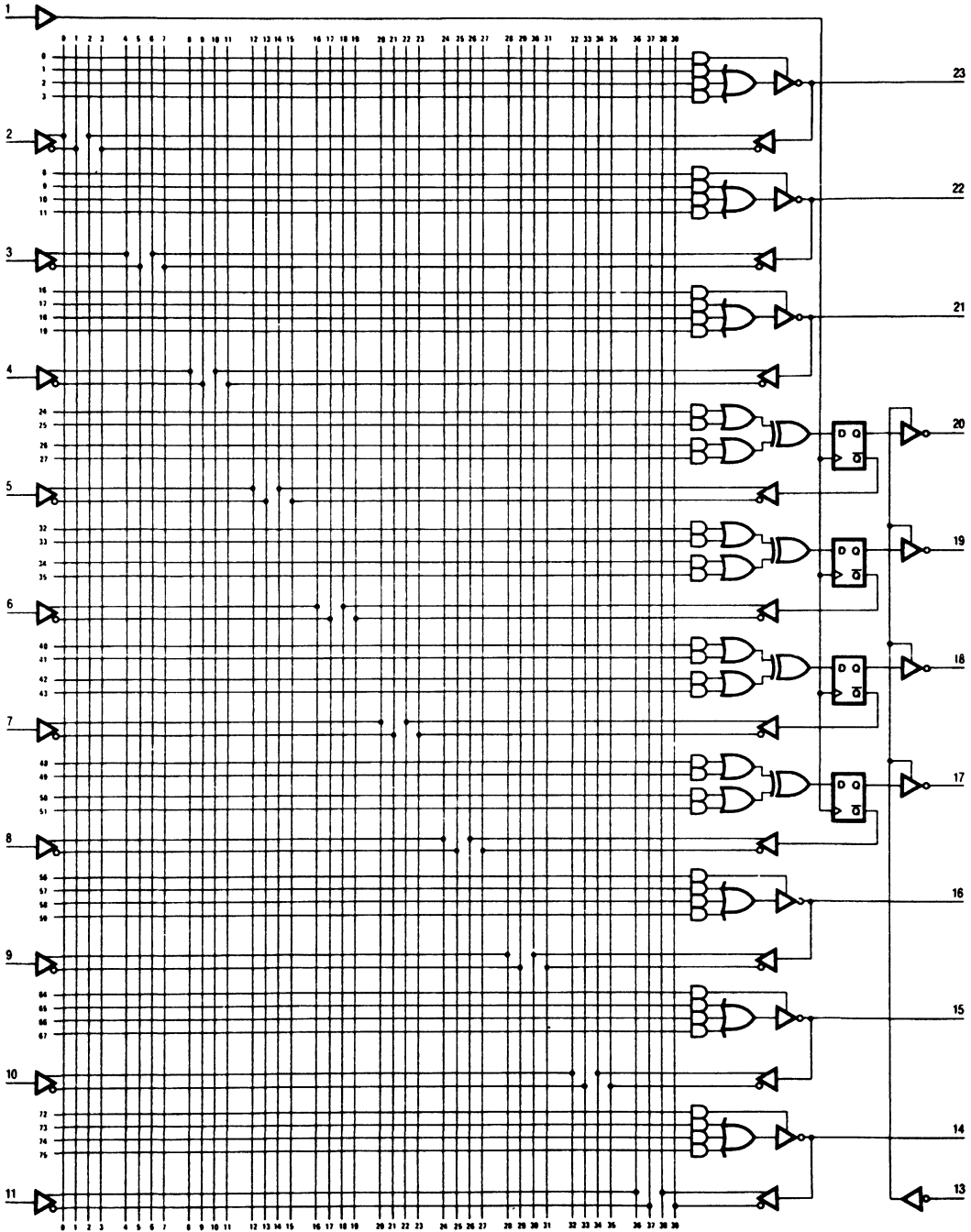
**20X8**



L000650M

Medium 24X Series  
20X4 Logic Diagram

20X4



L00060M

2

**Large 24RS Series**  
**20S10, 20RS10, 20RS8, 20RS4**

**Large 24RS Series**

|           | ARRAY INPUTS | OUTPUTS       |            | STANDARD                  |                         |
|-----------|--------------|---------------|------------|---------------------------|-------------------------|
|           |              | COMBINATORIAL | REGISTERED | t <sub>PD</sub> *<br>(ns) | I <sub>CC</sub><br>(mA) |
| PAL20S10  | 20           | 10            | 0          | 35/40                     | 240                     |
| PAL20RS10 | 20           | 0             | 10         | 35                        | 240                     |
| PAL20RS8  | 20           | 2             | 8          | 35/40                     | 240                     |
| PAL20RS4  | 20           | 6             | 4          | 35/40                     | 240                     |

\*35ns active low, 40ns active high

**Description**

The Large 24RS Series offers product term sharing, which allows up to sixteen product terms to be used at a single output.

**Enable**

The combinatorial outputs are enabled by a product term. The registered outputs are enabled by a common enable pin.

**Programmable Polarity**

Each flip-flop has individually programmable polarity. The unprogrammed state is active low.

**Product Term Sharing**

Product term sharing allows each pair of outputs to share its product terms with one output or the other (not both). Each

pair has a total of sixteen product terms; thus, one output can use zero to sixteen terms while the other has sixteen to zero. Product terms can only be shared mutually exclusively. If both outputs need the same term, it must be created twice, once for each output.

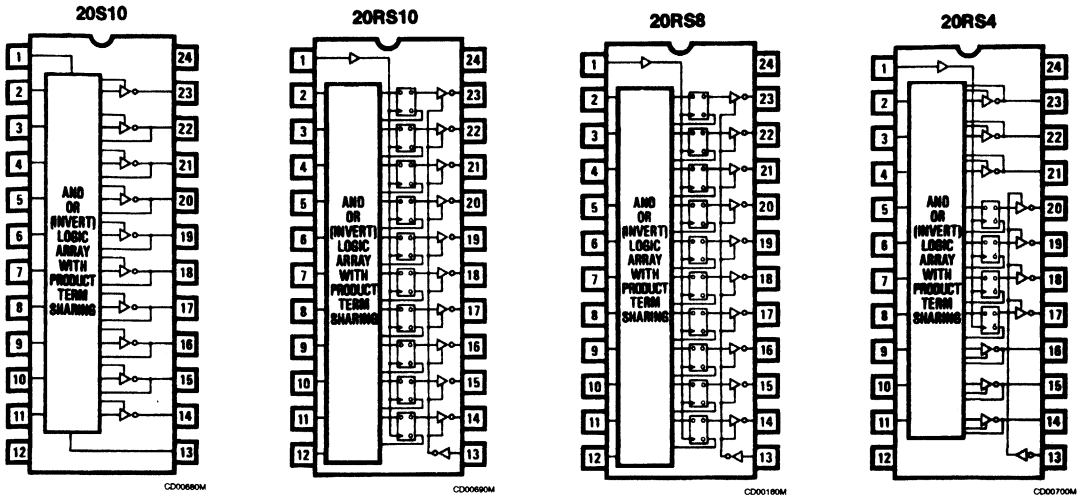
**Preload and Power-up Reset**

The 24RS Series offers register preload for device testability. The registers can be preloaded from the outputs by using supervoltages (see waveforms at end of section) in order to simplify functional testing. The 24RS Series also offers Power-up Reset, whereby the registers power up to a logic LOW, setting the active-low outputs to a logic HIGH.



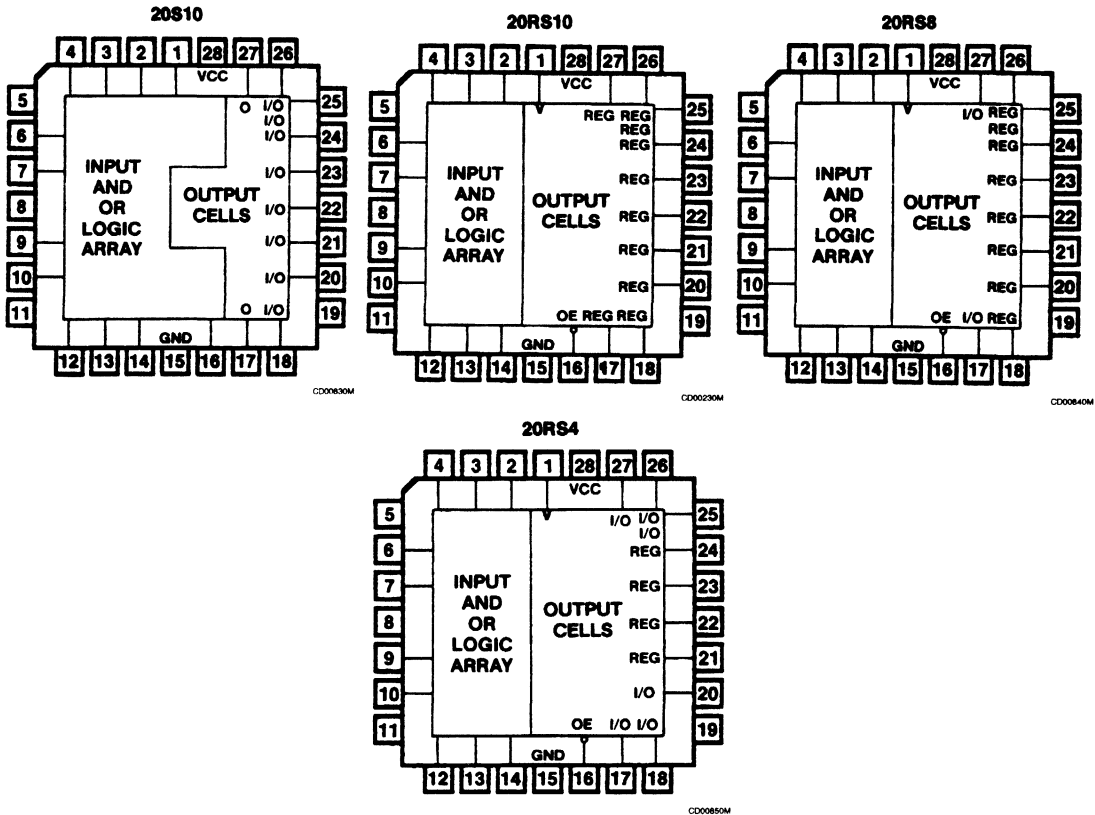
**Large 24RS Series**  
**20S10, 20RS10, 20RS8, 20RS4**

**DIP Pinouts**



**2**

**PLCC Pinouts**



**Large 24RS Series**  
**20S10, 20RS10, 20RS8, 20RS4**

**Operating Conditions**

| SYMBOL   | PARAMETER                                  |                          | MILITARY |     |     | COMMERCIAL |     |      | UNIT |    |
|----------|--|--------------------------|----------|-----|-----|------------|-----|------|------|----|
|          |  |                          | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |    |
| $V_{CC}$ | Supply voltage                             |                          | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |    |
| $t_w$    | Width of clock                             | Low                      | 20       | 10  |     | 15         | 10  |      | ns   |    |
|          |  | High                     | 20       | 10  |     | 15         | 10  |      |      |    |
| $t_{su}$ | Setup time from input or feedback to clock | 20RS10<br>20RS8<br>20RS4 | 40       | 25  |     | 35         | 25  |      | ns   |    |
| $t_h$    | Hold time                                  |                          | 0        | -10 |     | 0          | -10 |      | ns   |    |
| $T_A$    | Operating free-air temperature             |                          | -55      |     |     | 0          |     |      | 75   | °C |
| $T_C$    | Operating case temperature                 |                          |          |     |     | 125        |     |      |      | °C |

**Electrical Characteristics (Over Operating Conditions)**

| SYMBOL      | PARAMETER                    | TEST CONDITION        |                      | MIN                      | TYP   | MAX   | UNIT          |               |
|-------------|------------------------------|-----------------------|----------------------|--------------------------|-------|-------|---------------|---------------|
| $V_{IL}^1$  | Low-level input voltage      |                       |                      |                          |       | 0.8   | V             |               |
| $V_{IH}^1$  | High-level input voltage     |                       |                      | 2                        |       |       | V             |               |
| $V_{IC}$    | Input clamp voltage          | $V_{CC} = \text{MIN}$ | $I_I = -18\text{mA}$ |                          | -0.8  | -1.5  | V             |               |
| $I_{IL}^2$  | Low-level input current      | $V_{CC} = \text{MAX}$ | $V_I = 0.4\text{V}$  |                          | -0.02 | -0.25 | mA            |               |
| $I_{IH}^2$  | High-level input current     | $V_{CC} = \text{MAX}$ | $V_I = 2.4\text{V}$  |                          |       | 25    | $\mu\text{A}$ |               |
| $I_I$       | Maximum input current        | $V_{CC} = \text{MAX}$ | $V_I = 5.5\text{V}$  |                          |       | 1     | mA            |               |
| $V_{OL}$    | Low-level output voltage     | $V_{CC} = \text{MIN}$ | Mil                  | $I_{OL} = 12\text{mA}$   | 2.4   | 0.3   | 0.5           | V             |
|             |                              |                       | Com                  | $I_{OL} = 24\text{mA}$   |       |       |               |               |
| $V_{OH}$    | High-level output voltage    | $V_{CC} = \text{MIN}$ | Mil                  | $I_{OH} = -2\text{mA}$   | 2.4   | 2.8   |               | V             |
|             |                              |                       | Com                  | $I_{OH} = -3.2\text{mA}$ |       |       |               |               |
| $I_{OZL}^2$ | Off-state output current     | $V_{CC} = \text{MAX}$ |                      | $V_O = 0.4\text{V}$      |       |       | -100          | $\mu\text{A}$ |
| $I_{OZH}^2$ |                              |                       |                      | $V_O = 2.4\text{mA}$     |       |       | 100           |               |
| $I_{OS}^3$  | Output short-circuit current | $V_{CC} = 5\text{V}$  |                      | $V_O = 0\text{V}$        | -30   | -70   | -130          | mA            |
| $I_{CC}$    | Supply current               | $V_{CC} = \text{MAX}$ |                      |                          |       | 175   | 240           | mA            |

1. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. I/O pin leakage is the worst case of  $I_{IL}$  and  $I_{OZL}$  (or  $I_{IH}$  and  $I_{OZH}$ ).
3. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Large 24RS Series**  
**20S10, 20RS10, 20RS8, 20RS4**

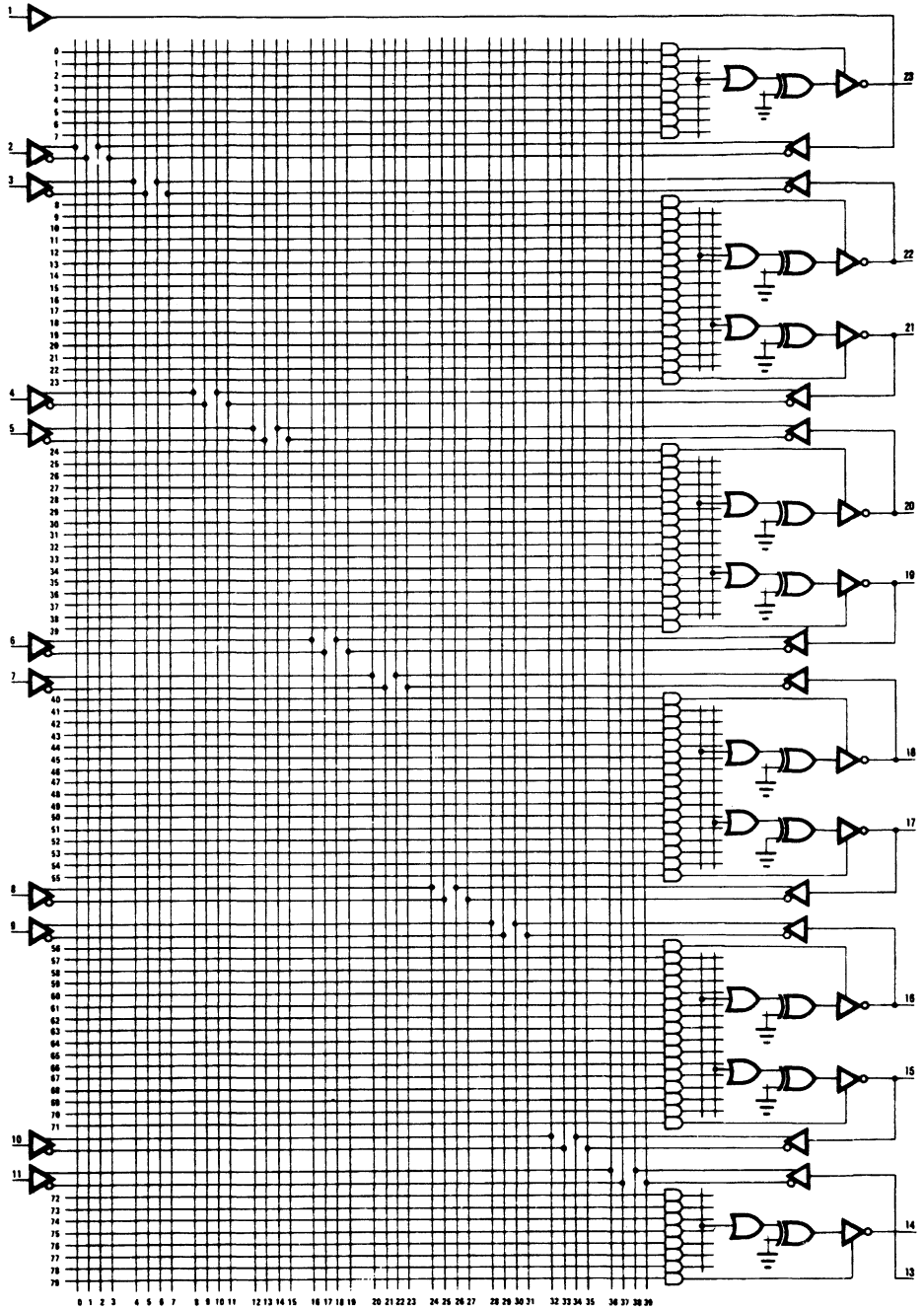
**Switching Characteristics** (Over Operating Conditions)

| SYMBOL    | PARAMETER                                       |                      | TEST CONDITIONS                                       | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|-----------|---|----------------------|---|----------|-----|-----|------------|-----|-----|------|
|           |   |                      |   | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{PD}$  | Input or feedback to output 20S10, 20RS8, 20RS4 | Polarity fuse intact | Commercial<br>$R_1 = 200\Omega$<br>$R_2 = 390K\Omega$ |          | 25  | 40  |            | 25  | 35  | ns   |
|           |   | Polarity fuse blown  |   |          | 30  | 45  |            | 30  | 40  |      |
| $t_{CLK}$ | Clock to output or feedback                     |                      |   |          | 12  | 20  |            | 12  | 17  | ns   |
| $t_{PZX}$ | Pin 13 to output enable except 20S10            |                      |   |          | 10  | 25  |            | 10  | 20  | ns   |
| $t_{PXZ}$ | Pin 13 to output disable except 20S10           |                      |   |          | 11  | 25  |            | 11  | 20  | ns   |
| $t_{PZX}$ | Input to output enable                          | 20S10, 20RS8, 20RS4  |   |          | 25  | 35  |            | 25  | 35  | ns   |
| $t_{PZX}$ | Input to output disable                         | 20S10, 20RS8, 20RP4  | Military<br>$R_1 = 390\Omega$<br>$R_2 = 750\Omega$    |          | 13  | 30  |            | 13  | 25  | ns   |
| $f_{MAX}$ | Maximum frequency                               | 20RS10, 20RS8, 20RS4 |   | 18       | 28  |     | 20         | 28  | MHz |      |

2

Large 24RS Series  
20S10 Logic Diagram

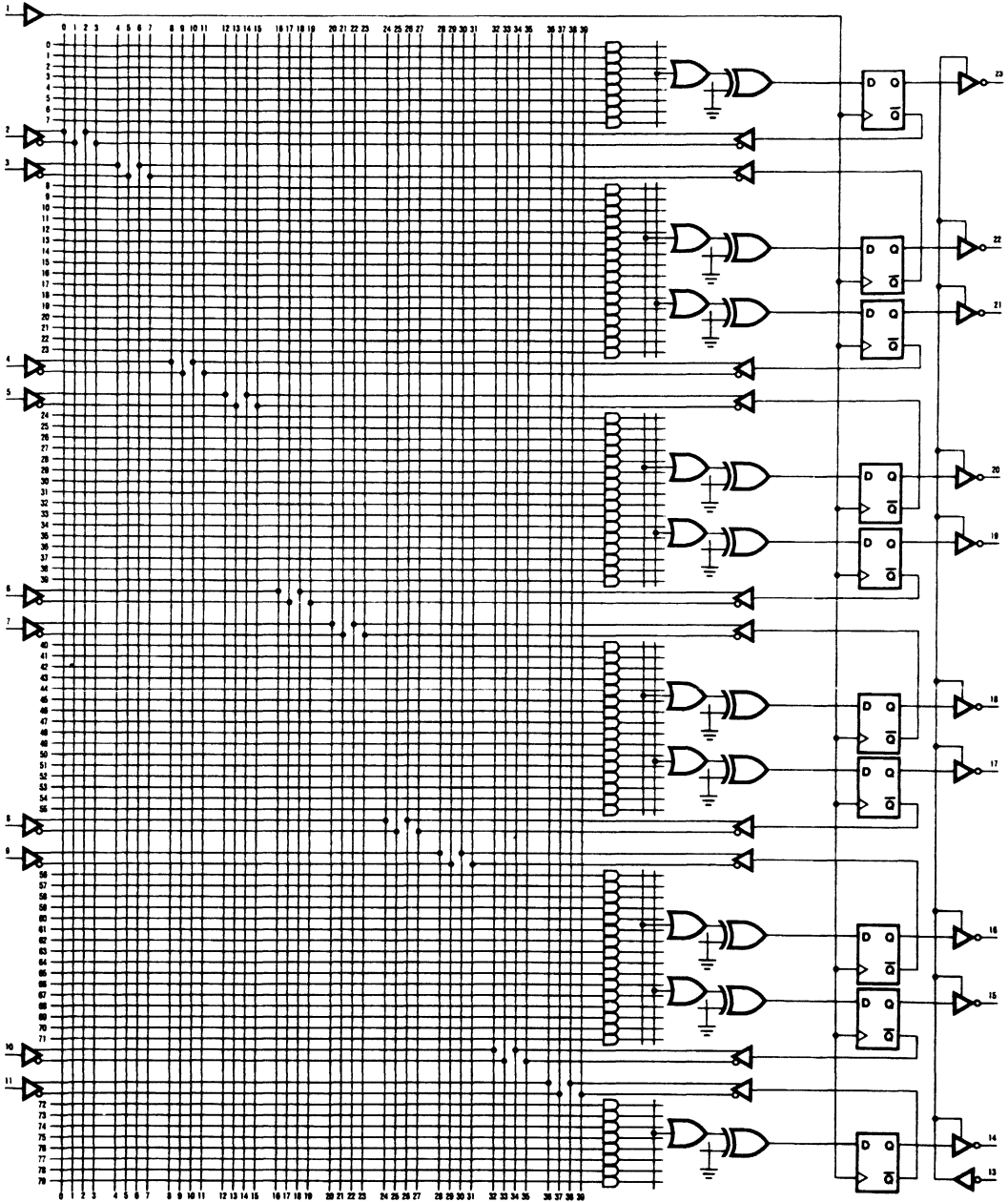
20S10



LD00670M

Large 24RS Series  
20RS10 Logic Diagram

20RS10

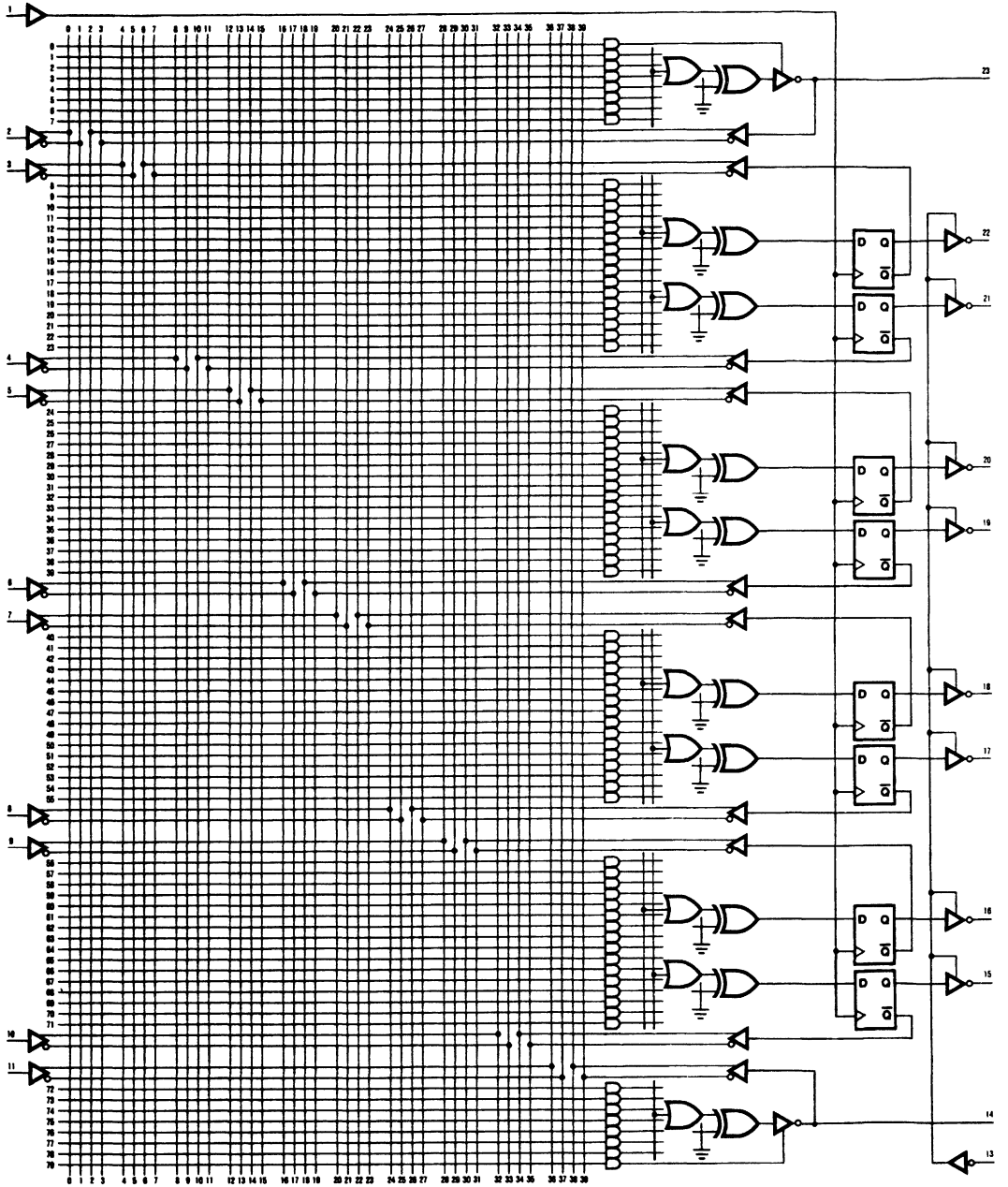


2

L100680M

Large 24RS Series  
20RS8 Logic Diagram

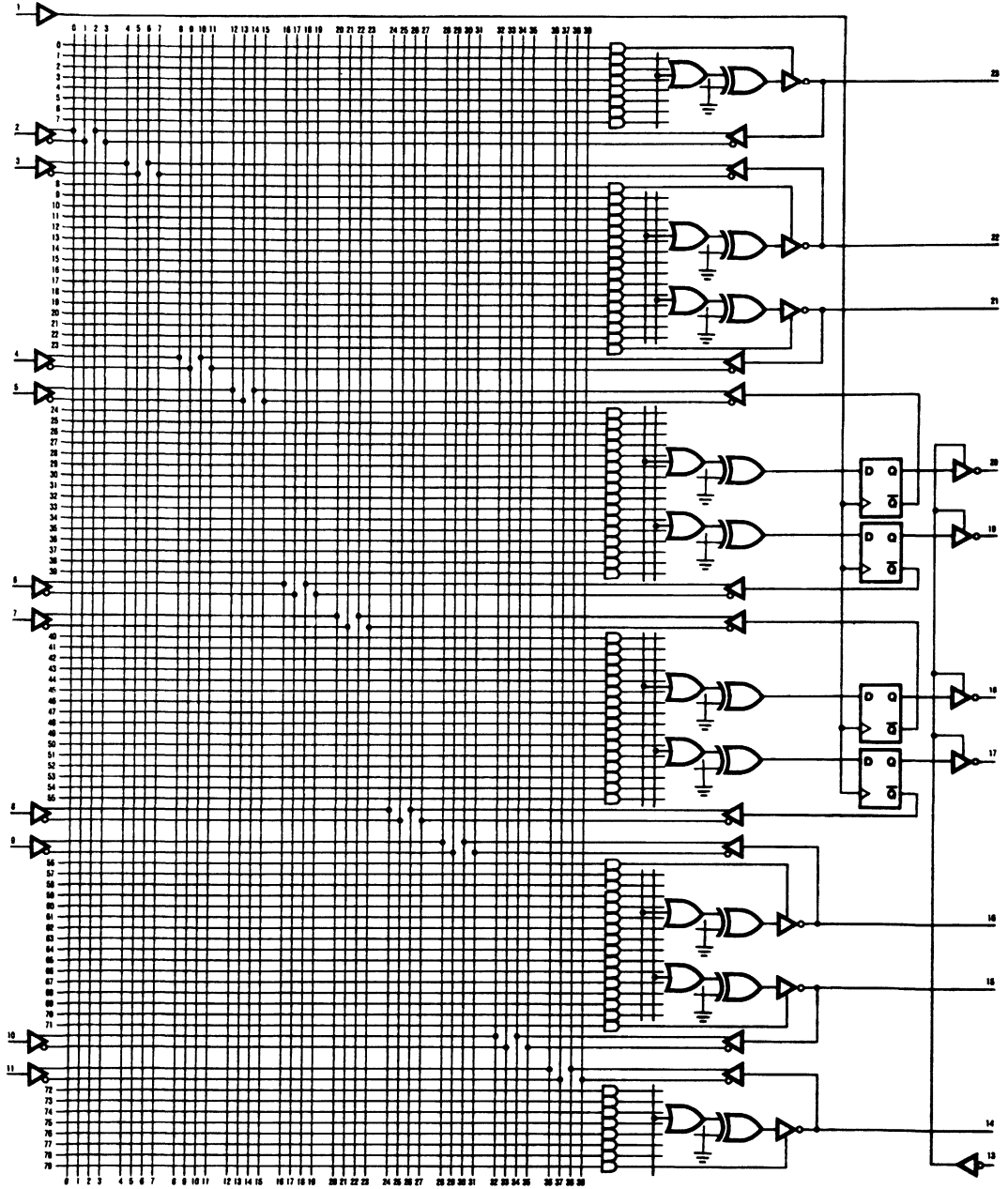
20RS8



L00690M

**Large 24RS Series  
20RS4 Logic Diagram**

**20RS4**



**2**

LD00700M

## **Large 24RA (PAL20RA10)**

### **Description**

The PAL20RA10 is a 24-pin registered asynchronous PAL device. This versatile device features programmable clock, enable, set, and reset, all of which can operate asynchronously to other flip-flops in the same device. It also has individual flop-flop bypass, allowing this one device to provide any combination of registered and combinatorial outputs.

### **Programmable Clock**

The clock input to each flip-flop comes from the programmable array, allowing the flip-flops to be clocked independently if desired.

### **Programmable Set and Reset**

Each flip-flop has a product line for asynchronous set and one product for asynchronous reset. If the chosen product line is high, the flip-flop will set (become a logic HIGH), or reset (become a logic LOW). The sense of the output pin is inverted if the output is active low.

### **Programmable Polarity**

Each flip-flop has individually programmable polarity. The unprogrammed state is active low.

### **Programmable Flip-flop Bypass**

If both the set and reset product lines are high, the flip-flop is bypassed and the output becomes combinatorial. Thus each output can be configured to be registered or combinatorial.

### **Programmable and Hard-Wired Three-State Outputs**

The PAL20RA10 provides a product term dedicated to output control. There is also an output control pin (pin 13). The output is enabled if both the output control pin is low and the output control product term is high. If the output control pin is high all outputs will be disabled. If an output control product term is low, then that output will be disabled.

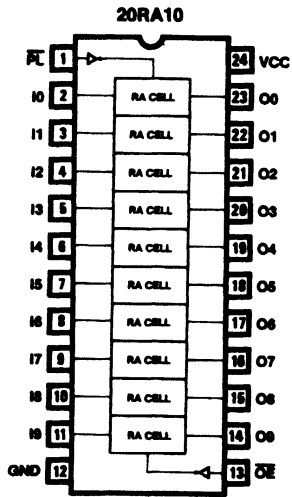
### **Register Preload and Power-up Reset**

Each device also offers register preload for device testability. The registers can be preloaded from the outputs by using TTL level signals in order to simplify functional testing. This series also offers Power-up Reset, whereby the registers power up to a logic LOW, setting the active-low outputs to a logic HIGH.



**Large 24RA  
20RA10**

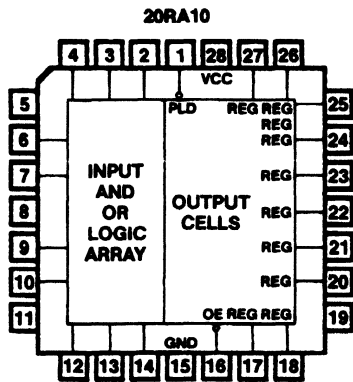
**DIP Pinout**



CD00720M

**2**

**PLCC Pinout**



CD00810M

**Large 24RA  
20RA10**

**Operating Conditions**

| SYMBOL           | PARAMETER                                 |                      | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|------------------|---|----------------------|----------|-----|-----|------------|-----|------|------|
|                  |   |                      | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| V <sub>CC</sub>  | Supply voltage                            |                      | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| t <sub>w</sub>   | Width of clock                            | Low                  | 25       | 13  |     | 20         | 13  |      | ns   |
|                  |   | High                 | 25       | 13  |     | 20         | 13  |      |      |
| t <sub>wp</sub>  | Preload pulse width                       |                      | 45       | 15  |     | 35         | 15  |      | ns   |
| t <sub>su</sub>  | Setup time for input or feedback to clock |                      | 25       | 10  |     | 20         | 10  |      | ns   |
| t <sub>sup</sub> | Preload setup time                        |                      | 30       | 5   |     | 25         | 5   |      | ns   |
| t <sub>h</sub>   | Hold time                                 | Polarity fuse intact | 10       | -2  |     | 10         | -2  |      | ns   |
|                  |   | Polarity fuse blown  | 0        | -6  |     | 0          | -6  |      |      |
| t <sub>hp</sub>  | Preload hold time                         |                      | 30       | 5   |     | 25         | 5   |      | ns   |
| T <sub>A</sub>   | Operating free-air temperature            |                      | -55      |     |     | 0          |     | 75   | °C   |
| T <sub>C</sub>   | Operating case temperature                |                      |          |     | 125 |            |     |      | °C   |

**Electrical Characteristics (Over Operating Conditions)**

| SYMBOL                       | PARAMETER                    | TEST CONDITION        |  | MIN  | TYP   | MAX   | UNIT |
|------------------------------|------------------------------|-----------------------|--|------|-------|-------|------|
| V <sub>IL</sub> <sup>1</sup> | Low-level input voltage      |                       |  |      |       | 0.8   | V    |
| V <sub>IH</sub> <sup>1</sup> | High-level input voltage     |                       |  | 2    |       |       | V    |
| V <sub>IC</sub>              | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA                       |      | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>2</sup> | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V                        |      | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>2</sup> | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V                        |      |       | 25    | μA   |
| I <sub>I</sub>               | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V                        |      |       | 1     | mA   |
| V <sub>OL</sub>              | Low-level output voltage     | V <sub>CC</sub> = MIN | I <sub>OL</sub> = 8mA                        |      | 0.3   | 0.5   | V    |
| V <sub>OH</sub>              | High-level output voltage    | V <sub>CC</sub> = MIN | I <sub>OH</sub> : Mil-2mA Com-3.2mA          | 2.4  | 2.8   |       | V    |
| I <sub>OZ</sub> <sup>2</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 2.4 V/V <sub>O</sub> = 0.4V | -100 |       | 100   | μA   |
| I <sub>OS</sub> <sup>3</sup> | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V                          | -30  | -70   | -130  | mA   |
| I <sub>CC</sub>              | Supply current               | V <sub>CC</sub> = MAX |  |      | 155   | 200   | mA   |

1. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
3. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**Large 24RA  
20RA10**

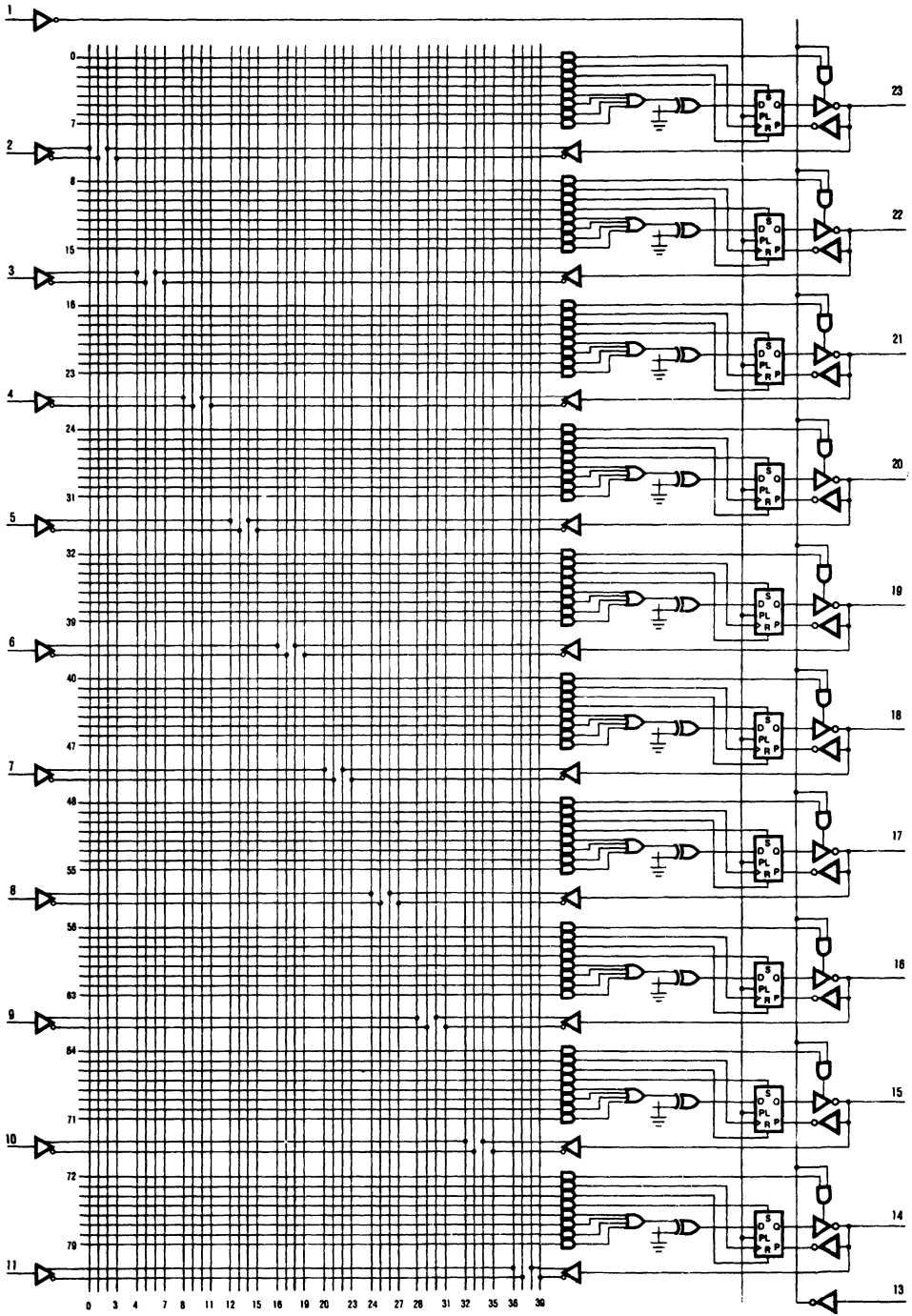
**Switching Characteristics** (Over Operating Conditions)

| SYMBOL           | PARAMETER                   |                      | TEST CONDITIONS                                 | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|------------------|-----------------------------|----------------------|---|----------|-----|-----|------------|-----|-----|------|
|                  |                             |                      |   | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| t <sub>PD</sub>  | Input or feedback to output | Polarity fuse intact | R <sub>1</sub> = 560Ω<br>R <sub>2</sub> = 1.1KΩ |          | 20  | 35  |            | 20  | 30  | ns   |
|                  |                             | Polarity fuse blown  |   |          | 25  | 40  |            | 25  | 35  |      |
| t <sub>CLK</sub> | Clock to output or feedback |                      |   | 10       | 17  | 35  | 10         | 17  | 30  | ns   |
| t <sub>S</sub>   | Input to asynchronous set   |                      |   |          | 22  | 40  |            | 22  | 35  | ns   |
| t <sub>R</sub>   | Input to asynchronous reset |                      |   |          | 27  | 45  |            | 27  | 40  | ns   |
| t <sub>PZX</sub> | Pin 13 to output enable     |                      |   |          | 10  | 25  |            | 10  | 20  | ns   |
| t <sub>PXZ</sub> | Pin 13 to output disable    |                      |   |          | 10  | 25  |            | 10  | 20  | ns   |
| t <sub>PZX</sub> | Input to output enable      |                      |   |          | 18  | 35  |            | 18  | 30  | ns   |
| t <sub>PXZ</sub> | Input to output disable     |                      |   |          | 15  | 35  |            | 15  | 30  | ns   |
| f <sub>MAX</sub> | Maximum frequency           |                      |   |          | 16  | 35  |            | 20  | 35  | MHz  |

**2**

**Large 24RA  
20RA10 Logic Diagram**

**20RA10**



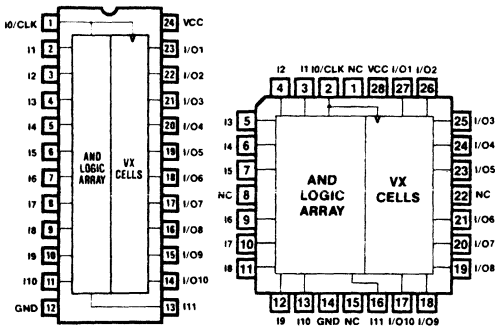
LD00710M

## High Speed Programmable Array Logic PAL32VX10, PAL32VX10A

### Features/Benefits

- Dual independent feedback paths allow buried state registers or input registers
- Programmable flip-flops allow J-K, S-R, T or D types for the most efficient use of product terms
- 10 input/output macrocells for flexibility
- Programmable registered or combinatorial outputs
- Programmable output polarity
- Global register asynchronous preset/synchronous reset or synchronous preset/asynchronous reset
- Automatic register preset on power up
- Preloadable output registers for testability
- Varied product term distribution  
–Up to 16 product terms per output
- High speed  
–25ns "A" version  
–30ns standard version
- Space-saving 24-pin 300-mil SKINNYDIP® package or 28-pin chip carrier
- Pin-compatible functional superset of 22V10

### Pin Configurations

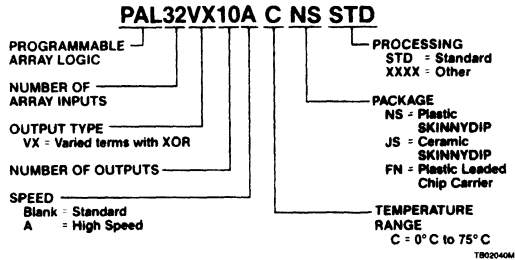


SKINNYDIP Package

Plastic Leaded Chip Carrier

CO01950M

### Ordering Information



### General Description

The PAL32VX10 is a high-density Programmable Array Logic (PAL®) device which implements a sum-of-products transfer function via a user-programmable AND logic array and a fixed OR logic array. Featured are ten highly flexible input/output macrocells which are user-configurable for combinatorial or registered operation. Each flip-flop can be programmed to be either a J-K, S-R, T, or D-type for optimal design of state machines and other synchronous logic. In addition, a unique dual feedback architecture allows I/O capability for each macrocell in both combinatorial and registered configurations. This can be achieved even when register feedback is present, and allows implementation of buried flip-flops while preserving the external macrocell input. Supplied in space-saving 300-mil-wide dual in-line packages or 28-pin chip carriers, the PAL32VX10 offers a powerful, space saving alternative to SSI/MSI logic devices, while providing the advantage of instant prototyping. Security fuses defeat readout after programming and make proprietary designs difficult to copy.

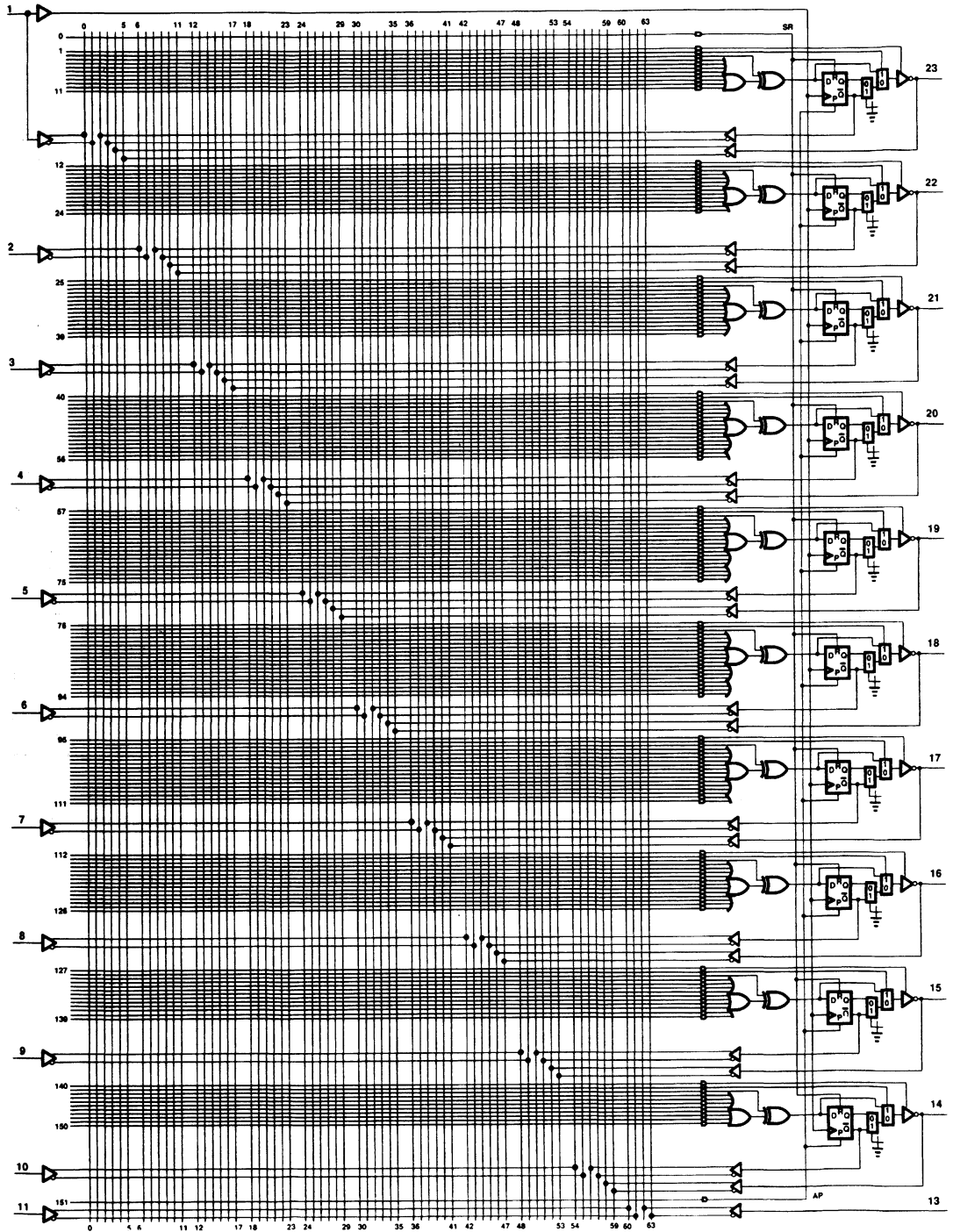
The PAL32VX10 is fabricated using Monolithic Memories' advanced oxide-isolated bipolar process for high speed and low power. TiW fuse links provide high reliability and programming yields. Special on-chip test circuits allow full AC, DC, and functional testing before programming. Preloadable output registers facilitate functional testing.

The PAL32VX10 can be programmed on standard PAL device programmers, fitted with appropriate programming modules and configuration software. Design development is supported by Monolithic Memories' PALASM® 2 software as well as by other programmable logic CAD tools available from third party vendors. Approved development tools are listed on page 10.

2

High Speed Programmable Array Logic  
PAL32VX10, PAL32VX10A

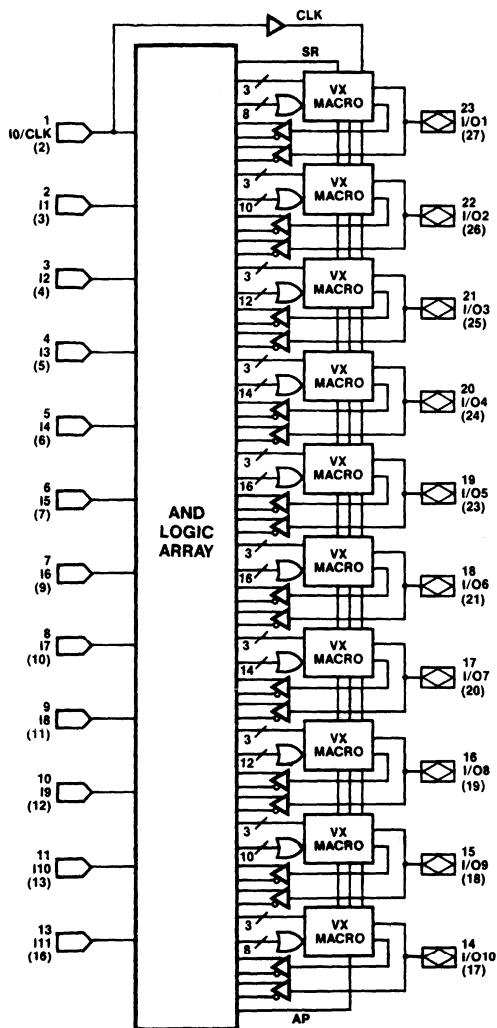
Logic Diagram



LD01030M

## High Speed Programmable Array Logic PAL32VX10, PAL32VX10A

### Block Diagram



Note: PLCC pin numbers are indicated in parentheses.  
PLCC pins 1, 8, 15, and 22 are not connected.

### Description of Architecture

The PAL32VX10 has twelve dedicated input lines and ten programmable I/O macrocells. Pin 1 serves either as an array input or as a clock for all flip-flops. Buffers for device inputs have complementary outputs to provide user-programmable input signal polarity. The fuse matrix implements a programmable AND logic array, which drives a fixed OR logic array.

The high level of flexibility built into each macrocell, shown in Figure 1, allows the PAL32VX10 to implement over thirty different architecture options. Each macrocell can be individually programmed to implement a variety of combinatorial or registered logic functions.

### Dual Output Feedback

Dual feedback paths associated with each macrocell provide independent feedback paths directly into the array from both the flip-flop output and the output pin. Unlike other devices which have a single feedback path, the PAL32VX10 allows each output to have full I/O capability when configured as either a combinatorial output or a registered output, even if register feedback to the array is used. Thus registers can be loaded from their outputs.

If a macrocell is configured as a dedicated input, by disabling the three-state output buffer, the dual feedback architecture allows use of the associated register as an input register or as a "buried" state register, avoiding waste of the flip-flop, as shown in Figure 2.

2

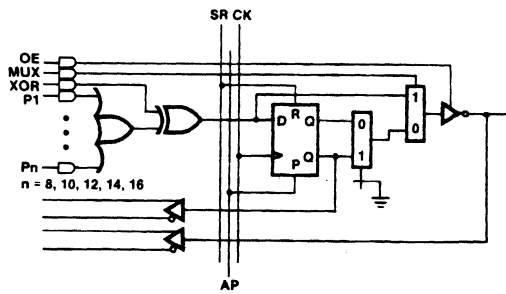


Figure 1. PAL32VX10 Macrocell

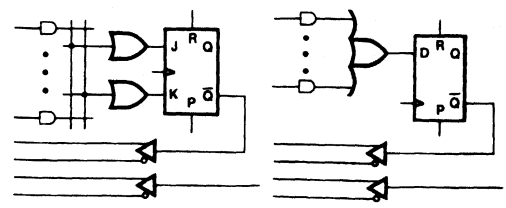


Figure 2. Buried Flip-Flops with Dedicated Inputs

### Programmable Flip-Flops

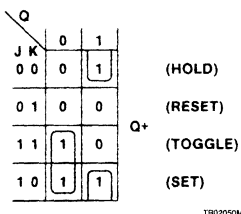
Each output macrocell contains a unique programmable flip-flop consisting of a basic D-type flip-flop driven by an XOR gate. This allows the user to choose the optimal flip-flop for the design, since either J-K, S-R, or T-type flip-flops can be synthesized from such a structure without wasting product terms.

As indicated in the macrocell logic diagram, one input of the XOR gate is connected to a single product term, while the second input is connected to the output of the OR logic array. The XOR gate output feeds the input of the D flip-flop. The way in which the XOR gate is used to synthesize the different flip-flop types is described in detail below.

**D Flip-Flop.** The D flip-flop option is implemented directly. In this configuration, the XOR gate on the input of the flip-flop can be used to program the logic polarity of the transfer function.

**J-K Flip-Flop.** The J-K flip-flop option can be easily synthesized with a more sophisticated manipulation of the XOR gate inputs and the D flip-flop output.

The transfer function of a J-K flip-flop can be mapped in the Karnaugh Map of Figure 3, where Q+ represents the next state of the flip-flop:



**Figure 3. J-K Flip-Flop Transfer Function**

Dropping the ( + ) for simplicity, the equivalent Boolean expression for Q+ is:

$$Q = \bar{K} \cdot Q + J \cdot \bar{Q}$$

In general, J and K can be sum-of-product expressions which are provided in the PAL architecture only in active-high form. Thus, a direct implementation of  $\bar{K}$  expressions must invoke a DeMorgan transformation, which can use excessive product terms. This can be avoided by rewriting the equation for Q without inversions on the J or K inputs.

The XOR gate can be used to construct a logically equivalent expression without any inversions on the J or K inputs. The rewritten Boolean expression is:

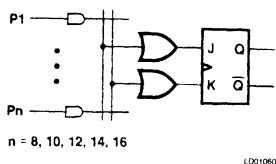
$$Q = Q + : (J \cdot \bar{Q} + K \cdot Q)$$

To check that these expressions are logically equivalent, change the XOR to its equivalent sum of products form (remember  $A + B = A \cdot \bar{B} + \bar{A} \cdot B$ ) and reduce (using DeMorgan's theorem):

$$\begin{aligned} Q &= Q \cdot (J \cdot \bar{Q} + K \cdot Q) + \bar{Q} \cdot (J \cdot \bar{Q} + K \cdot Q) \\ Q &= Q \cdot (\bar{J} + Q) \cdot (\bar{K} + \bar{Q}) + \bar{Q} \cdot J \cdot \bar{Q} + \bar{Q} \cdot K \cdot Q \\ Q &= Q \cdot (\bar{J} \cdot \bar{K} + \bar{J} \cdot \bar{Q} + Q \cdot \bar{K} + Q \cdot \bar{Q}) + J \cdot \bar{Q} \\ Q &= \bar{J} \cdot \bar{K} \cdot Q + \bar{K} \cdot Q + J \cdot \bar{Q} \end{aligned}$$

which simplifies to  $Q = \bar{K} \cdot Q + J \cdot \bar{Q}$ .

Since J and K are, in general, sums of products, J and K in either expression can be substituted with  $(J_1 + J_2 + \dots + J_m)$  and  $(K_1 + K_2 + \dots + K_n - m)$ , where n is the total number of product terms associated with a given output macrocell. Thus, the total n-product term resource is shared between the J and K control inputs (Figure 4). Note that all J terms will contain  $\bar{Q}$  and all K terms will contain Q.



**Figure 4. J-K Flip-Flop Logic Equivalent; J and K Can Also be Active-Low**

The above discussions have assumed that it was most convenient to "group ones" in the Karnaugh Map. Sometimes it takes fewer product terms to "group zeros", i.e., implement the inversion of the desired function. The equations shown in Table 1 are equivalent and can be interchanged to optimize product term utilization. This can be readily proved through logic reductions similar to that above.

|                             |   |
|-----------------------------|---|
| J and K active high         | $Q = Q + : (J \cdot \bar{Q} + J \cdot Q)$                   |
| J active high, K active low | $Q = J \cdot \bar{Q} + \bar{K} \cdot Q$                     |
| J active low, K active high | $\bar{Q} = \bar{J} \cdot \bar{Q} + K \cdot Q$               |
| J and K active low          | $Q = \bar{Q} + : (\bar{J} \cdot \bar{Q} + \bar{K} \cdot Q)$ |

Note: J = sum of products J1 + J2 + ... + Jm  
 K = sum of products K1 + K2 + ... + Kn - m  
 n = total number of available product terms for a given macrocell (8 to 16)

**Table 1. J-K Flip-Flop Transfer Functions**

**S-R Flip-Flop.** The S-R flip-flop has a truth table identical to that of the J-K flip-flop, with the exception that the J = K = 1 (toggle) condition is not allowed. The S-R flip-flop implementation is identical to that of the J-K flip-flop, with J-K replaced by S-R, and the S = R = 1 condition avoided.

**T Flip-Flop.** A T (toggle) flip-flop either holds its state or toggles, depending on the logic state of the T input. The T flip-flop is a subset of the J-K flip-flop and can be considered equivalent to a J-K type with J = K. The general transfer function and its active-low T equivalent are both given in Table 2.

|                           |
|---------------------------|
| $Q = Q + : T$             |
| $Q = \bar{Q} + : \bar{T}$ |

Note: T = sum of products T1 + T2 + T3 + ... + Tn

**Table 2. T Flip-Flop Transfer Functions**



## High Speed Programmable Array Logic PAL32VX10, PAL32VX10A

### Summary

The PAL32VX10 can synthesize J-K, S-R, T, and D flip-flops, whichever is most convenient for the application, without sacrificing product terms. Additionally, the synthesized equations can use the active-high or active-low forms of the inputs, allowing the designer to minimize product term requirements.

### Flip-Flop Bypass

Any output in the PAL32VX10 can be configured to be combinatorial by bypassing the output flip-flop. This is done by setting the output multiplexer to the appropriate state. The multiplexer is controlled by a product term which can be set unconditionally for a permanent combinatorial (all fuses opened, product term high) or registered (all fuses intact, product term low) output configuration, or can be programmed to bypass the output flip-flop "on the fly," allowing signals to be routed directly to output pins under user-specified conditions.

### Varied Product Term Distribution

An increased number of product terms has been provided in the PAL32VX10 over previous generation PAL devices. These terms are distributed among the ten macrocells in a varied manner, ranging from eight to sixteen terms per output. The five output pairs have 8, 10, 12, 14, or 16 product terms available for the OR gate within each macrocell. In addition, each macrocell has one XOR product term and two architecture control product terms.

### Programmable I/O

Each macrocell has a three-state output buffer with programmable three-state control. Control is implemented by a single product term, allowing specification of enable/disable functions controlled by any device input or output. Each macrocell can be configured as a dedicated input by disabling the buffer drive capability. When this is done, the associated register can still be used as an input register or buried state register, due to the independent register feedback path.

### Programmable Preset and Reset

The ten macrocell flip-flops share common programmable preset and reset control for easy system initialization. The Q outputs of the register will go to the logic low state following a low-to-high transition on pin 1 (I0/CLK) when the synchronous reset (SR) product term is asserted. The register will be forced to the logic high state independent of the clock when the asynchronous preset (AP) product term is asserted.

### Programmable Polarity

The polarity of each macrocell output can be set active high or active low.

**Combinatorial Outputs.** The XOR gate provides polarity control for combinatorial outputs, with the single product term

to the XOR gate controlling the invert/not invert function. With all fuses intact, there is no inversion through the XOR gate, creating an active low output. Opening all fuses forces the product term high, inverting data and creating an active high output.

**Registered Outputs.** Output polarity for registered outputs can be determined in two ways. For D-type registered outputs, polarity can be set by the XOR gate, as is the case with combinatorial outputs. Using this method to set polarity, preset and reset will not be affected.

Polarity, as observed from the output pin, can also be determined by the flip-flop output multiplexer. Note that this does not affect the polarity of the register feedback signal, but does affect preset and reset. By changing the flip-flop output multiplexer, the preset and reset functions are exchanged, relative to the controlling product terms.

With the multiplexer fuse intact, the Q output is routed to the output pin, configuring an active low output. With the multiplexer fuse opened,  $\bar{Q}$  is routed to the output pin, and synchronous reset becomes synchronous preset. Similarly, asynchronous reset becomes asynchronous preset.

Polarity options for J-K, S-R, and T flip-flops have been discussed in the section on programmable flip-flops.

### Power-Up Preset

All flip-flops power up to a logic high for predictable system initialization. Outputs of the PAL32VX10 will be high or low depending on the state of the register output multiplexers.

### Register Preload

The register on the PAL32VX10 can be preloaded to facilitate functional testing of complex state machine designs. This feature allows direct loading of arbitrary states, thereby making it unnecessary to cycle through long test vector sequences to reach a desired state. In addition, transitions from illegal states can be verified by loading in illegal states and observing proper recovery.

### Security Fuse

After programming and verification, a PAL32VX10 design can be secured by programming the security fuses. Once programmed, these fuses defeat readback of the internal fuse pattern by a device programmer, making proprietary designs very difficult to copy.

### Quality and Testability

The PAL32VX10 offers a very high level of built-in quality. Special on-chip test circuitry provides a means of verifying performance of all AC and DC parameters prior to programming. In addition, these built-in test paths verify complete functionality of each device to provide the highest post-programming functional yields in the industry.

2

**High Speed Programmable Array Logic  
PAL32VX10, PAL32VX10A**

**Absolute Maximum Ratings**

|                                |                     |                    |
|--------------------------------|---------------------|--------------------|
|                                | <b>Operating</b>    | <b>Programming</b> |
| Supply voltage $V_{CC}$ .....  | -0.5V to 7V .....   | -0.5V to 12V       |
| Input voltage .....            | -1.5V to 5.5V ..... | -1.0V to 22V       |
| Off-state output voltage ..... | 5.5V .....          | 12V                |
| Storage temperature .....      |                     | -65°C to +150°C    |

**Operating Conditions**

| SYMBOL   | PARAMETER                                  | COMMERCIAL <sup>1</sup>          |     |      |      |     |      | UNIT |
|----------|--|----------------------------------|-----|------|------|-----|------|------|
|          |  | STD                              |     |      | A    |     |      |      |
|          |  | MIN                              | TYP | MAX  | MIN  | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                             | 4.75                             | 5   | 5.25 | 4.75 | 5   | 5.25 | V    |
| $t_w$    | Width of clock                             | Low                              | 20  | 10   |      | 18  | 10   | ns   |
|          |  | High                             | 20  | 10   |      | 18  | 10   |      |
| $t_{su}$ | Setup time from input or feedback to clock | Product terms $P_1$ - $P_n$ , SR | 30  | 20   |      | 25  | 20   | ns   |
|          |  | Product term XOR                 | 35  | 25   |      | 30  | 25   |      |
| $t_h$    | Hold time                                  | 0                                | -10 |      | 0    | -10 |      | ns   |
| $t_{aw}$ | Asynchronous preset width                  | -30                              | 20  |      | 25   | 20  |      | ns   |
| $t_{ar}$ | Asynchronous preset recovery time          | -30                              | 20  |      | 25   | 20  |      | ns   |
| $t_{sr}$ | Asynchronous reset recovery time           | -30                              | 20  |      | 25   | 20  |      | ns   |
| $T_A$    | Operating case temperature                 | 0                                | 25  | 75   | 0    | 25  | 75   | °C   |

**Electrical Characteristics Over Operating Conditions**

| SYMBOL      | PARAMETER                    | TEST CONDITION                                 | MIN                 | TYP   | MAX   | UNIT          |               |
|-------------|------------------------------|--|---------------------|-------|-------|---------------|---------------|
| $V_{IL}^2$  | Low-level input voltage      |  |                     |       | 0.8   | V             |               |
| $V_{IH}^2$  | High-level input voltage     |  | 2                   |       |       | V             |               |
| $V_{IC}$    | Input clamp voltage          | $V_{CC} = \text{MIN}$ $I_I = -18\text{mA}$     |                     | -0.8  | -1.5  | V             |               |
| $I_{IL}^3$  | Low-level input current      | $V_{CC} = \text{MAX}$ $V_I = 0.4\text{V}$      |                     | -0.02 | -0.25 | mA            |               |
| $I_{IH}^3$  | High-level input current     | $V_{CC} = \text{MAX}$ $V_I = 2.4\text{V}$      |                     |       | 25    | $\mu\text{A}$ |               |
| $I_I$       | Maximum input current        | $V_{CC} = \text{MAX}$ $V_I = 5.5\text{V}$      |                     |       | 200   | $\mu\text{A}$ |               |
| $V_{OL}$    | Low-level output voltage     | $V_{CC} = \text{MIN}$ $I_{OL} = 16\text{mA}$   |                     | 0.35  | 0.5   | V             |               |
| $V_{OH}$    | High-level output voltage    | $V_{CC} = \text{MIN}$ $I_{OH} = -3.2\text{mA}$ | 2.4                 | 3.4   |       | V             |               |
| $I_{OZL}^3$ | Off-state output current     | $V_{CC} = \text{MAX}$                          | $V_O = 0.4\text{V}$ |       |       | -100          | $\mu\text{A}$ |
| $I_{OZH}^3$ |                              |  | $V_O = 2.4\text{V}$ |       |       | 100           | $\mu\text{A}$ |
| $I_{OS}^4$  | Output short-circuit current | $V_{CC} = 5\text{V}$ $V_O = 0\text{V}$         | -30                 | -70   | -130  | mA            |               |
| $I_{CC}$    | Supply current               | $V_{CC} = \text{MAX}$                          |                     | 140   | 180   | mA            |               |
| $C_{IN}$    | Input capacitance            | $V_{IN} = 2.0\text{V}$ at $f = 1\text{MHz}$    |                     | 6     |       | pF            |               |
| $C_{OUT}$   | Output capacitance           | $V_{OUT} = 2.0\text{V}$ at $f = 1\text{MHz}$   |                     | 11    |       |               |               |

- The PAL32VX10/A is designed to operate over the full military operating conditions. For availability and specifications contact Monolithic Memories.
- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of  $I_{IL}$  and  $I_{OZL}$  (or  $I_{IH}$  and  $I_{OZH}$ ).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

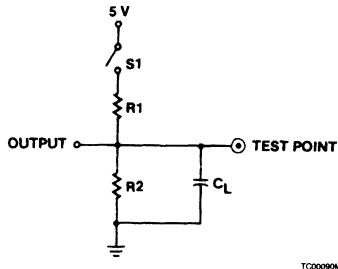
**High Speed Programmable Array Logic  
PAL32VX10, PAL32VX10A**

**Switching Characteristics** Over Operating Conditions

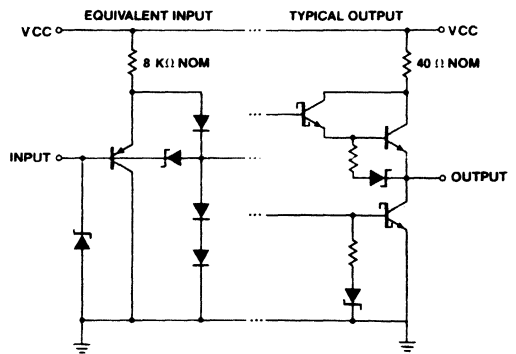
| SYMBOL    | PARAMETER   |                             | TEST CONDITION                         | STD |     |      | A   |      |     | UNIT |     |
|-----------|---|-----------------------------|--|-----|-----|------|-----|------|-----|------|-----|
|           |   |                             |  | MIN | TYP | MAX  | MIN | TYP  | MAX |      |     |
| $t_{PD}$  | Input or feedback to output   | Product terms $P_1$ - $P_n$ | $R_1 = 200\Omega$<br>$R_2 = 390\Omega$ |     | 15  | 30   |     | 15   | 25  | ns   |     |
|           |   | Product term XOR            |  |     | 25  | 35   |     | 20   | 30  |      |     |
| $t_{CLK}$ | Clock to output or feedback   |                             |  |     | 10  | 15   |     | 10   | 15  | ns   |     |
| $t_{PZX}$ | Input to output enable  |                             |  |     | 20  | 30   |     | 20   | 25  | ns   |     |
| $t_{PXZ}$ | Input to output disable   |                             |  |     | 20  | 30   |     | 20   | 25  | ns   |     |
| $t_{AP}$  | Asynchronous preset to output   |                             |  |     | 20  | 30   |     | 20   | 25  | ns   |     |
| $t_{CR}$  | Input or feedback to registered output from combinatorial configuration |                             |  |     | 75  | 90   |     | 75   | 90  | ns   |     |
| $t_{RC}$  | Input or feedback to combinatorial output from registered configuration |                             |  |     | 75  | 90   |     | 75   | 90  | ns   |     |
| $f_{MAX}$ | Maximum frequency   | Feedback (1/ $t_{P1}$ )     |  |     |     | 22.5 | 35  |      | 25  | 35   | MHz |
|           |   | Product terms $P_1$ - $P_0$ |  |     |     |      |     |      |     |      |     |
|           |   | Product term XOR            |  |     |     |      |     |      |     |      |     |
|           |   | No feedback (1/ $t_{P2}$ )  |  |     |     |      |     |      |     |      |     |
|           |   |                             |  |     | 20  | 30   |     | 22.2 | 30  |      |     |
|           |   |                             |  |     | 25  | 40   |     | 27.7 | 40  |      |     |

**2**

**Switching Test Load**



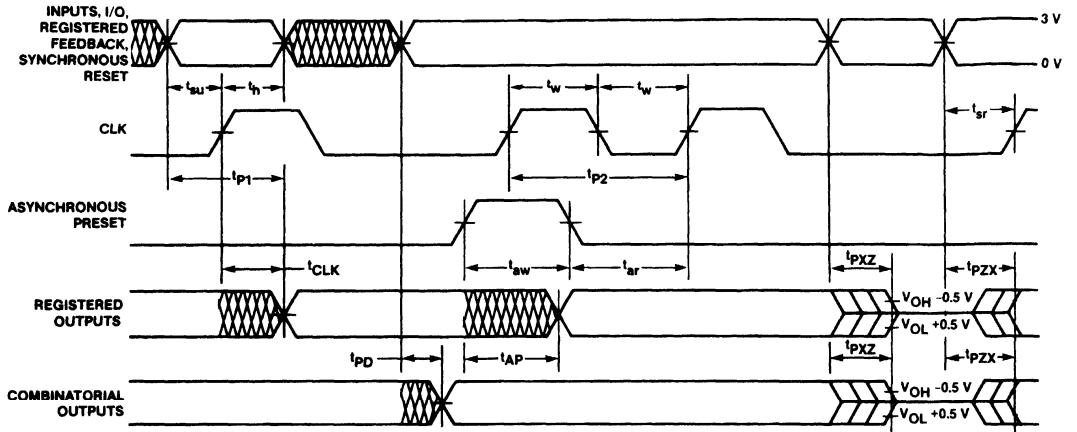
**Schematic of Inputs and Outputs**



- Notes:
- $t_{PD}$  is tested with switch  $S_1$  closed.  $C_L = 50\text{pF}$  and measured at 1.5V output level.
  - $t_{PZX}$  is measured at the 1.5V output level with  $C_L = 50\text{pF}$ .  $S_1$  is open for high impedance to "1" test, and closed for high impedance to "0" test.
  - $t_{PXZ}$  is tested with  $C_L = 5\text{pF}$ .  $S_1$  is open for "1" to high impedance test, measured at  $V_{OH} - 0.5\text{V}$  output level;  $S_1$  is closed for "0" to high impedance test measured at  $V_{OL} + 0.5\text{V}$  output level.

# High Speed Programmable Array Logic PAL32VX10, PAL32VX10A

## Switching Waveforms



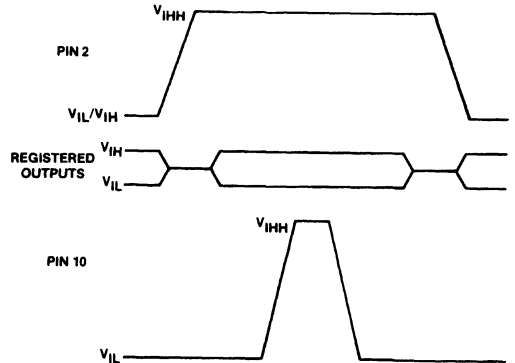
WF00340M

## Output Register Preload

The preload function allows the register to be loaded from the output pins. This feature aids functional testing of sequential designs by allowing direct setting of output states. The procedure is:

1. Raise  $V_{CC}$  to 4.5V.
2. Disable output registers by setting pin 2 to  $V_{IH}$ (12V).
3. Apply  $V_{IL}/V_{IH}$  to all registered output pins. Leave combinational outputs floating.
4. Pulse pin 10 to  $V_{IH}$ , then back to 0V.
5. Remove  $V_{IL}/V_{IH}$  from all output registers.
6. Remove high voltage from pin 2.
7. Enable registered outputs per programmed pattern.
8. Verify for  $V_{OL}/V_{OH}$  at all registered output pins.

Note:  $V_{IH} = 11.0$  (MIN), 11.5 (TYP) and 12.0 (MAX).



WF00350M

## Key to Timing Diagrams

| WAVEFORM | INPUTS                          | OUTPUTS                                |
|----------|---------------------------------|--|
|          | DON'T CARE;<br>CHANGE PERMITTED | CHANGING;<br>STATE UNKNOWN             |
|          | NOT<br>APPLICABLE               | CENTER LINE IS<br>HIGH IMPEDANCE STATE |
|          | MUST BE STEADY                  | WILL BE STEADY                         |

WF00360M

## High Speed Programmable Array Logic PAL32VX10, PAL32VX10A

### f<sub>MAX</sub> Parameters

The parameter f<sub>MAX</sub> is the maximum speed at which the PAL device is guaranteed to operate. Because flexibility inherent to PAL devices allows a choice of clocked flip-flop designs, for the convenience of the user, f<sub>MAX</sub> is specified to address two major classes of synchronous designs.

The simplest type of synchronous design can be described as a data path application. In this case, data is presented to the data terminal of the flip-flop and clocked through; no feedback

is employed (Figure 1). Under these conditions, the frequency of operation is limited by the greater of the data setup time (t<sub>su</sub>) or the minimum clock period (t<sub>w high</sub> + t<sub>w low</sub>, or t<sub>P2</sub>). This parameter is designated f<sub>MAX</sub> (no feedback).

For synchronous sequential designs, i.e., state machines, where logical feedback is required, inputs to flip-flop data terminals originate from the device input pins or flip-flop outputs via the internal feedback paths (Figure 2). Under these conditions, f<sub>MAX</sub> is defined as the reciprocal of (t<sub>su</sub> + t<sub>CLK</sub>), or t<sub>P1</sub>, and is designated f<sub>MAX</sub> (feedback).

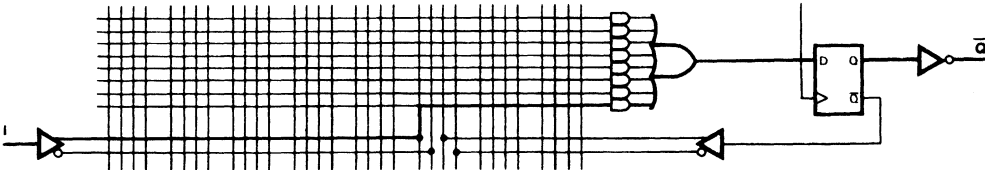


Figure 1. Data Path Register Configuration Without Feedback, Q = I

LD01070M

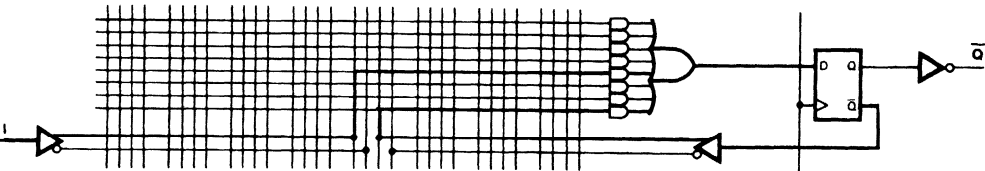


Figure 2. State Machine Configuration With Feedback, Q = I + Q̄

LD01080M

### Use of XOR Product Term

The speed of the PAL32VX10 is specified according to the use of the Exclusive-OR (XOR) product term in the macrocell. Note that the macrocell data input is a function of the two-input XOR gate, whose inputs are the OR of the product terms P1-Pn and the single additional XOR product term (Figure 3).

The specification for the path through the single XOR product term is 5ns slower than through the P1-Pn product terms and the OR gate. As a result, if the single XOR product term is changing, the macrocell data input will not be available until 5ns later than if only the P1-Pn product terms were changing. This difference between paths affects t<sub>PD</sub>, t<sub>su</sub>, and f<sub>MAX</sub> (feedback). As a result, these three parameters are specified both for only the P1-Pn product terms changing ("Product terms P1-Pn") and with the single XOR product term changing ("Product term XOR") (Figure 4).

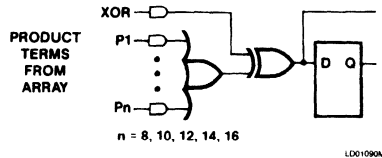


Figure 3.

LD01090M

| SPECIFICATION   |                     | EXPLANATION   |
|---|---------------------|---|
| t <sub>PD</sub> , t <sub>su</sub> , f <sub>MAX</sub> (feedback) | Product terms P1-Pn | If only the P1-Pn product terms are changing (XOR term is not changing) |
|   | Product term XOR    | If XOR term is changing   |

Figure 4.

**High Speed Programmable Array Logic  
PAL32VX10, PAL32VX10A**

| MANUFACTURER   | PROGRAMMER CONFIGURATION   |
|--|--|
| Data I/O Corp.<br>10525 Willows Rd. NE, PO Box 97046<br>Redmond, WA 98073-9746<br>(800) 247-5700   | System 29A, 29B<br>LogicPak™ 303A<br>Adapter 303A-011A/B-V01<br><br>Family/Pinout Code:<br>22-77 |
| Digelec Inc.<br>1602 Lawrence Ave., Suite 113<br>Ocean, NJ 07712<br>(201) 493-2420   | Contact manufacturer   |
| Digital Media<br>11770 East Warner Ave., Suite 225<br>Fountain Valley, CA 92708<br>(714) 751-1373  | Contact manufacturer   |
| Japan Macnics Corp.<br>2999 Monterey/Salinas Hwy.<br>Monterey, CA 93940<br>(408) 373-3607  | Contact manufacturer   |
| Kontron Electronics Inc.<br>1230 Charleston Rd.<br>Mountain View, CA 94039-7230<br>(415) 965-7020  | System EPP-80<br>Module UPM-B rev. 1.48 or later   |
| Micropross<br>Parc d'activite des Pres<br>5, rue Denis-Papin<br>59650 Villeneuve-d'Ascq<br>(20) 47.90.40   | Contact manufacturer   |
| Stag Microsystems Inc.<br>528-5 Weddell Dr.<br>Sunnyvale, CA 94089<br>(408) 745-1991   | Contact manufacturer   |
| Storey Systems<br>3201 N. Hwy 67, Suite H<br>Mesquite, TX 75150<br>(214) 270-4135  | Contact manufacturer   |
| Structured Design<br>988 Bryant Way<br>Sunnyvale, CA 94087<br>(408) 988-0725   | Contact manufacturer   |
| Valley Data Sciences<br>Charleston Business Park<br>2426 Charleston Rd.<br>Mountain View, CA 94043<br>(415) 968-2900                               | Contact manufacturer   |
| Varix Corp.<br>1210 E. Campbell Rd., Suite 100<br>Richardson, TX 75081<br>(214) 437-0777   | Contact manufacturer   |
| MANUFACTURER   | SOFTWARE DEVELOPMENT SYSTEM  |
| Monolithic Memories, Inc.<br>IdeaLogic® Exchange M/S 09-25<br>2175 Mission College Blvd.<br>Santa Clara, CA 95054-1592<br>(800) 247-6527 ext. 6105 | PALASM® 2 Software rev. 2.21 and later   |
| Data I/O Corp.<br>10525 Willows Rd. NE, PO Box 97046<br>Redmond, WA 98073-9746<br>(800) 247-5700   | ABEL™ Software — Contact manufacturer  |
| Personal CAD Systems<br>Assisted Technology Division<br>1290 Parkmoor Ave.<br>San Jose, CA 95126<br>(408) 971-1300                                 | CUPL™ Software — Contact manufacturer  |

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LogicPak and ABEL are trademarks of Data I/O Corporation.  
CUPL is a trademark of Personal CAD Systems.

## PMS14R21/A

### Features/Benefits

- User-programmable synchronous state machine
- 25MHz maximum frequency for compatibility with 12.5MHz processors
- 14 inputs (8 external), 8 outputs, 128 states
- PAL<sup>®</sup> array optimizes product terms and states
- Internal feedback adds versatility and control
- Optimized for four-way branching
- User-selectable asynchronous preset or asynchronous enable function
- Power-up preset for start-up in known state
- Diagnostics-On-Chip<sup>™</sup> shadow register eases chip and board-level testing
- PROSE<sup>™</sup> device software makes it easy to "write your sequencer in PROSE"
- Programmed on standard logic programmers
- Security fuse prevents pattern duplication
- Space-saving 24-pin 300-mil SKINNYDIP<sup>®</sup> and 28-pin PLCC and LCC packages

### Description

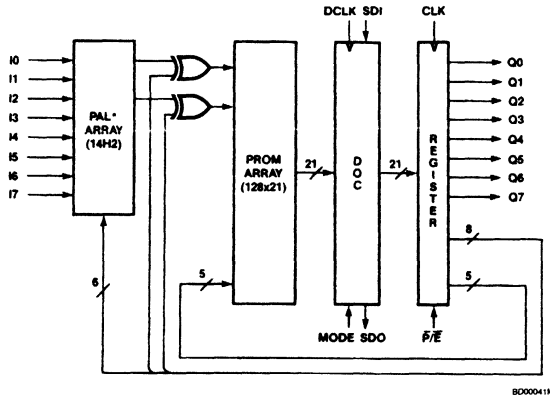
The PMS14R21 programmable sequencer is the first member of the PROSE (PROgrammable SEquencer) family. The PMS14R21 is a high-speed, 14-input, 8-output state machine. It consists of a 128x21 PROM array preceded by a 14H2 PAL array. The PAL array is efficient for a large number of input conditions, while the PROM array is optimal for a large number of product terms and states. The combination allows a very efficient state machine with a large number of inputs and state bits. The PAL array, with eight product terms per output, operates on the eight conditional and six state inputs to select two control bits to the PROM. Two Exclusive-OR gates between the two arrays help to minimize product terms and redundant states. Five lines feed back from the PROM to form the primary address for the next state. The PROM stores up to 128 states of eight outputs and thirteen feedback control signals.

### Applications

- High speed sequential logic
- Peripheral controller
- Cache control sequencer
- Signal processing sequencer
- Industrial control

2

### Block Diagram



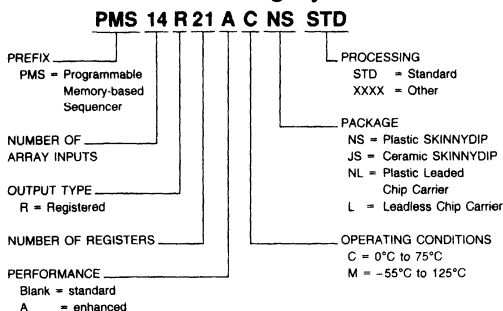
### Definition of Signals

I0-I7 Primary inputs to the PAL array  
 Q0-Q7 Outputs from the register  
 $\bar{P}/\bar{E}$  Programmable asynchronous preset ( $\bar{P}$ ) or asynchronous enable ( $\bar{E}$ )

CLK Clock for output register  
 DCLK Clock for diagnostic register  
 MODE Selects diagnostic functions  
 SDI Serial data input to shadow register  
 SDO Serial data output from shadow register

PROSE<sup>™</sup> and Diagnostics-On-Chip<sup>™</sup> are trademarks of Monolithic Memories, Inc.

**PROSE Part Numbering System**



**Diagnostics-On-Chip Feature**

The PMS14R21 is the newest member of the Diagnostics-On-Chip family. These devices incorporate a serial shadow register on-chip which facilitates board-level testing. The shadow register has a Serial Data Input (SDI), Serial Data Output (SDO) and its own clock (DCLK). The MODE control configures the shadow register either in parallel with the output register or in serial shift mode (see function table). Other devices with this feature are listed below.

**Diagnostics Family Members**

| PART NUMBER | DESCRIPTION                         |
|-------------|-------------------------------------|
| 53/63DA441  | 1K x 4 PROM (async. enables)        |
| 53/63DA442  | 1K x 4 PROM (async/sync. enables)   |
| 53/63DA841  | 2K x 4 PROM                         |
| 53/63D1641  | 4K x 4 PROM (async. enable)         |
| 53/63DA1643 | 4K x 4 PROM (async. initialization) |
| 54/74S818   | 8-bit register                      |

**Diagnostic Function Table**

| INPUTS |     |     |      | OUTPUTS                          |   |                 | OPERATION  |
|--------|-----|-----|------|----------------------------------|---|-----------------|--|
| MODE   | SDI | CLK | DCLK | Q <sub>20</sub> - Q <sub>0</sub> | S <sub>20</sub> - S <sub>0</sub>                          | SDO             |  |
| L      | X   | ↑   | *    | Q <sub>n</sub> ← PROM            | HOLD  | S <sub>20</sub> | Load output register from PROM array                                     |
| L      | X   | *   | ↑    | HOLD                             | S <sub>n</sub> ← S <sub>n-1</sub><br>S <sub>0</sub> ← SDI | S <sub>20</sub> | Shift shadow register data   |
| L      | X   | ↑   | ↑    | Q <sub>n</sub> ← PROM            | S <sub>n</sub> ← S <sub>n-1</sub><br>S <sub>0</sub> ← SDI | S <sub>20</sub> | Load output register from PROM array while shifting shadow register data |
| H      | X   | ↑   | *    | Q <sub>n</sub> ← S <sub>n</sub>  | HOLD  | SDI             | Load output register from shadow register                                |
| H      | L   | *   | ↑    | HOLD                             | S <sub>n</sub> ← Q <sub>n</sub>                           | SDI             | Load shadow register from output bus and feedback                        |
| H      | H   | *   | ↑    | HOLD                             | HOLD  | SDI             | † No operation   |

\* Clock must be steady or falling.  
† Reserved operation for 54/74S818 8-Bit Diagnostic Register.

**Software Support**

PROSE device software from Monolithic Memories provides full support for the PMS14R21. Based on PALASM<sup>®2</sup> syntax, the software automatically converts a state machine description directly into the PAL and PROM array fuse maps, for downloading to a programmer. The syntax supports both Mealy and Moore state machine models, and makes optimal use of the features of the PROSE device. Simulation support is also provided, both for design checking and for generation of test vectors for device testing. Additional support is available from third-party software vendors, including the ABEL<sup>™</sup> package from Data I/O.

**Programming**

Both the PAL and PROM arrays are programmed on standard logic programmers using the JEDEC programming format. The TiW fuses program from the low to the high state. Programming also sets the architectural fuse which selects between asynchronous preset or asynchronous output enable; the unprogrammed state is preset. If asynchronous preset is selected, asserting the pin low will set all outputs and feedback bits high.

**Power-up Preset**

Power-up preset is provided for system start-up in a known state. It has the same effect as preset; all output register bits go high.



## PAL10H20P8

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### Features/Benefits

- 20 logic inputs: 12 external, 8 feedback
- 8 outputs with programmable polarity
- ECL technology for ultra-high speed — max  $t_{PD} = 6\text{ns}$
- 32 product terms with term sharing
- 10KH ECL compatible
- Fully AC tested
- Input pull-down resistors
- Voltage compensated
- Space-saving 24-pin SKINNYDIP® and 28-pin PLCC packages
- Programmable using standard TTL programmers with adapter
- Greater than 99% programming yield
- Security fuse prevents unauthorized copying

### Description

The PAL10H20P8 is a 10KH family compatible ECL PAL device having twelve dedicated inputs and eight outputs with feedback. A programmable AND array and a fixed OR array make possible the implementation of a wide variety of logic functions with far fewer packages than with SSI devices. The logic is implemented by opening metal fuse connections within the AND array. Designs can be specified by using any of a variety of software packages which accept the design and assemble a file that can be downloaded into a device programmer. Fuses are programmed using any of the qualified PAL device programmers.

The outputs are equipped with programmable polarity. They can drive a  $50\Omega$  termination (to  $V_{CC} - 2.0\text{V}$ ). Product term sharing is provided to allow greater flexibility in assigning product terms to outputs.

The input pins have  $50\text{k}\Omega$  internal pull-down resistors, which allow unused inputs to be left open. Open inputs will assume a logic low state.

### Features

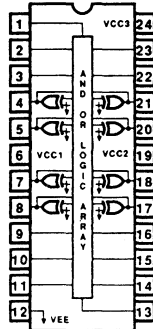
Each output has a programmable polarity fuse, allowing for more efficient representation of many logic functions. Each output is active high with polarity fuse intact, and active low with the polarity fuse blown.

The programmable AND array contains a total of thirty-two product terms. Product terms are arranged in groups of eight. The terms in each group can be shared mutually exclusively between two adjacent output cells. If a particular product term is needed for two outputs, then two identical product terms are generated: one for each output.

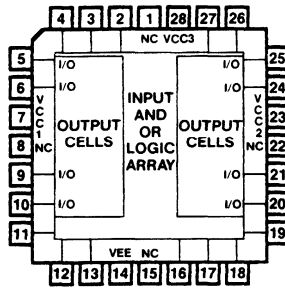
A security fuse is provided to help protect the fuse pattern from unauthorized copying. Once the security fuse has been programmed, it is no longer possible to verify the contents of the fuse array electrically. The security fuse has no effect on functionality.

# PAL10H20P8

## DIP Pinout



## PLCC Pinout



CD00880M

## PAL10H20P8

### Absolute Maximum Ratings

These ratings specify the conditions above which the device may be permanently damaged. AC and DC specifications are not necessarily guaranteed over this range.

|  |                |
|--|----------------|
| Supply voltage $V_{EE}$ ( $V_{CC1} = V_{CC2} = V_{CC3} = 0V$ ) ..... | -8.0V to 0V    |
| Input voltage $V_I$ ( $V_{CC1} = V_{CC2} = V_{CC3} = 0V$ ) .....     | 0V to $V_{EE}$ |
| Output current, $I_{OUT}$  |                |
| Continuous .....   | 35mA           |
| Surge .....  | 100mA          |
| Storage temperature range, $T_{stg}$ .....                           | -65°C to 150°C |

### Operating Conditions

| SYMBOL   | PARAMETER                        | COMMERCIAL |      |       | UNIT |
|----------|----------------------------------|------------|------|-------|------|
|          |                                  | MIN        | TYP  | MAX   |      |
| $V_{EE}$ | Supply voltage ( $V_{CC} = 0V$ ) | -5.46      | -5.2 | -4.94 | V    |
| $T_A$    | Operating free-air temperature   | 0          |      | 75    | °C   |

2

### Electrical Characteristics $V_{EE} = -5.2V \pm 5%$ (See note 1)

| SYMBOL    | PARAMETER            | TEST CONDITIONS                        | 0°C   |       | 25°C  |       | 75°C  |        | UNIT     |
|-----------|----------------------|--|-------|-------|-------|-------|-------|--------|----------|
|           |                      |  | MIN   | MAX   | MIN   | MAX   | MIN   | MAX    |          |
| $I_{EE}$  | Power supply current | Inputs $V_{IN} = V_{IH}$ Max           | -     | 210   | -     | 210   | -     | 210    | mA       |
| $I_{inH}$ | Input current high   | $V_{IH}$ Min < $V_{in}$ < $V_{IH}$ Max | -     | 425   | -     | 265   | -     | 265    | μA       |
| $I_{inL}$ | Input current low    | $V_{IL}$ Min < $V_{in}$ < $V_{IL}$ Max | 0.5   | -     | 0.5   | -     | 0.3   | -      | μA       |
| $V_{OH}$  | High output voltage  | (See Note 2)                           | -1.02 | -0.84 | -0.98 | -0.81 | -0.92 | -0.735 | $V_{dc}$ |
| $V_{OL}$  | Low output voltage   | (See Note 2)                           | -1.95 | -1.63 | -1.95 | -1.63 | -1.95 | -1.60  | $V_{dc}$ |
| $V_{iH}$  | High input voltage   | (See Note 2)                           | -1.17 | -0.84 | -1.13 | -0.81 | -1.07 | -0.735 | $V_{dc}$ |
| $V_{iL}$  | Low input voltage    | (See Note 2)                           | -1.95 | -1.48 | -1.95 | -1.48 | -1.95 | -1.45  | $V_{dc}$ |

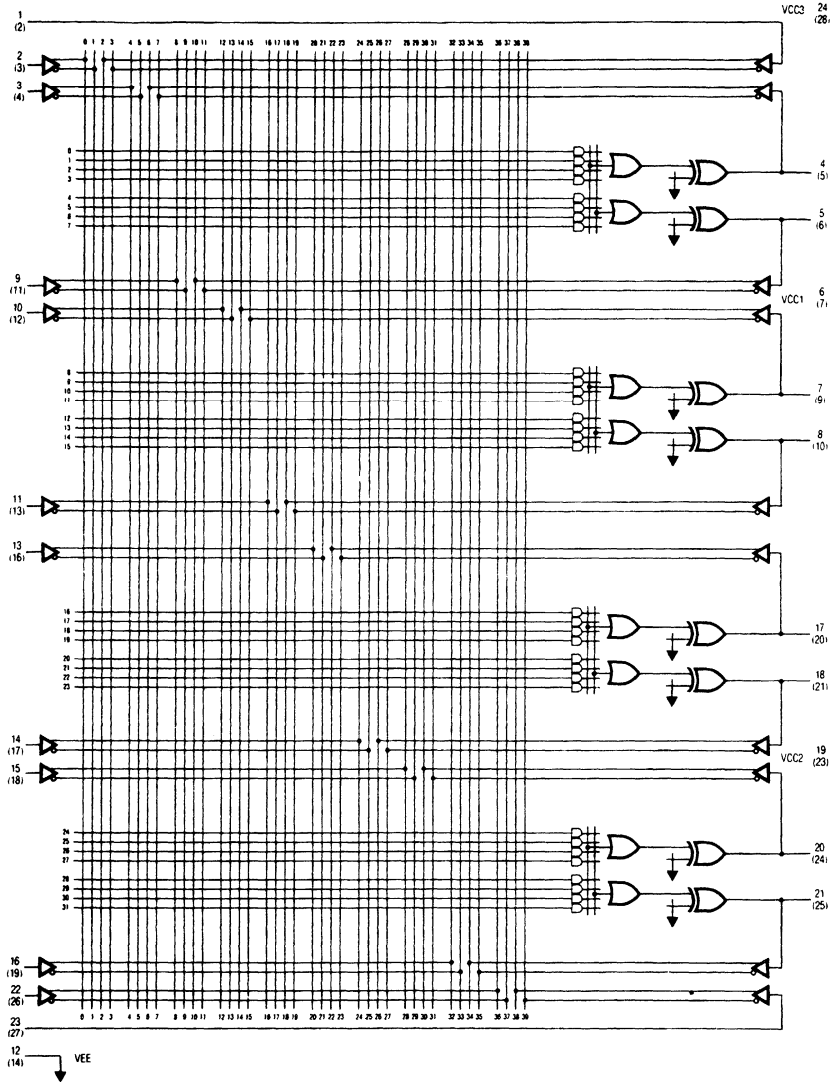
### Switching Characteristics $V_{EE} = -5.2V \pm 5%$ (See note 2)

| SYMBOL   | PARAMETER           | 0°C |     | 25°C |     | 75°C |     | UNIT |
|----------|---------------------|-----|-----|------|-----|------|-----|------|
|          |                     | MIN | MAX | MIN  | MAX | MIN  | MAX |      |
| $t_{PD}$ | Propagation delay   | 2.0 | 6.0 | 2.0  | 6.0 | 2.0  | 6.0 | ns   |
| $t_R$    | Rise time (20%-80%) | 0.7 | 2.2 | 0.7  | 2.0 | 0.7  | 2.2 | ns   |
| $t_F$    | Fall time (80%-20%) | 0.7 | 2.2 | 0.7  | 2.0 | 0.7  | 2.2 | ns   |

- Note:
1. Each ECL 10KH series circuit has been designed to meet the specifications shown in test table after thermal equilibrium has been established. The circuit is in test socket or mounted on a printed board and transverse air flow greater than 500 linear fpm is maintained.
  2. Outputs are terminated through a 50Ω resistor to  $V_{CC} - 2.0V$ . Discrete carbon resistors should be used for terminations. Multiple-resistor packs and metal film discrete resistors are inductive and should be avoided. The single-ended nature of the outputs demands strict adherence to ground and termination plane design techniques.
  3. If pin 13 (PLCC pin 16) is not used, it should be left open or terminated to  $V_{TT}$  ( $= V_{CC} - 2.0V$ ). It should not be terminated to  $V_{EE}$ .

# PAL10H20P8

## Logic Diagram



LD008404

**MegaPAL Devices**  
**32R16, 64R32**

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**MegaPAL Devices**

|          | ARRAY INPUTS | REGISTERED OUTPUTS | $t_{PD}$<br>(ns) | $I_{CC}$<br>(mA) |
|----------|--------------|--------------------|------------------|------------------|
| PAL32R16 | 32           | 16                 | 40               | 280              |
| PAL64R32 | 64           | 32                 | 50               | 640              |

**Description**

The MegaPAL Devices offer very high density programmable logic.

**Programmable Polarity**

Each flip-flop has individually programmable polarity. The unprogrammed state is active low.

**Product Term Sharing**

Product term sharing allows each pair of outputs to share its product terms with one output or the other (not both). Each pair has a total of sixteen product terms; thus, one output can use zero to sixteen terms while the other has sixteen to zero. Product terms can only be shared mutually exclusively. If both outputs need the same term, it must be created twice, once for each output.

**Register Bypass**

Registers in either device can be bypassed in banks of eight, creating a set of combinatorial outputs.

**Reset**

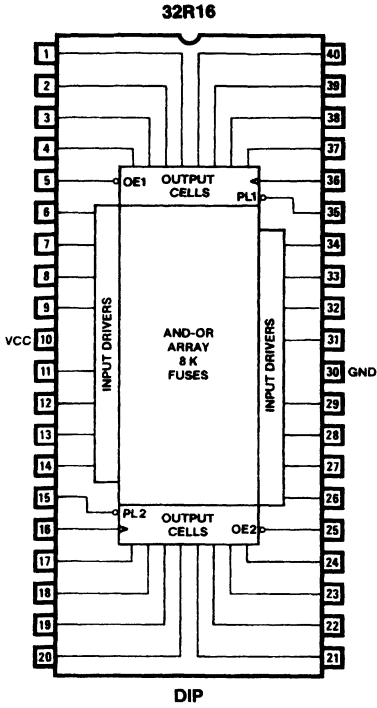
The PAL64R32 also features asynchronous reset (previously called preset). The reset function sets a bank of eight registers to a logic LOW, setting the output HIGH if active low.

**Register Preload and Power-up Reset**

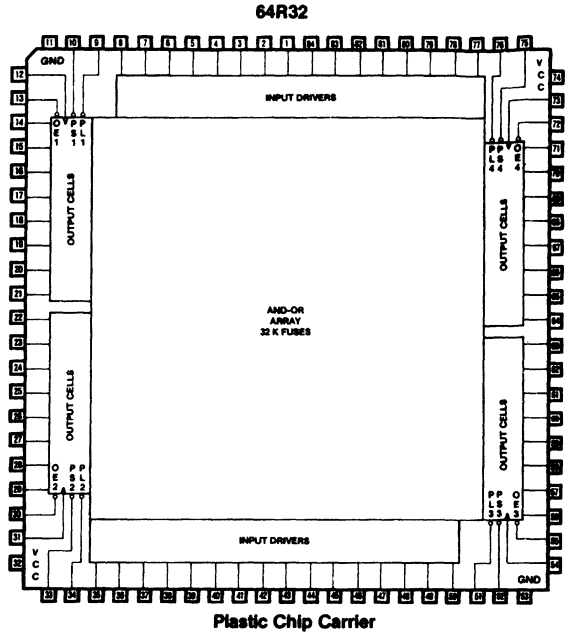
Both devices also offer register preload for device testability. The registers can be preloaded from the outputs by using TTL level signals in order to simplify functional testing. This series also offers Power-up Reset, whereby the registers power up to a logic LOW, setting active-low outputs to a logic HIGH.

**2**

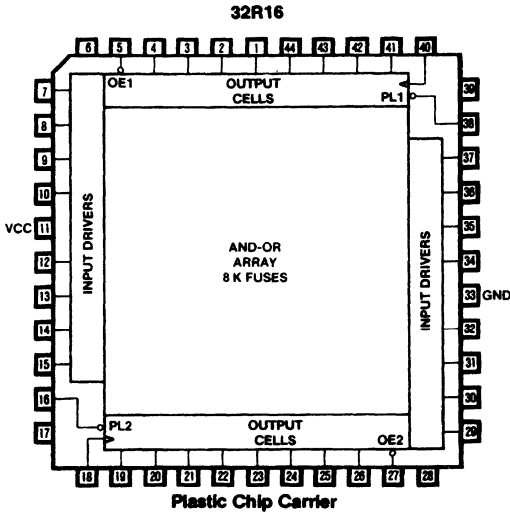
**MegaPAL Devices**  
**32R16, 64R32**



CD06250M



CD06260M



CD06270M

**MegaPAL Devices  
64R32**

**Testing Conditions**

| SYMBOL    | PARAMETER            | COMMERCIAL |     |     | UNIT |
|-----------|----------------------|------------|-----|-----|------|
|           |                      | MIN        | TYP | MAX |      |
| $t_{wp}$  | Preload pulse width  | 35         |     |     | ns   |
| $t_{sup}$ | Preload setup time   | 50         |     |     | ns   |
| $t_{hp}$  | Preload hold time    | 5          |     |     | ns   |
| $t_{PRW}$ | Preset pulse width   | 25         |     |     | ns   |
| $t_{PRR}$ | Preset recovery time | 35         |     |     | ns   |

**2**

**MegaPAL Devices  
32R16**

**Operating Conditions**

| SYMBOL           | PARAMETER                      |                      | MILITARY |     |     | COMMERCIAL |     |      | UNIT |
|------------------|--------------------------------|----------------------|----------|-----|-----|------------|-----|------|------|
|                  |                                |                      | MIN      | TYP | MAX | MIN        | TYP | MAX  |      |
| V <sub>CC</sub>  | Supply voltage                 |                      | 4.5      | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| t <sub>w</sub>   | Width of clock                 | Low                  | 25       |     |     | 20         |     |      | ns   |
|                  |                                | High                 | 25       |     |     | 20         |     |      |      |
| t <sub>wp</sub>  | Preload pulse width            |                      | 45       |     |     | 35         |     |      | ns   |
| t <sub>su</sub>  | Setup time for input to clock  | Polarity fuse intact | 50       |     |     | 40         |     |      | ns   |
|                  |                                | Polarity fuse blown  | 50       |     |     | 40         |     |      |      |
| t <sub>sup</sub> | Preload setup time             |                      | 30       |     |     | 25         |     |      | ns   |
| t <sub>h</sub>   | Hold time                      |                      | 0        | -10 |     | 0          | -10 |      | ns   |
| t <sub>hp</sub>  | Preload hold time              |                      | 10       |     |     | 5          |     |      | ns   |
| T <sub>A</sub>   | Operating free-air temperature |                      | -55      |     |     | 0          |     | 75   | °C   |
| T <sub>C</sub>   | Operating case temperature     |                      |          |     | 125 |            |     |      | °C   |

**Electrical Characteristics (Over Operating Conditions)**

| SYMBOL                        | PARAMETER                    | TEST CONDITION        |                              | MIN | TYP   | MAX   | UNIT |
|-------------------------------|------------------------------|-----------------------|------------------------------|-----|-------|-------|------|
| V <sub>IL</sub> <sup>1</sup>  | Low-level input voltage      |                       |                              |     |       | 0.8   | V    |
| V <sub>IH</sub> <sup>1</sup>  | High-level input voltage     |                       |                              | 2   |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA       |     | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>2</sup>  | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V        |     | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>2</sup>  | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V        |     |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V        |     |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN | Mil I <sub>OL</sub> = 8mA    |     | 0.3   | 0.5   | V    |
|                               |                              |                       | Com I <sub>OL</sub> = 8mA    |     |       |       |      |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN | Mil I <sub>OH</sub> = -2mA   | 2.4 | 2.8   |       | V    |
|                               |                              |                       | Com I <sub>OH</sub> = -3.2mA |     |       |       |      |
| I <sub>OZL</sub> <sup>2</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0.4V        |     |       | -100  | μA   |
| I <sub>OZH</sub> <sup>2</sup> |                              |                       | V <sub>O</sub> = 2.4V        |     |       | 100   | μA   |
| I <sub>OS</sub> <sup>3</sup>  | Output short-circuit current | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0V          | -30 | -70   | -130  | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX |                              |     | 200   | 280   | mA   |

**Switching Characteristics (Over Operating Conditions)**

| SYMBOL           | PARAMETER                   |                      | TEST CONDITIONS                                 | MILITARY |     |     | COMMERCIAL |     |     | UNIT |
|------------------|-----------------------------|----------------------|---|----------|-----|-----|------------|-----|-----|------|
|                  |                             |                      |   | MIN      | TYP | MAX | MIN        | TYP | MAX |      |
| t <sub>PD</sub>  | Input to output             | Polarity fuse intact | R <sub>1</sub> = 560Ω<br>R <sub>2</sub> = 1.1KΩ |          |     | 50  |            |     | 40  | ns   |
|                  |                             | Polarity fuse blown  |   |          |     | 55  |            |     | 45  |      |
| t <sub>CLK</sub> | Clock to output or feedback |                      |   |          |     | 30  |            |     | 25  | ns   |
| t <sub>PZX</sub> | Output enable               |                      |   |          |     | 25  |            |     | 20  | ns   |
| t <sub>PXZ</sub> | Output disable              |                      |   |          |     | 25  |            |     | 20  | ns   |
| f <sub>MAX</sub> | Maximum frequency           |                      |   |          | 14  |     |            | 16  |     | MHz  |

1. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
3. No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.



**MegaPAL Devices  
64R32**

**Operating Conditions**

| SYMBOL          | PARAMETER                      |                      | COMMERCIAL <sup>1</sup> |     |      | UNIT |
|-----------------|--------------------------------|----------------------|-------------------------|-----|------|------|
|                 |                                |                      | MIN                     | TYP | MAX  |      |
| V <sub>CC</sub> | Supply voltage                 |                      | 4.75                    | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                 | Low                  | 20                      |     |      | ns   |
|                 |                                | High                 | 20                      |     |      |      |
| t <sub>su</sub> | Setup time from input to clock | Polarity fuse intact | 40                      |     |      | ns   |
|                 |                                | Polarity fuse blown  | 40                      |     |      |      |
| t <sub>h</sub>  | Hold time                      |                      | 0                       | -10 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature |                      | 0                       |     | 75   | °C   |
| T <sub>C</sub>  | Operating case temperature     |                      |                         |     |      | °C   |

**2**

**Electrical Characteristics (Over Operating Conditions)**

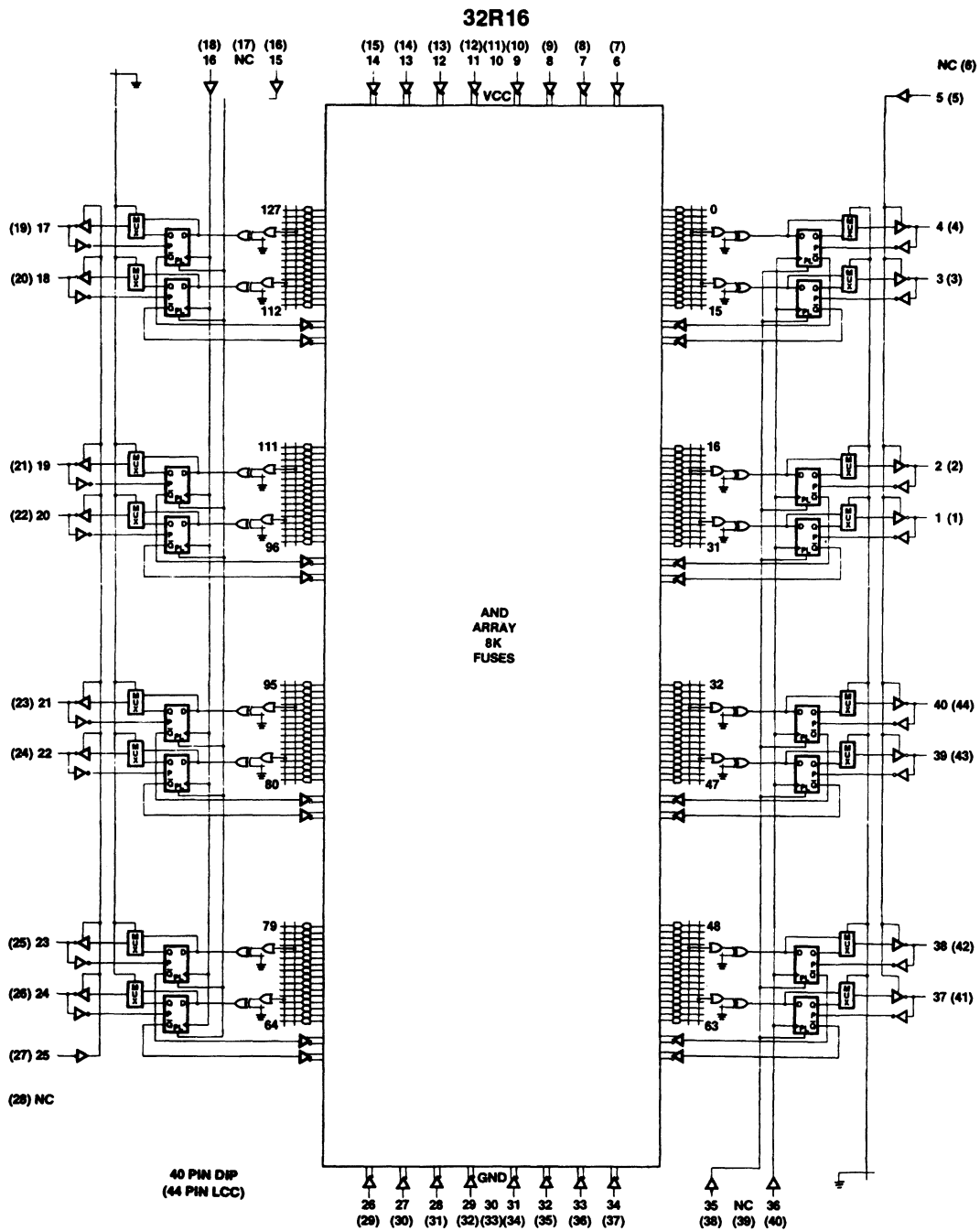
| SYMBOL                        | PARAMETER                    | TEST CONDITION        |                          | COMMERCIAL |       |       | UNIT |
|-------------------------------|------------------------------|-----------------------|--------------------------|------------|-------|-------|------|
|                               |                              |                       |                          | MIN        | TYP   | MAX   |      |
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage      |                       |                          |            |       | 0.8   | V    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage     |                       |                          | 2          |       |       | V    |
| V <sub>IC</sub>               | Input clamp voltage          | V <sub>CC</sub> = MIN | I <sub>I</sub> = -18mA   |            | -0.8  | -1.5  | V    |
| I <sub>IL</sub> <sup>3</sup>  | Low-level input current      | V <sub>CC</sub> = MAX | V <sub>I</sub> = 0.4V    |            | -0.02 | -0.25 | mA   |
| I <sub>IH</sub> <sup>3</sup>  | High-level input current     | V <sub>CC</sub> = MAX | V <sub>I</sub> = 2.4V    |            |       | 25    | μA   |
| I <sub>I</sub>                | Maximum input current        | V <sub>CC</sub> = MAX | V <sub>I</sub> = 5.5V    |            |       | 1     | mA   |
| V <sub>OL</sub>               | Low-level output voltage     | V <sub>CC</sub> = MIN | I <sub>OL</sub> = 8mA    |            | 0.3   | 0.5   | V    |
| V <sub>OH</sub>               | High-level output voltage    | V <sub>CC</sub> = MIN | I <sub>OH</sub> = -0.4mA | 2.4        | 2.8   |       | V    |
| I <sub>OZL</sub> <sup>3</sup> | Off-state output current     | V <sub>CC</sub> = MAX | V <sub>O</sub> = 0.4V    |            |       | -100  | μA   |
| I <sub>OZH</sub> <sup>3</sup> |                              |                       | V <sub>O</sub> = 2.4V    |            |       | 100   | μA   |
| I <sub>OS</sub> <sup>4</sup>  | Output short-circuit current | V <sub>CC</sub> = 5V  | V <sub>O</sub> = 0V      | -10        | -40   | -60   | mA   |
| I <sub>CC</sub>               | Supply current               | V <sub>CC</sub> = MAX |                          |            | 400   | 640   | mA   |

**Switching Characteristics (Over Operating Conditions)**

| SYMBOL           | PARAMETER                   |                      | TEST CONDITIONS                                 | COMMERCIAL |     |     | UNIT |     |
|------------------|-----------------------------|----------------------|---|------------|-----|-----|------|-----|
|                  |                             |                      |   | MIN        | TYP | MAX |      |     |
| t <sub>PD</sub>  | Input to output             | Polarity fuse intact | R <sub>1</sub> = 560Ω<br>R <sub>2</sub> = 1.1KΩ |            |     | 50  | ns   |     |
|                  |                             | Polarity fuse blown  |   |            |     | 55  |      |     |
| t <sub>CLK</sub> | Clock to output or feedback |                      |   |            |     | 22  | ns   |     |
| t <sub>PZX</sub> | Output enable               |                      |   |            |     | 30  | ns   |     |
| t <sub>PXZ</sub> | Output disable              |                      |   |            |     | 30  | ns   |     |
| t <sub>PRH</sub> | Preset to output            |                      |   |            |     | 35  | ns   |     |
| f <sub>MAX</sub> | Maximum frequency           |                      |   |            | 16  | 20  |      | MHz |

- The PAL64R32 Series is designed to operate over the full military operating conditions. For availability and specifications, contact Monolithic Memories.
- These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
- I/O pin leakage is the worst case of I<sub>IL</sub> and I<sub>OZL</sub> (or I<sub>IH</sub> and I<sub>OZH</sub>).
- No more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

**MegaPAL Devices**  
**32R16 Logic Diagram**



L000720M

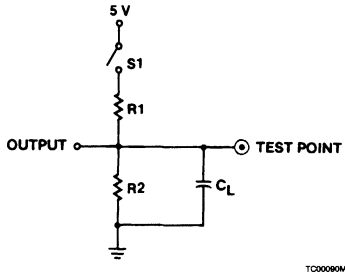


## Test Load

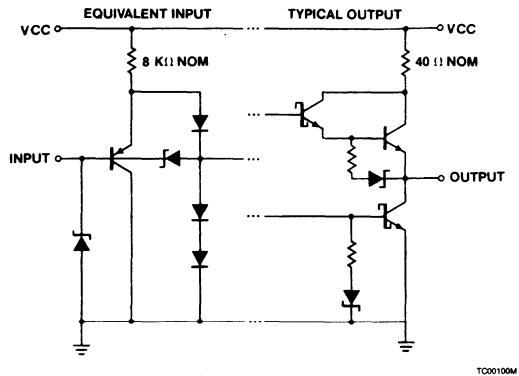
### Absolute Maximum Ratings

|                                | Operating           | Programming        |
|--------------------------------|---------------------|--------------------|
| Supply voltage $V_{CC}$ .....  | -0.5V to 7V .....   | -0.5V to 12V ..... |
| Input voltage .....            | -1.5V to 5.5V ..... | -1.0V to 22V ..... |
| Off-state output voltage ..... | 5.5V .....          | 12V .....          |
| Storage temperature .....      | -65°C to +150°C     |                    |

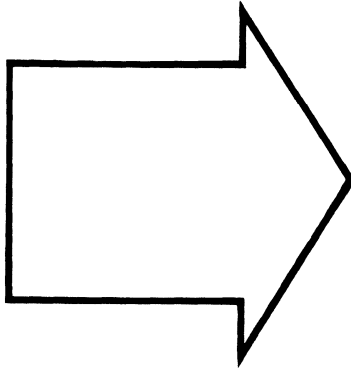
### Switching Test Load



### Schematic of Inputs and Outputs



- Notes:
1.  $t_{pD}$  is tested with switch  $S_1$  closed,  $C_L = 50\text{pF}$  and measured at 1.5V output level.
  2.  $t_{pZX}$  is measured at the 1.5V output level with  $C_L = 50\text{pF}$ .  $S_1$  is open for high impedance to "1" test, and closed for high impedance to "0" test.
  3.  $t_{pXZ}$  is tested with  $C_L = 5\text{pF}$ .  $S_1$  is open for "1" to high impedance test, measured at  $V_{OH} - 0.5\text{V}$  output level;  $S_1$  is closed for "0" to high impedance test measured at  $V_{OL} + 0.5\text{V}$  output level.



|   |           |
|---|-----------|
| <b>PAL® Device Introduction</b>         | <b>1</b>  |
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| <b>PALASM® Software Syntax</b>          | <b>6</b>  |
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**MMI PAL® Device Programmer Reference Guide**

**Data I/O Corporation**

**20 Pin Device Families**

10525 Willows Road N.E.  
 PO Box 97046  
 Redmond, WA 98073-9746  
 (800) 247-5700

|                                 |
|---------------------------------|
| Models 19, 29A, 29B<br>Model 60 |
|---------------------------------|

| Series   | Part Number            | System                     | LogicPak™ | Adapter                         | Family Code | Pinout Code |
|--|------------------------|----------------------------|-----------|---------------------------------|-------------|-------------|
| Small 20/-2 Combinatorial                          | PAL10H8/-2             | Model 60<br>Rev. V05       | 303A      | 303A-002-V08<br>303A-011A/B-V01 | 22          | 18          |
|  | PAL10L8/-2             |                            |           |                                 |             | 13          |
|  | PAL12H6/-2             |                            |           |                                 |             | 19          |
|  | PAL12L6/-2             | Models<br>19<br>29A<br>29B | 14        |                                 |             |             |
|  | PAL14H4/-2             |                            | 20        |                                 |             |             |
|  | PAL14L4/-2             |                            | 15        |                                 |             |             |
|  | PAL16H2/-2             |                            | 22        |                                 |             |             |
|  | PAL16L2/-2             |                            | 16        |                                 |             |             |
|  | PAL16C1/-2             |                            | 21        |                                 |             |             |
| Medium 20/<br>20A/20A-2/4/<br>20B-2/-4<br>Standard | PAL16L8/A/-2/-4/B-2/-4 |                            |           |                                 | ↓           | 17          |
|  | PAL16R8/A/-2/-4/B-2/-4 |                            |           |                                 |             | 24          |
|  | PAL16R6/A/-2/-4/B-2/-4 |                            |           |                                 |             | ↓           |
|  | PAL16R4/A/-2/-4/B-2/-4 |                            |           |                                 |             | ↓           |
| Medium<br>20B/D                                    | PAL16L8B/D             |                            |           |                                 | 30          | 17          |
|  | PAL16R8B/D             |                            |           |                                 |             | 24          |
|  | PAL16R6B/D             |                            |           |                                 |             | ↓           |
|  | PAL16R4B/D             |                            |           |                                 |             | ↓           |
| Medium<br>20BP<br>Standard                         | PAL16L8BP              |                            | 303A-V04  |                                 | 22          | 17          |
|  | PAL16R8BP              |                            | ↓         |                                 |             |             |
|  | PAL16R6BP              |                            | 67        |                                 |             |             |
|  | PAL16R4BP              |                            | ↓         |                                 |             |             |
| Medium 20PA<br>Programmable<br>Polarity            | PAL16P8A               |                            |           |                                 | ↓           | 30          |
|  | PAL16RP8A              |                            |           |                                 |             | 31          |
|  | PAL16RP6A              |                            |           |                                 |             | ↓           |
|  | PAL16RP4A              |                            |           |                                 |             | ↓           |
| Large 20<br>Arithmetic                             | PAL16X4                |                            | 303A      |                                 | ↓           | 24          |
|  | PAL16A4                |                            | ↓         |                                 |             |             |
| Large 20RA<br>Asynchronous                         | PAL16RA8               |                            |           |                                 | ↓           | 30          |

**3**

Note: The software and hardware revisions listed are the earliest revisions that support these products.  
 Later software and hardware revisions can also be assumed to support these products.

## MMI PAL<sup>®</sup> Device Programmer Reference Guide

### Data I/O

### 24 Pin and MegaPAL<sup>™</sup> Device Families

| Series   | Part Number             | System                     | LogicPak <sup>™</sup> | Adapter                         | Family Code | Pinout Code |
|--|-------------------------|----------------------------|-----------------------|---------------------------------|-------------|-------------|
| <b>Small 24 Combinatorial</b>                  | PAL12L10                | Model 60                   | 303A                  | 303A-002-V08                    | 22          | 01          |
|  | PAL14L8                 | Rev. V05                   | ↓                     | 303A-011A/B-V01                 |             | 02          |
|  | PAL16L6                 | Models<br>19<br>29A<br>29B | ↓                     | ↓                               |             | 03          |
|  | PAL18L4                 |                            | ↓                     | ↓                               |             | 04          |
|  | PAL20L2                 |                            | ↓                     | ↓                               |             | 05          |
|  | PAL20C1                 |                            | ↓                     | ↓                               |             | 12          |
| <b>Small 24A Decoder</b>                       | PAL6L16A                | ↓                          | ↓                     | ↓                               | 48          |             |
|  | PAL8L14A                | ↓                          | ↓                     | ↓                               | 49          |             |
| <b>Medium 24A/<br/>24A-2/B<br/>Standard</b>    | PAL20L8A/-2/B           | ↓                          | ↓                     | ↓                               | 26          |             |
|  | PAL20R8A/-2/B           | ↓                          | ↓                     | ↓                               | 27          |             |
|  | PAL20R6A/-2/B           | ↓                          | ↓                     | ↓                               | ↓           |             |
|  | PAL20R4A/-2/B           | ↓                          | ↓                     | ↓                               | ↓           |             |
| <b>Medium 24X<br/>Exclusive-OR</b>             | PAL20L10                | ↓                          | ↓                     | ↓                               | 06          |             |
|  | PAL20X10                | ↓                          | ↓                     | ↓                               | 23          |             |
|  | PAL20X8                 | ↓                          | ↓                     | ↓                               | ↓           |             |
|  | PAL20X4                 | ↓                          | ↓                     | ↓                               | ↓           |             |
| <b>Medium 24XA<br/>Exclusive-OR</b>            | PAL20L10A               | ↓                          | 303A-V04              | ↓                               | 06          |             |
|  | PAL20X10A               | ↓                          | ↓                     | ↓                               | 36          |             |
|  | PAL20X8A                | ↓                          | ↓                     | ↓                               | ↓           |             |
|  | PAL20X4A                | ↓                          | ↓                     | ↓                               | ↓           |             |
| <b>Large 24RS<br/>Shared<br/>Product Terms</b> | PAL20S10                | ↓                          | ↓                     | ↓                               | 43          |             |
|  | PAL20RS10               | ↓                          | ↓                     | ↓                               | 44          |             |
|  | PAL20RS8                | ↓                          | ↓                     | ↓                               | 46          |             |
|  | PAL20RS4                | ↓                          | ↓                     | ↓                               | 46          |             |
| <b>Large 24A<br/>Registered XOR</b>            | PAL22RX8A               | ↓                          | ↓                     | 303A-011A/B-V01                 | 78          |             |
| <b>Large 24/A<br/>Varied XOR</b>               | PAL32VX10/A             | ↓                          | ↓                     | ↓                               | 77          |             |
| <b>Large 24RA<br/>Asynchronous</b>             | PAL20RA10               | ↓                          | 303A                  | 303A-002-V08<br>303A-011A/B-V01 | 45          |             |
| <b>ECL<br/>Combinatorial</b>                   | PAL10H20P8 <sup>1</sup> | ↓                          | 303A-V04              | 303A-ECL                        | 42          |             |
| <b>MegaPAL<sup>™</sup><br/>Devices</b>         | PAL32R16                | Model 29B                  | 303A                  | 303A-088-A/B                    | ↓           | 47          |
|  | PAL64R32                |                            | 350A/-23/A/B          | ↓                               | 84          |             |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products.  
Later software and hardware revisions can also be assumed to support these products.

<sup>1</sup>Not supported on Model 19



## MMI PAL® Device Programmer Reference Guide

**Digelec**

**20 Pin Device Families**

1602 Lawrence Ave.  
Suite 113  
Ocean, NJ 07712  
(201) 493-2420

System UP803

| Series   | Part Number            | FAM 52 Rev. | Adapter   | Adapter Rev. |          |           |          |                   |           |          |
|--|------------------------|-------------|-----------|--------------|----------|-----------|----------|-------------------|-----------|----------|
| <b>Small 20/-2<br/>Combinatorial</b>                         | PAL10H8/-2             | 5.4<br>↓    | DA53<br>↓ | A-3<br>↓     |          |           |          |                   |           |          |
|  | PAL10L8/-2             |             |           |              |          |           |          |                   |           |          |
|  | PAL12H6/-2             |             |           |              |          |           |          |                   |           |          |
|  | PAL12L6/-2             |             |           |              |          |           |          |                   |           |          |
|  | PAL14H4/-2             |             |           |              |          |           |          |                   |           |          |
|  | PAL14L4/-2             |             |           |              |          |           |          |                   |           |          |
|  | PAL16H2/-2             |             |           |              |          |           |          |                   |           |          |
|  | PAL16L2/-2             |             |           |              |          |           |          |                   |           |          |
|  | PAL16C1/-2             |             |           |              |          |           |          |                   |           |          |
| <b>Medium 20/<br/>20A/20A-2/4/<br/>20B-2/-4<br/>Standard</b> | PAL16L8/A/-2/-4/B-2/-4 | 5.4<br>↓    | DA53<br>↓ | A-3<br>↓     |          |           |          |                   |           |          |
|  | PAL16R8/A/-2/-4/B-2/-4 |             |           |              |          |           |          |                   |           |          |
|  | PAL16R6/A/-2/-4/B-2/-4 |             |           |              |          |           |          |                   |           |          |
|  | PAL16R4/A/-2/-4/B-2/-4 |             |           |              |          |           |          |                   |           |          |
| <b>Medium<br/>20B/D</b>                                      | PAL16L8B/D             |             |           |              | 5.4<br>↓ | DA53<br>↓ | A-3<br>↓ |                   |           |          |
|  | PAL16R8B/D             |             |           |              |          |           |          |                   |           |          |
|  | PAL16R6B/D             |             |           |              |          |           |          |                   |           |          |
|  | PAL16R4B/D             |             |           |              |          |           |          |                   |           |          |
| <b>Medium<br/>20BP<br/>Standard</b>                          | PAL16L8BP              |             |           |              |          |           |          | 5.4<br>↓          | DA53<br>↓ | A-3<br>↓ |
|  | PAL16R8BP              |             |           |              |          |           |          |                   |           |          |
|  | PAL16R6BP              |             |           |              |          |           |          |                   |           |          |
|  | PAL16R4BP              |             |           |              |          |           |          |                   |           |          |
| <b>Medium 20PA<br/>Programmable<br/>Polarity</b>             | PAL16P8A               | 5.4<br>↓    | DA53<br>↓ | A-3<br>↓     |          |           |          |                   |           |          |
|  | PAL16RP8A              |             |           |              |          |           |          |                   |           |          |
|  | PAL16RP6A              |             |           |              |          |           |          |                   |           |          |
|  | PAL16RP4A              |             |           |              |          |           |          |                   |           |          |
| <b>Large 20<br/>Arithmetic</b>                               | PAL16X4                |             |           |              | 5.4<br>↓ | DA53<br>↓ | A-3<br>↓ |                   |           |          |
|  | PAL16A4                |             |           |              |          |           |          |                   |           |          |
| <b>Large 20RA<br/>Asynchronous</b>                           | PAL16RA8               |             |           |              |          |           |          | Under Development |           |          |

3

NOTE: The software and hardware revisions listed are the earliest revisions that support these products.  
Later software and hardware revisions can also be assumed to support these products.

## MMI PAL<sup>®</sup> Device Programmer Reference Guide

**Digelec**

**24 Pin and MegaPAL<sup>™</sup> Device Families**

| Series   | Part Numbers  | FAM 52            | Adapter   | Adapter Rev. |          |           |          |                   |           |          |
|--|---------------|-------------------|-----------|--------------|----------|-----------|----------|-------------------|-----------|----------|
| <b>Small 24 Combinatorial</b>                  | PAL12L10      | 5.4<br>↓          | DA55<br>↓ | C-1<br>↓     |          |           |          |                   |           |          |
|  | PAL14L8       |                   |           |              |          |           |          |                   |           |          |
|  | PAL16L6       |                   |           |              |          |           |          |                   |           |          |
|  | PAL18L4       |                   |           |              |          |           |          |                   |           |          |
|  | PAL20L2       |                   |           |              |          |           |          |                   |           |          |
|  | PAL20C1       |                   |           |              |          |           |          |                   |           |          |
| <b>Small 24A Decoder</b>                       | PAL6L16A      | Under Development |           |              |          |           |          |                   |           |          |
|  | PAL8L14A      |                   |           |              |          |           |          |                   |           |          |
| <b>Medium 24A/<br/>24A-2/B<br/>Standard</b>    | PAL20L8A/-2/B | 5.4<br>↓          | DA55<br>↓ | C-1<br>↓     |          |           |          |                   |           |          |
|  | PAL20R8A/-2/B |                   |           |              |          |           |          |                   |           |          |
|  | PAL20R6A/-2/B |                   |           |              |          |           |          |                   |           |          |
|  | PAL20R4A/-2/B |                   |           |              |          |           |          |                   |           |          |
| <b>Medium 24X<br/>Exclusive-OR</b>             | PAL20L10      |                   |           |              | 5.4<br>↓ | DA55<br>↓ | C-1<br>↓ |                   |           |          |
|  | PAL20X10      |                   |           |              |          |           |          |                   |           |          |
|  | PAL20X8       |                   |           |              |          |           |          |                   |           |          |
|  | PAL20X4       |                   |           |              |          |           |          |                   |           |          |
| <b>Medium 24XA<br/>Exclusive-OR</b>            | PAL20L10A     |                   |           |              |          |           |          | 5.4<br>↓          | DA55<br>↓ | C-1<br>↓ |
|  | PAL20X10A     |                   |           |              |          |           |          |                   |           |          |
|  | PAL20X8A      |                   |           |              |          |           |          |                   |           |          |
|  | PAL20X4A      |                   |           |              |          |           |          |                   |           |          |
| <b>Large 24RS<br/>Shared<br/>Product Terms</b> | PAL20S10      | 5.4<br>↓          | DA55<br>↓ | C-1<br>↓     |          |           |          |                   |           |          |
|  | PAL20RS10     |                   |           |              |          |           |          |                   |           |          |
|  | PAL20RS8      |                   |           |              |          |           |          |                   |           |          |
|  | PAL20RS4      |                   |           |              |          |           |          |                   |           |          |
| <b>Large 24A<br/>Registered XOR</b>            | PAL22RX8A     |                   |           |              | 5.4<br>↓ | DA55<br>↓ | C-1<br>↓ |                   |           |          |
| <b>Large 24/A<br/>Varied XOR</b>               | PAL32VX10/A   |                   |           |              |          |           |          |                   |           |          |
| <b>Large 24RA<br/>Asynchronous</b>             | PAL20RA10     |                   |           |              |          |           |          |                   |           |          |
| <b>ECL<br/>Combinatorial</b>                   | PAL10H20P8    |                   |           |              |          |           |          |                   |           |          |
| <b>MegaPAL<sup>™</sup><br/>Devices</b>         | PAL32R16      |                   |           |              |          |           |          | Under Development |           |          |
|  | PAL64R32      |                   |           |              |          |           |          |                   |           |          |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products.  
Later software and hardware revisions can also be assumed to support these products.

**MMI PAL® Device Programmer Reference Guide**

**Kontron**

**20 Pin Device Families**

1230 Charleston Road  
 Mountain View, CA 94039-7230  
 (415) 965-7020

System MPP-80S

System EPP-80

| Series   | Part Number            | Socket Adapter                  | UPM-B Rev. |
|--|------------------------|---------------------------------|------------|
| <b>Small 20/-2<br/>Combinatorial</b>                         | PAL10H8/-2             | SA-27<br>↓                      | 1.44<br>↓  |
|  | PAL10L8/-2             |                                 |            |
|  | PAL12H6/-2             |                                 |            |
|  | PAL12L6/-2             |                                 |            |
|  | PAL14H4/-2             |                                 |            |
|  | PAL14L4/-2             |                                 |            |
|  | PAL16H2/-2             |                                 |            |
|  | PAL16L2/-2             |                                 |            |
|  | PAL16C1/-2             |                                 |            |
| <b>Medium 20/<br/>20A/20A-2/4/<br/>20B-2/-4<br/>Standard</b> | PAL16L8/A/-2/-4/B-2/-4 | ↓                               | ↓          |
|  | PAL16R8/A/-2/-4/B-2/-4 |                                 |            |
|  | PAL16R6/A/-2/-4/B-2/-4 |                                 |            |
|  | PAL16R4/A/-2/-4/B-2/-4 |                                 |            |
| <b>Medium<br/>20B/D</b>                                      | PAL16L8B/D             | Under Development               | ↓          |
|  | PAL16R8B/D             |                                 |            |
|  | PAL16R6B/D             |                                 |            |
|  | PAL16R4B/D             |                                 |            |
| <b>Medium<br/>20BP<br/>Standard</b>                          | PAL16L8BP              | SA-27<br>Under Development<br>↓ | ↓          |
|  | PAL16R8BP              |                                 |            |
|  | PAL16R6BP              |                                 |            |
|  | PAL16R4BP              |                                 |            |
| <b>Medium 20PA<br/>Programmable<br/>Polarity</b>             | PAL16P8A               | ↓                               | ↓          |
|  | PAL16RP8A              |                                 |            |
|  | PAL16RP6A              |                                 |            |
|  | PAL16RP4A              |                                 |            |
| <b>Large 20<br/>Arithmetic</b>                               | PAL16X4                | ↓                               | ↓          |
|  | PAL16A4                |                                 |            |
| <b>Large 20RA<br/>Asynchronous</b>                           | PAL16RA8               | ↓                               | 1.47       |

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NOTE: The software and hardware revisions listed are the earliest revisions that support these products.  
 Later software and hardware revisions can also be assumed to support these products.

# Kontron

## 24 Pin and MegaPAL™ Device Families

| Series                                 | Part Number   | Socket Adapter    | UPM-B Rev.        |                        |                        |
|--|---------------|-------------------|-------------------|------------------------|------------------------|
| <b>Small 24 Combinatorial</b>          | PAL12L10      | SA-27-1           | 1.44<br>↓         |                        |                        |
|  | PAL14L8       |                   |                   |                        |                        |
|  | PAL16L6       |                   |                   |                        |                        |
|  | PAL18L4       |                   |                   |                        |                        |
|  | PAL20L2       |                   |                   |                        |                        |
|  | PAL20C1       |                   |                   |                        |                        |
| <b>Small 24A Decoder</b>               | PAL6L16A      | Under Development | 1.48              |                        |                        |
|  | PAL8L14A      |                   |                   |                        |                        |
| <b>Medium 24A/ 24A-2/B Standard</b>    | PAL20L8A/-2/B | SA-27-1<br>↓      | 1.44<br>↓         |                        |                        |
|  | PAL20R8A/-2/B |                   |                   |                        |                        |
|  | PAL20R6A/-2/B |                   |                   |                        |                        |
|  | PAL20R4A/-2/B |                   |                   |                        |                        |
| <b>Medium 24X Exclusive-OR</b>         | PAL20L10      |                   |                   |                        |                        |
|  | PAL20X10      |                   |                   |                        |                        |
|  | PAL20X8       |                   |                   |                        |                        |
|  | PAL20X4       |                   |                   |                        |                        |
| <b>Medium 24XA Exclusive-OR</b>        | PAL20L10A     |                   |                   |                        |                        |
|  | PAL20X10A     |                   |                   |                        |                        |
|  | PAL20X8A      |                   |                   |                        |                        |
|  | PAL20X4A      |                   |                   |                        |                        |
| <b>Large 24RS Shared Product Terms</b> | PAL20S10      |                   |                   | Under Development<br>↓ | Under Development<br>↓ |
|  | PAL20RS10     |                   |                   |                        |                        |
|  | PAL20RS8      |                   |                   |                        |                        |
|  | PAL20RS4      |                   |                   |                        |                        |
| <b>Large 24A Registered XOR</b>        | PAL22RX8A     | Under Development |                   |                        |                        |
| <b>Large 24/A Varied XOR</b>           | PAL32VX10/A   | 1.48              |                   |                        |                        |
| <b>Large 24RA Asynchronous</b>         | PAL20RA10     | 1.44              |                   |                        |                        |
| <b>ECL Combinatorial</b>               | PAL10H20P8    | 1.47              |                   |                        |                        |
| <b>MegaPAL™ Devices</b>                | PAL32R16      | Under Development | Under Development |                        |                        |
|  | PAL64R32      |                   |                   |                        |                        |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.

**MMI PAL® Device Programmer Reference Guide**

**Micropress**

**20 Pin Device Families**

Parc d'activite des Pres  
5, rue Denis-Papin  
59650 Villeneuve-d'Ascq  
Tel 20479040

|            |
|------------|
| ROM 5000   |
| Programmer |

| Series   | Part Number            | Rev.              |
|--|------------------------|-------------------|
| <b>Small 20/-2 Combinatorial</b>                             | PAL10H8/-2             | 3.5               |
|  | PAL10L8/-2             |                   |
|  | PAL12H6/-2             |                   |
|  | PAL12L6/-2             |                   |
|  | PAL14H4/-2             |                   |
|  | PAL14L4/-2             |                   |
|  | PAL16H2/-2             |                   |
|  | PAL16L2/-2             |                   |
|  | PAL16C1/-2             |                   |
| <b>Medium 20/<br/>20A/20A-2/4/<br/>20B-2/-4<br/>Standard</b> | PAL16L8/A/-2/-4/B-2/-4 | ↓                 |
|  | PAL16R8/A/-2/-4/B-2/-4 |                   |
|  | PAL16R6/A/-2/-4/B-2/-4 |                   |
|  | PAL16R4/A/-2/-4/B-2/-4 |                   |
| <b>Medium<br/>20B/D</b>                                      | PAL16L8B/D             | ↓                 |
|  | PAL16R8B/D             |                   |
|  | PAL16R6B/D             |                   |
|  | PAL16R4B/D             |                   |
| <b>Medium<br/>20BP<br/>Standard</b>                          | PAL16L8BP              | ↓                 |
|  | PAL16R8BP              |                   |
|  | PAL16R6BP              |                   |
|  | PAL16R4BP              |                   |
| <b>Medium 20PA<br/>Programmable<br/>Polarity</b>             | PAL16P8A               | ↓                 |
|  | PAL16RP8A              |                   |
|  | PAL16RP6A              |                   |
|  | PAL16RP4A              |                   |
| <b>Large 20<br/>Arithmetic</b>                               | PAL16X4                | ↓                 |
|  | PAL16A4                |                   |
| <b>Large 20RA<br/>Asynchronous</b>                           | PAL16RA8               | Under Development |

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NOTE: The software and hardware revisions listed are the earliest revisions that support these products.  
Later software and hardware revisions can also be assumed to support these products.

## MMI PAL<sup>®</sup> Device Programmer Reference Guide

### Micropress

### 24 Pin and MegaPAL<sup>™</sup> Device Families

| Series   | Part Number   | Rev.              |
|--|---------------|-------------------|
| <b>Small 24 Combinatorial</b>                  | PAL12L10      | 3.5<br>↓          |
|  | PAL14L8       |                   |
|  | PAL16L6       |                   |
|  | PAL18L4       |                   |
|  | PAL20L2       |                   |
|  | PAL20C1       |                   |
| <b>Small 24A Decoder</b>                       | PAL6L16A      | Under Development |
|  | PAL8L14A      |                   |
| <b>Medium 24A/<br/>24A-2/B<br/>Standard</b>    | PAL20L8A/-2/B | 3.5<br>↓          |
|  | PAL20R8A/-2/B |                   |
|  | PAL20R6A/-2/B |                   |
|  | PAL20R4A/-2/B |                   |
| <b>Medium 24X<br/>Exclusive-OR</b>             | PAL20L10      |                   |
|  | PAL20X10      |                   |
|  | PAL20X8       |                   |
|  | PAL20X4       |                   |
| <b>Medium 24XA<br/>Exclusive-OR</b>            | PAL20L10A     |                   |
|  | PAL20X10A     |                   |
|  | PAL20X8A      |                   |
|  | PAL20X4A      |                   |
| <b>Large 24RS<br/>Shared<br/>Product Terms</b> | PAL20S10      |                   |
|  | PAL20RS10     |                   |
|  | PAL20RS8      |                   |
|  | PAL20RS4      |                   |
| <b>Large 24A<br/>Registered XOR</b>            | PAL22RX8A     |                   |
| <b>Large 24/A Varied<br/>XOR</b>               | PAL32VX10/A   |                   |
| <b>Large 24RA<br/>Asynchronous</b>             | PAL20RA10     |                   |
| <b>ECL Combinatorial</b>                       | PAL10H20P8    |                   |
| <b>MegaPAL<sup>™</sup><br/>Devices</b>         | PAL32R16      | Under Development |
|  | PAL64R32      |                   |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.



**MMI PAL<sup>®</sup> Device Programmer Reference Guide**

**Promac**

**24 Pin and MegaPAL<sup>™</sup> Device Families**

| Series                                 | Part Number   | Software Rev.     | S1/S2                  |      |
|--|---------------|-------------------|------------------------|------|
| <b>Small 24 Combinatorial</b>          | PAL12L10      | 3.0<br>↓          | 2/2                    |      |
|  | PAL14L8       |                   | 2/3                    |      |
|  | PAL16L6       |                   | 2/4                    |      |
|  | PAL18L4       |                   | 2/5                    |      |
|  | PAL20L2       |                   | 2/6                    |      |
|  | PAL20C1       |                   | 2/1                    |      |
| <b>Small 24A Decoder</b>               | PAL6L16A      |                   |                        | 3/11 |
|  | PAL8L14A      |                   |                        | 3/10 |
| <b>Medium 24A/24A-2/B Standard</b>     | PAL20L8A/-2/B |                   |                        | 2/8  |
|  | PAL20R8A/-2/B |                   |                        | 2/9  |
|  | PAL20R6A/-2/B |                   |                        | 2/10 |
|  | PAL20R4A/-2/B |                   |                        | 2/11 |
| <b>Medium 24X Exclusive-OR</b>         | PAL20L10      |                   |                        | 2/7  |
|  | PAL20X10      |                   |                        | 2/12 |
|  | PAL20X8       |                   |                        | 2/13 |
|  | PAL20X4       |                   |                        | 2/14 |
| <b>Medium 24XA Exclusive-OR</b>        | PAL20L10A     |                   |                        | 2/7  |
|  | PAL20X10A     |                   |                        | 2/15 |
|  | PAL20X8A      |                   |                        | 3/0  |
|  | PAL20X4A      |                   |                        | 3/1  |
| <b>Large 24RS Shared Product Terms</b> | PAL20S10      |                   | 3/5                    |      |
|  | PAL20RS10     |                   | 3/6                    |      |
|  | PAL20RS8      |                   | 3/7                    |      |
|  | PAL20RS4      |                   | 3/8                    |      |
| <b>Large 24A Registered XOR</b>        | PAL22RX8A     |                   | Under Development<br>↓ |      |
| <b>Large 24/A Varied XOR</b>           | PAL32VX10/A   |                   |                        |      |
| <b>Large 24RA Asynchronous</b>         | PAL20RA10     |                   | 3/4                    |      |
| <b>ECL Combinatorial</b>               | PAL10H20P8    |                   | Under Development      |      |
| <b>MegaPAL<sup>™</sup> Devices</b>     | PAL32R16      | Under Development |                        |      |
|  | PAL64R32      |                   |                        |      |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.



## MMI PAL® Device Programmer Reference Guide

### Stag Microsystems

20 Pin Device Families

1600 Wyatt Dr. Suite 3  
 Santa Clara, CA 95054  
 (408) 988-1118

|      |
|------|
| ZL30 |
| PPZ  |

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| Series   | Part Number            | Code  | ZL30 Rev.  | ZM2200  |
|--|------------------------|-------|------------|---------|
| <b>Small 20/-2<br/>Combinatorial</b>                         | PAL10H8/-2             | 20-20 | 30-35<br>↓ | 14<br>↓ |
|  | PAL10L8/-2             | 20-25 |            |         |
|  | PAL12H6/-2             | 20-21 |            |         |
|  | PAL12L6/-2             | 20-26 |            |         |
|  | PAL14H4/-2             | 20-22 |            |         |
|  | PAL14L4/-2             | 20-27 |            |         |
|  | PAL16H2/-2             | 20-23 |            |         |
|  | PAL16L2/-2             | 20-28 |            |         |
| <b>Medium 20/<br/>20A/20A-2/4/<br/>20B-2/-4<br/>Standard</b> | PAL16L8/A/-2/-4/B-2/-4 | 20-29 | ↓          | ↓       |
|  | PAL16R8/A/-2/-4/B-2/-4 | 20-30 |            |         |
|  | PAL16R6/A/-2/-4/B-2/-4 | 20-31 |            |         |
|  | PAL16R4/A-2/-4/B-2/-4  | 20-32 |            |         |
| <b>Medium<br/>20B/D</b>                                      | PAL16L8B/D             | 22-29 | 30-39<br>↓ | 12<br>↓ |
|  | PAL16R8B/D             | 22-30 |            |         |
|  | PAL16R68/D             | 22-31 |            |         |
|  | PAL16R4B/D             | 22-32 |            |         |
| <b>Medium<br/>20BP<br/>Standard</b>                          | PAL16L8BP              | 20-29 | 30-35<br>↓ | 14      |
|  | PAL16R8BP              | 20-30 |            | 19      |
|  | PAL16R6BP              | 20-31 |            | ↓       |
|  | PAL16R4BP              | 20-32 |            | ↓       |
| <b>Medium 20PA<br/>Programmable<br/>Polarity</b>             | PAL16P8A               | 20-38 | ↓          | 12      |
|  | PAL16RP8A              | 20-11 |            | ↓       |
|  | PAL16RP6A              | 20-12 |            | ↓       |
|  | PAL16RP4A              | 20-13 |            | ↓       |
| <b>Large 20<br/>Arithmetic</b>                               | PAL16X4                | 20-33 | ↓          | 14      |
|  | PAL16A4                | 20-34 |            |         |
| <b>Large 20RA<br/>Asynchronous</b>                           | PAL16RA8               | 20-19 | 30-37      | 12      |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.

# Stag Microsystems

## 24 Pin and MegaPAL<sup>™</sup> Device Families

| Series                                 | Part Number   | Code  | ZL30 Rev.              | ZM2200  |
|--|---------------|-------|------------------------|---------|
| <b>Small 24 Combinatorial</b>          | PAL12L10      | 21-50 | 30-35<br>↓             | 14      |
|  | PAL14L8       | 21-51 |                        |         |
|  | PAL16L6       | 21-52 |                        | 12<br>↓ |
|  | PAL18L4       | 21-53 |                        |         |
|  | PAL20L2       | 21-54 |                        |         |
|  | PAL20C1       | 21-55 |                        |         |
| <b>Small 24A Decoder</b>               | PAL6L16A      |       | Under Development      |         |
|  | PAL8L14A      |       |                        |         |
| <b>Medium 24A/24A-2/B Standard</b>     | PAL20L8A/-2/B | 21-56 | 30-35<br>↓             | 12<br>↓ |
|  | PAL20R8A/-2/B | 21-57 |                        |         |
|  | PAL20R6A/-2/B | 21-58 |                        |         |
|  | PAL20R4A/-2/B | 21-59 |                        |         |
| <b>Medium 24X Exclusive-OR</b>         | PAL20L10      | 21-60 | ↓                      | ↓       |
|  | PAL20X10      | 21-61 |                        |         |
|  | PAL20X8       | 21-62 |                        |         |
|  | PAL20X4       | 21-63 |                        |         |
| <b>Medium 24XA Exclusive-OR</b>        | PAL20L10A     | 21-60 | ↓                      | ↓       |
|  | PAL20X10A     | 21-61 |                        |         |
|  | PAL20X8A      | 21-62 |                        |         |
|  | PAL20X4A      | 21-63 |                        |         |
| <b>Large 24RS Shared Product Terms</b> | PAL20S10      | 21-81 | 30-39<br>↓             | ↓       |
|  | PAL20RS10     | 21-80 |                        |         |
|  | PAL20RS8      | 21-79 |                        |         |
|  | PAL20RS4      | 21-78 |                        |         |
| <b>Large 24A Registered XOR</b>        | PAL22RX8A     |       | Under Development<br>↓ |         |
| <b>Large 24A Varied XOR</b>            | PAL32VX10/A   |       |                        |         |
| <b>Large 24RA Asynchronous</b>         | PAL20RA10     | 21-77 | 30-37                  |         |
| <b>ECL Combinatorial</b>               | PAL10H20P8    |       | Under Development      |         |
| <b>MegaPAL<sup>™</sup> Devices</b>     | PAL32R16      |       | Under Development      |         |
|  | PAL64R32      |       |                        |         |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products.  
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## MMI PAL® Device Programmer Reference Guide

### Storey Systems

20 Pin Device Families

3201 North Hwy. 67  
Suite H  
Mesquite, TX 75150  
(214) 270-4135

P240  
Programmer

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| Series   | Part Number            | Rev.                         |
|--|------------------------|------------------------------|
| <b>Small 20/-2<br/>Combinatorial</b>                         | PAL10H8/-2             | 2.0<br>↓                     |
|  | PAL10L8/-2             |                              |
|  | PAL12H6/-2             |                              |
|  | PAL12L6/-2             |                              |
|  | PAL14H4/-2             |                              |
|  | PAL14L4/-2             |                              |
|  | PAL16H2/-2             |                              |
|  | PAL16L2/-2             |                              |
|  | PAL16C1/-2             |                              |
| <b>Medium 20/<br/>20A/20A-2/4/<br/>20B-2/-4<br/>Standard</b> | PAL16L8/A/-2/-4/B-2/-4 | ↓                            |
|  | PAL16R8/A/-2/-4/B-2/-4 |                              |
|  | PAL16R6/A/-2/-4/B-2/-4 |                              |
|  | PAL16R4/A/-2/-4/B-2/-4 |                              |
| <b>Medium<br/>20B/D</b>                                      | PAL16L8B/D             | 4.0<br>↓                     |
|  | PAL16R8B/D             |                              |
|  | PAL16R6B/D             |                              |
|  | PAL16R4B/D             |                              |
| <b>Medium<br/>20BP<br/>Standard</b>                          | PAL16L8BP              | 2.0<br><br>Under Development |
|  | PAL16R8BP              |                              |
|  | PAL16R6BP              |                              |
|  | PAL16R4BP              |                              |
| <b>Medium 20PA<br/>Programmable<br/>Polarity</b>             | PAL16P8A               | 4.0<br>↓                     |
|  | PAL16RP8A              |                              |
|  | PAL16RP6A              |                              |
|  | PAL16RP4A              |                              |
| <b>Large 20<br/>Arithmetic</b>                               | PAL16X4                | 2.0                          |
|  | PAL16A4                |                              |
| <b>Large 20RA<br/>Asynchronous</b>                           | PAL16RA8               | 4.04                         |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products.  
Later software and hardware revisions can also be assumed to support these products.

## Storey Systems

## 24 Pin and MegaPAL<sup>™</sup> Device Families

| Series                             | Part Number   | Rev.                   |
|------------------------------------|---------------|------------------------|
| Small 24 Combinatorial             | PAL12L10      | 2.0<br>↓               |
|                                    | PAL14L8       |                        |
|                                    | PAL16L6       |                        |
|                                    | PAL18L4       |                        |
|                                    | PAL20L2       |                        |
|                                    | PAL20C1       |                        |
| Small 24A Decoder                  | PAL6L16A      | Under Development      |
|                                    | PAL8L14A      |                        |
| Medium 24A/<br>24A-2/B<br>Standard | PAL20L8A/-2/B | 2.0<br>↓               |
|                                    | PAL20R8A/-2/B |                        |
|                                    | PAL20R6A/-2/B |                        |
|                                    | PAL20R4A/-2/B |                        |
| Medium 24X Exclusive-OR            | PAL20L10      | ↓                      |
|                                    | PAL20X10      |                        |
|                                    | PAL20X8       |                        |
|                                    | PAL20X4       |                        |
| Medium 24XA Exclusive-OR           | PAL20L10A     | Under Development<br>↓ |
|                                    | PAL20X10A     |                        |
|                                    | PAL20X8A      |                        |
|                                    | PAL20X4A      |                        |
| Large 24RS Shared Product Terms    | PAL20S10      | ↓                      |
|                                    | PAL20RS10     |                        |
|                                    | PAL20RS8      |                        |
|                                    | PAL20RS4      |                        |
| Large 24A Registered XOR           | PAL22RX8Aa    | ↓                      |
| Large 24/A Varied XOR              | PAL32VX10/A   |                        |
| Large 24RA Asynchronous            | PAL20RA10     | 4.04                   |
| ECL Combinatorial                  | PAL10H20P8    | Under Development      |
| MegaPAL <sup>™</sup> Devices       | PAL32R16      |                        |
|                                    | PAL64R32      |                        |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.

## MMI PAL® Device Programmer Reference Guide

### Structured Design

20 Pin Device Families

1700 Wyatt Drive  
Suite 7  
Santa Clara, CA 95054  
(408) 988-0725

SD 20/24 System  
  
SD 1000 System

| Series   | Part Number            | SD 20/24          | SD 1000   |
|--|------------------------|-------------------|-----------|
| <b>Small 20/-2<br/>Combinatorial</b>                         | PAL10H8/-2             | 1.6<br>↓          | 1.05<br>↓ |
|  | PAL10L8/-2             |                   |           |
|  | PAL12H6/-2             |                   |           |
|  | PAL12L6/-2             |                   |           |
|  | PAL14H4/-2             |                   |           |
|  | PAL14L4/-2             |                   |           |
|  | PAL16H2/-2             |                   |           |
|  | PAL16L2/-2             |                   |           |
|  | PAL16C1/-2             |                   |           |
| <b>Medium 20/<br/>20A/20A-2/4/<br/>20B-2/-4<br/>Standard</b> | PAL16L8/A/-2/-4/B-2/-4 | ↓                 | ↓         |
|  | PAL16R8/A/-2/-4/B-2/-4 |                   |           |
|  | PAL16R6/A/-2/-4/B-2/-4 |                   |           |
|  | PAL16R4/A/-2/-4/B-2/-4 |                   |           |
| <b>Medium<br/>20B/D</b>                                      | PAL16L8B/D             | Under Development | ↓         |
|  | PAL16R8B/D             |                   |           |
|  | PAL16R6B/D             |                   |           |
|  | PAL16R4B/D             |                   |           |
| <b>Medium<br/>20BP<br/>Standard</b>                          | PAL16L8BP              | 1.6               | 1.05      |
|  | PAL16R8BP              |                   |           |
|  | PAL16R6BP              |                   |           |
|  | PAL16R4BP              |                   |           |
| <b>Medium 20PA<br/>Programmable<br/>Polarity</b>             | PAL16P8A               | Under Development |           |
|  | PAL16RP8A              |                   |           |
|  | PAL16RP6A              |                   |           |
|  | PAL16RP4A              |                   |           |
| <b>Large 20<br/>Arithmetic</b>                               | PAL16X4                | 1.6               | 1.05      |
|  | PAL16A4                |                   |           |
| <b>Large 20RA<br/>Asynchronous</b>                           | PAL16RA8               | Under Development |           |

3

NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.

## Structured Design

## 24 Pin and MegaPAL™ Device Families

| Series                                 | Part Number   | SD 20/24          | SD 1000   |                        |  |
|--|---------------|-------------------|-----------|------------------------|--|
| <b>Small 24 Combinatorial</b>          | PAL12L10      | 1.6<br>↓          | 1.05<br>↓ |                        |  |
|  | PAL14L8       |                   |           |                        |  |
|  | PAL16L6       |                   |           |                        |  |
|  | PAL18L4       |                   |           |                        |  |
|  | PAL20L2       |                   |           |                        |  |
|  | PAL20C1       |                   |           |                        |  |
| <b>Small 24A Decoder</b>               | PAL6L16A      | Under Development |           |                        |  |
|  | PAL8L14A      |                   |           |                        |  |
| <b>Medium 24A/24A-2/B Standard</b>     | PAL20L8A/-2/B | 1.6<br>↓          | 1.05<br>↓ |                        |  |
|  | PAL20R8A/-2/B |                   |           |                        |  |
|  | PAL20R6A/-2/B |                   |           |                        |  |
|  | PAL20R4A/-2/B |                   |           |                        |  |
| <b>Medium 24X Exclusive-OR</b>         | PAL20L10      | 1.6<br>↓          | 1.05<br>↓ |                        |  |
|  | PAL20X10      |                   |           |                        |  |
|  | PAL20X8       |                   |           |                        |  |
|  | PAL20X4       |                   |           |                        |  |
| <b>Medium 24XA Exclusive-OR</b>        | PAL20L10A     |                   |           |                        |  |
|  | PAL20X10A     |                   |           |                        |  |
|  | PAL20X8A      |                   |           |                        |  |
|  | PAL20X4A      |                   |           |                        |  |
| <b>Large 24RS Shared Product Terms</b> | PAL20S10      |                   |           | Under Development<br>↓ |  |
|  | PAL20RS10     |                   |           |                        |  |
|  | PAL20RS8      |                   |           |                        |  |
|  | PAL20RS4      |                   |           |                        |  |
| <b>Large 24A Registered XOR</b>        | PAL22RX8A     |                   |           |                        |  |
| <b>Large 24/A Varied XOR</b>           | PAL32VX10/A   |                   |           |                        |  |
| <b>Large 24RA Asynchronous</b>         | PAL20RA10     |                   |           |                        |  |
| <b>ECL Combinatorial</b>               | PAL10H20P8    |                   |           |                        |  |
| <b>MegaPAL™ Devices</b>                | PAL32R16      |                   |           |                        |  |
|  | PAL64R32      |                   |           |                        |  |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.

**MMI PAL® Device Programmer Reference Guide**

**Valley Data Sciences**

**20 Pin Device Families**

Charleston Business Park  
 2426 Charleston Road  
 Mountain View, CA 94043  
 (415) 968-2900

|                          |
|--------------------------|
| 160 Series<br>Programmer |
|--------------------------|

**3**

| Series   | Part Number            | Rev.              |
|--|------------------------|-------------------|
| <b>Small 20/-2<br/>Combinatorial</b>                         | PAL10H8/-2             | 1.03              |
|  | PAL10L8/-2             | ↓                 |
|  | PAL12H6/-2             |                   |
|  | PAL12L6/-2             |                   |
|  | PAL14H4/-2             |                   |
|  | PAL14L4/-2             |                   |
|  | PAL16H2/-2             |                   |
|  | PAL16L2/-2             |                   |
|  | PAL16C1/-2             |                   |
| <b>Medium 20/<br/>20A/20A-2/4/<br/>20B-2/-4<br/>Standard</b> | PAL16L8/A/-2/-4/B-2/-4 |                   |
|  | PAL16R8/A/-2/-4/B-2/-4 |                   |
|  | PAL16R6/A/-2/-4/B-2/-4 |                   |
|  | PAL16R4/A/-2/-4/B-2/-4 |                   |
| <b>Medium<br/>20B/D</b>                                      | PAL16L8B/D             |                   |
|  | PAL16R8B/D             |                   |
|  | PAL16R6B/D             |                   |
|  | PAL16R4B/D             |                   |
| <b>Medium<br/>20BP<br/>Standard</b>                          | PAL16L8BP              |                   |
|  | PAL16R8BP              |                   |
|  | PAL16R6BP              | Under Development |
|  | PAL16R4BP              |                   |
| <b>Medium 20PA<br/>Programmable<br/>Polarity</b>             | PAL16P8A               | 1.03              |
|  | PAL16RP8A              | ↓                 |
|  | PAL16RP6A              |                   |
|  | PAL16RP4A              |                   |
| <b>Large 20<br/>Arithmetic</b>                               | PAL16X4                |                   |
|  | PAL16A4                | ↓                 |
| <b>Large 20RA<br/>Asynchronous</b>                           | PAL16RA8               | Under Development |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.

| Series   | Part Number   | Rev.               |
|--|---------------|--------------------|
| <b>Small 24 Combinatorial</b>                  | PAL12L10      | 1.03<br>↓          |
|  | PAL14L8       |                    |
|  | PAL16L6       |                    |
|  | PAL18L4       |                    |
|  | PAL20L2       |                    |
|  | PAL20C1       |                    |
| <b>Small 24A Decoder</b>                       | PAL6L16A      | Under Development  |
|  | PAL8L14A      |                    |
| <b>Medium 24A/<br/>24A-2/B<br/>Standard</b>    | PAL20L8A/-2/B | 1.03<br>↓          |
|  | PAL20R8A/-2/B |                    |
|  | PAL20R6A/-2/B |                    |
|  | PAL20R4A/-2/B |                    |
| <b>Medium 24X<br/>Exclusive-OR</b>             | PAL20X10      |                    |
|  | PAL20L10      |                    |
|  | PAL20X8       |                    |
|  | PAL20X4       |                    |
| <b>Medium 24XA<br/>Exclusive-OR</b>            | PAL20X10A     |                    |
|  | PAL20L10A     |                    |
|  | PAL20X8A      |                    |
|  | PAL20X4A      |                    |
| <b>Large 24RS<br/>Shared<br/>Product Terms</b> | PAL20RS10     |                    |
|  | PAL20S10      |                    |
|  | PAL20RS8      |                    |
|  | PAL20RS4      |                    |
| <b>Large 24A<br/>Registered XOR</b>            | PAL22RX8A     |                    |
| <b>Large 24/A Varied<br/>XOR</b>               | PAL32VX10/A   |                    |
| <b>Large 24RA<br/>Asynchronous</b>             | PAL20RA10     |                    |
| <b>ECL<br/>Combinatorial</b>                   | PAL10H20P8    | Under Development  |
| <b>MegaPAL™<br/>Devices</b>                    | PAL32R16      | 1.04 + 1.1 Adapter |
|  | PAL64R32      | Under Development  |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products.  
 Later software and hardware revisions can also be assumed to support these products.



## MMI PAL<sup>®</sup> Device Programmer Reference Guide

# Varix

## 20 Pin Device Families

1210 E. Campbell Road  
Richardson, TX 75081  
(214) 437-0777

OMNI  
Programmer



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| Series   | Part Number            | Rev.              |
|--|------------------------|-------------------|
| <b>Small 20/-2<br/>Combinatorial</b>                         | PAL10H8/-2             | 3.18<br>↓         |
|  | PAL10L8/-2             |                   |
|  | PAL12H6/-2             |                   |
|  | PAL12L6/-2             |                   |
|  | PAL14H4/-2             |                   |
|  | PAL14L4/-2             |                   |
|  | PAL16H2/-2             |                   |
|  | PAL16L2/-2             |                   |
|  | PAL16C1/-2             |                   |
| <b>Medium 20/<br/>20A/20A-2/4/<br/>20B-2/-4<br/>Standard</b> | PAL16L8/A/-2/-4/B-2/-4 | 3.18              |
|  | PAL16R8/A/-2/-4/B-2/-4 |                   |
|  | PAL16R6/A/-2/-4/B-2/-4 |                   |
|  | PAL16R4/A/-2/-4/B-2/-4 |                   |
| <b>Medium<br/>20B/D</b>                                      | PAL16L8B/D             | ↓                 |
|  | PAL16R8B/D             |                   |
|  | PAL16R6B/D             |                   |
|  | PAL16R4B/D             |                   |
| <b>Medium<br/>20BP<br/>Standard</b>                          | PAL16L8BP              | 3.18              |
|  | PAL16R8BP              | 5.00              |
|  | PAL16R6BP              | ↓                 |
|  | PAL16R4BP              | ↓                 |
| <b>Medium 20PA<br/>Programmable<br/>Polarity</b>             | PAL16P8A               | 3.18<br>↓         |
|  | PAL16RP8A              |                   |
|  | PAL16RP6A              |                   |
|  | PAL16RP4A              |                   |
| <b>Large 20<br/>Arithmetic</b>                               | PAL16X4                | ↓                 |
|  | PAL16A4                |                   |
| <b>Large 20RA<br/>Asynchronous</b>                           | PAL16RA8               | Under Development |

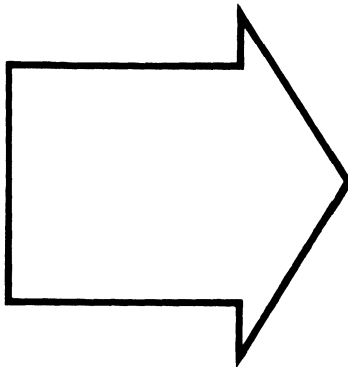
NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.

**Varix**

**24 Pin and MegaPAL™ Device Families**

| Series                                 | Part Number   | Rev.   |                   |
|--|---------------|--|-------------------|
| <b>Small 24 Combinatorial</b>          | PAL12L10      | 3.18<br>                |                   |
|  | PAL14L8       |  |                   |
|  | PAL16L6       |  |                   |
|  | PAL18L4       |  |                   |
|  | PAL20L2       |  |                   |
|  | PAL20C1       |  |                   |
| <b>Small 24A Decoder</b>               | PAL6L16A      |  |                   |
|  | PAL8L14A      |  |                   |
| <b>Medium 24A/ 24A-2/B Standard</b>    | PAL20L8A/-2/B |  |                   |
|  | PAL20R8A/-2/B |  |                   |
|  | PAL20R6A/-2/B |  |                   |
|  | PAL20R4A/-2/B |  |                   |
| <b>Medium 24X Exclusive-OR</b>         | PAL20L10      |  |                   |
|  | PAL20X10      |  |                   |
|  | PAL20X8       |  |                   |
|  | PAL20X4       |  |                   |
| <b>Medium 24XA Exclusive-OR</b>        | PAL20L10A     |  |                   |
|  | PAL20X10A     |  |                   |
|  | PAL20X8A      |  |                   |
|  | PAL20X4A      |  |                   |
| <b>Large 24RS Shared Product Terms</b> | PAL20S10      | Under Development<br> |                   |
|  | PAL20RS10     |  |                   |
|  | PAL20RS8      |  |                   |
|  | PAL20RS4      |  |                   |
| <b>Large 24A Registered XOR</b>        | PAL22RX8A     |  |                   |
| <b>Large 24/A Varied XOR</b>           | PAL32VX10/A   |  |                   |
| <b>Large 24RA Asynchronous</b>         | PAL20RA10     |  | 3.18              |
| <b>ECL Combinatorial</b>               | PAL10H20P8    |  | Under Development |
| <b>MegaPAL™ Devices</b>                | PAL32R16      |  |                   |
|  | PAL64R32      |  |                   |

NOTE: The software and hardware revisions listed are the earliest revisions that support these products. Later software and hardware revisions can also be assumed to support these products.



|   |           |
|---|-----------|
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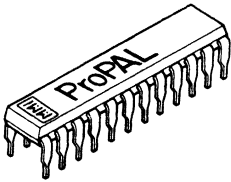
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## ProPAL™, HAL®, and ZHAL™ Devices: The Logical Solutions for Volume Programmable Logic

So you have discovered the convenience and flexibility of designing with PAL® devices from Monolithic Memories. You have implemented a design using PAL devices, and taken that design into production. Now may be the time to consider ways of reducing the efforts you put into programming, testing, and marking large volumes of PAL devices. Wouldn't it be more convenient if you could be relieved of the duties and costs of volume programming and testing and still reap the benefits afforded by programmable logic?

Or perhaps you are considering a semicustom product, but you're a little nervous about going to a gate array. Wouldn't it be preferable if you could find a semicustom product which allows easy, inexpensive prototyping, provides fast prototype turnaround, comes fully tested, can have a custom marking, has low NRE charges, provides design flexibility, and has an assured second source?

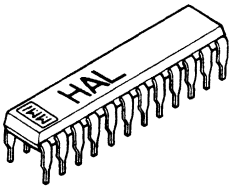
Well, Monolithic Memories, the inventor of the PAL device, offers the logical solutions. ProPAL, HAL, and ZHAL devices make the transition from user-programmed devices to customized production-ready devices easy and risk free.



CCD01010M

### ProPAL Devices

ProPAL (Programmed PAL) devices are simply PAL devices that Monolithic Memories programs and tests for you. You receive a fully functional unit without having to do the programming and testing. But you still have the flexibility to handle design changes easily.



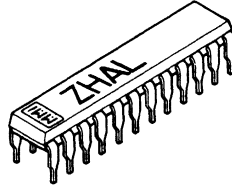
CCD01020M

### HAL Devices

HAL (Hard Array Logic) devices are to PAL devices as ROMs are to PROMs. Instead of fuses in the logic array, your pattern is implemented using metal links that are masked in during wafer fabrication. So your need to program devices is eliminated. And because the devices have their functionality masked in, Monolithic Memories can provide full functional testing before shipping the product. You can place the devices in your boards with a minimum of handling and the highest level of confidence.

Monolithic Memories offers a HAL device for every PAL device. Any PAL device design you program can be imple-

mented in a HAL version, allowing you to move smoothly into volume production.



CCD01000M

### ZHAL Devices

Monolithic Memories now provides a third alternative for the programmable logic user: new Zero-Standby-Power CMOS HAL devices.

For the first time there are HAL devices which can implement any pattern from the Series 20 and Series 24 PAL devices with the greatly reduced power consumption only CMOS can offer.

For high complexity designs reaching into the thousands of gates, Zero Power MegaHAL™ devices provide the natural semicustom VLSI alternative to gate arrays. The MegaPAL™ devices provide the flexibility and fast design turn-around you need for prototyping. Once you are ready for production, the CMOS MegaHAL devices provide the same functionality with Zero Power.

All of the ZHAL devices are fully HC/HCT compatible, making them easy to use in TTL and CMOS environments.

### Should You Use a PAL, ProPAL, or HAL Device?

PAL devices offer the flexibility and convenience needed for prototyping your innovative designs. They provide a means for designing an efficient system by integrating functions and saving you board space. For flexible production, it makes sense to program and test your own PAL devices. This is especially true if you need low volumes per pattern. You always have the option of making last minute design tweaks as you fine tune your system design.

Once your production volumes reach a moderate volume of a few thousand devices per year for each pattern, you may wish to dedicate your production resources to newer designs, instead of programming and testing production volumes. Yet in order to be able to make quick design updates, you might not want to commit to a HAL mask. ProPAL devices provide the ideal solution by eliminating programming and testing needs while retaining enough flexibility to accommodate design changes.

When you feel that your design has stabilized and your volume has ramped up to several thousand devices per year, a HAL device becomes the most cost effective way to purchase your programmable logic. By shifting the burdens to Monolithic Memories, who can handle large volumes easily, you can concentrate your energies on more productive projects.

### How Does MMI Do This?

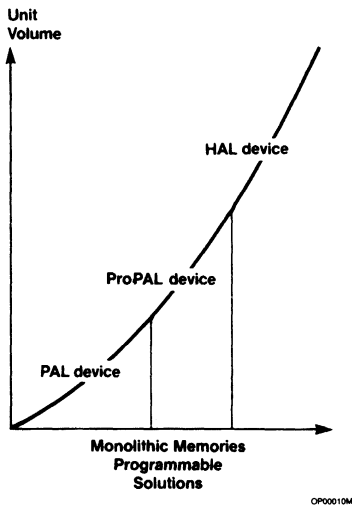
Monolithic Memories takes your proven PAL device design and either arranges to program ProPAL devices in volume, or generates a custom mask for a HAL or ZHAL device. And all

4

## ProPAL™, HAL®, and ZHAL™ Devices: The Logical Solutions for Volume Programmable Logic

without the normal risks inherent in purchasing a semicustom product. Why? Because:

- You can prototype your system and initiate production using standard Monolithic Memories PAL devices. You don't have to worry about making a mistake that could put your design schedule in jeopardy.
- The nominal Non-Recurring Engineering (NRE) charges for ProPAL and HAL devices are far lower than those normally required for a semicustom circuit. And they can even be amortized over your first production quantity.



- You save on the costs of programming devices. This will also shorten your production cycle, since you can plug the devices into the socket with no additional processing.
- All of the devices are tested for full functionality before they leave Monolithic Memories. You save on the costs of testing and generating test programs.
- Monolithic Memories is geared towards providing volumes of high quality devices. No one knows how to test programmable logic as well as Monolithic Memories. Between the thorough, efficient testing and marking capabilities and the option to provide burn-in for extra reliability, you can obtain a higher quality device that if you did the programming and testing yourself.
- MMI can provide custom marking. This saves you the added expense of stripping the mark from standard devices and then remarking them with your own mark.
- HAL devices are secure by design. If you prefer ProPAL devices, they can also be secured for you at the factory.
- ProPAL device lead time is only 1 to 2 weeks longer than that of unprogrammed PAL devices.
- HAL device turn-around time is a mere 6 to 8 weeks or less from acceptance of your design package to receipt of first units.

\*Floppy disks are accepted in standard DEC® AT-11 (RX01) or RSX-11M®, files 11 format, or an IBM PC™ 5-1/4 in. diskette. IBM compatible (800 or 1600 BPI) nine track magnetic tapes are accepted in unlabeled (card image), files-11, or VAX VMS® backup format. If magnetic media absolutely cannot be provided, legible printouts (signed and dated) from PALASM will be accepted. Please note that magnetic media are required if you have more than 50 vectors.

- If you find yourself with an unexpected demand, you need not turn away business for lack of HAL device stock. You can always use ProPAL devices to make up for any temporary shortfall.

### How Can You Take Advantage of This?

The following are some guidelines which you can use to help convert your designs to ProPAL, HAL or ZHAL devices.

#### 1. Send In Your Design

You will need to provide your logic equations from either PALASM®, PALASM 2 or ABEL™ on magnetic media\*.

When Monolithic Memories generates vectors for use in functionally testing your pattern, "seed" vectors are helpful in providing the foundation upon which the final test vectors will be based.

A master PAL device containing your design is needed for Monolithic Memories to verify that the pattern you submitted has been correctly processed. If you cannot provide a Monolithic Memories master PAL device, Monolithic Memories will accept your design inputs and provide ProPAL samples for your approval.

For your convenience, a checklist is included to help you prepare all of the necessary materials to be submitted to Monolithic Memories. This will also help Monolithic Memories process your design, resulting in smoother and faster turn-around. Copies of this form are available from your Sales Representative, or you can simply copy the attached form.

#### 2. MMI Will Verify the Design

Upon receiving your design package, Monolithic Memories will enter your design into their computer and verify that there are no format or syntax problems. A fuse map will be generated, and sample ProPAL devices programmed.

If any questions are encountered at this stage, they will be resolved with you before any further processing takes place.

#### 3. MMI Will Check the Samples

If you have approved immediate production of your devices, Monolithic Memories will make a fuse for fuse comparison between the samples and the master device you provide. If there are no discrepancies, test generation will be started immediately (or upon receipt of your purchase order).

If you prefer to see programmed sample ProPAL devices prior to initiating production, Monolithic Memories can provide them for your approval before proceeding further. Sample approval is also needed when no master devices are provided or when a discrepancy is found during verification.

#### 4. MMI Will Generate Test Vectors

A functional test sequence is generated using TGEN™, a proprietary software package. Any seed vectors you provide will be used to help initiate test generation. TGEN will check for hazards and race conditions, monitor fault coverage and systematically add vectors until test coverage goals are met.

Monolithic Memories has a test quality standard that sets as a minimum goal 90% coverage of all stuck-at faults. Lower coverage patterns can sometimes be processed as HAL devices, or it is possible to handle them as ProPAL devices only, but your approval will be needed. If acceptable coverage cannot be obtained, ways of increasing the testability of the design may have to be considered before Monolithic Memories can process the pattern.

**ProPAL™, HAL®, and ZHAL™ Devices:  
The Logical Solutions for Volume Programmable Logic**

For more detail on exactly how the test coverage is determined, refer to the article "PAL Design Function and Test Vectors" in this Handbook.

When suitable test coverage is obtained, as is normally the case, there is no need for you to be involved with vector generation. If, however, you wish to approve the test vectors before production units are generated, the vectors will be made available to you.

**5. MMI Will Generate Production Units**

After an acceptable test sequence has been generated, Monolithic Memories will generate the appropriate HAL or ZHAL mask and build the devices. Or, in the case of a ProPAL device, Monolithic Memories will arrange to program and test blank units.

**Having Your Devices Marked**

The standard Monolithic Memories mark consists of the device type, the package type, the date code, and the Monolithic Memories logo.

If you wish, you can have the standard marking replaced by a custom marking. The logo and date code are standard, but any other markings can be as you desire. The character and line limitations for the most common packages are in Table 1. If the package you want is not listed, your local representative can help you determine the guidelines you need.

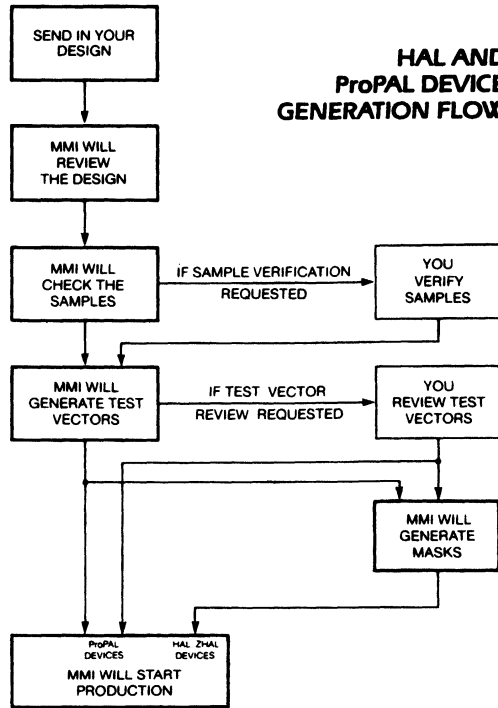
**Whom to Contact**

When you are ready to put the power of the Monolithic Memories factory to work for you, just contact your local Monolithic Memories sales representative. And let Monolithic Memories take care of your production programming, testing, and marking needs.

|                |                  |                                |
|----------------|------------------|--------------------------------|
| <b>PLASTIC</b> | 20 pin (300 mil) | 2 lines/13 characters per line |
|                | 24 pin (300 mil) | 2 lines/17 characters per line |
| <b>CERDIP</b>  | 20 pin (300 mil) | 2 lines/16 characters per line |
|                | 24 pin (300 mil) | 2 lines/17 characters per line |
| <b>PLCC</b>    | 20 lead          | 4 lines/11 characters per line |
|                | 28 lead          | 5 lines/12 characters per line |

Table 1

**HAL AND  
ProPAL DEVICE  
GENERATION FLOW**



**4**

800010M

PAL, HAL and PALASM are registered trademarks of Monolithic Memories, Inc. ProPAL, ZHAL, MegaPAL, MegaHAL and TGEN are trademarks of Monolithic Memories, Inc.

ABEL is a trademark of Data I/O Corp.

DEC, RSX, VAX, and VMS are registered trademarks of Digital Equipment Corp.

IBM PC is a trademark of International Business Machines, Inc.

## HAL/ProPAL CHECKLIST

Company name: \_\_\_\_\_

Address: \_\_\_\_\_

Contact: \_\_\_\_\_ Phone Number: \_\_\_\_\_

Do you want:    \_\_\_ HAL       \_\_\_ ProPAL       \_\_\_ ZHAL

Part Type: \_\_\_\_\_ Customer Part Number: \_\_\_\_\_

What package type do you want? \_\_\_\_\_

How do you want the devices marked?

\_\_\_ Standard

\_\_\_ Custom mark: please specify the mark below.

Refer to previous page

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

For ProPAL devices, do you want the security fuse blown? \_\_\_\_\_

Design Specification Format:

\_\_\_ PALASM

\_\_\_ PALASM 2

\_\_\_ ABEL

Input medium:

(Choose 1 of 3)

1. 9-track Magnetic Tape

\_\_\_ card image

\_\_\_ files-11

\_\_\_ VAX VMS backup

2. Floppy Disk

\_\_\_ RT-11

\_\_\_ RSX-11M

\_\_\_ IBM PC

3. \_\_\_PALASM printout (signed and dated)

The following items are requested but not required. Please check if provided:

\_\_\_ Seed vectors

\_\_\_ Master PAL device

### OPTIONS

A. \_\_\_ I want to start production immediately  
(or upon submittal of purchase order) if:

1. Design is acceptable;
2. MMI samples match my master device fuse for fuse;
3. Minimum test coverage goals are met.  
(Master device must be provided.)

B. \_\_\_ I want to verify the MMI generated sample  
devices prior to production implementation.

\_\_\_ I want to approve the test vectors prior to  
production implementation.

Please complete this form for each pattern submitted to Monolithic Memories, and include it in your design package.

Submitted by: \_\_\_\_\_ Date: \_\_\_\_\_

Title: \_\_\_\_\_



# Zero Power CMOS Hard Array Logic ZHAL™ 20A Series

## Features/Benefits

- Zero standby power
- 25-ns maximum propagation delay
- HC and HCT compatible
- Space saving PLCC available
- Low power alternative for Small and Medium 20-pin PAL® devices, including 16L8/16R8/16R6/16R4

## Description

The Zero Hard Array Logic (ZHAL) devices are ideal in low-power applications that require high-speed operation. These attributes are achieved through the use of Monolithic Memories' advanced high-speed CMOS process. Now system designers have the option of using a ZHAL device that matches fast PAL device speeds, but with the added advantage of zero standby power. These features are ideal for power-critical areas such as portable digital equipment or lap-top computers. This family of ZHAL devices utilizes a unique architecture that is designed for a high degree of flexibility in implementing most patterns of the listed 20-pin PAL/HAL® devices. Prototyping can be done using standard PAL devices before converting to ZHAL circuits for production. ZHAL devices are fabricated by Monolithic Memories with custom metallization masks defined by a user-supplied HAL Design Specification.

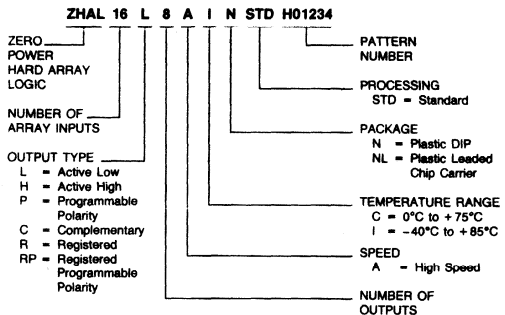
The ZHAL option in the PALASM®2 CAD package will confirm whether a design specification will fit within the ZHAL20 architecture. For more information on the ZHAL software, refer to the PALASM 2 User Manual.

For evaluation of the ZHAL20A circuit, sample patterns are available. See page 4-13 for details.

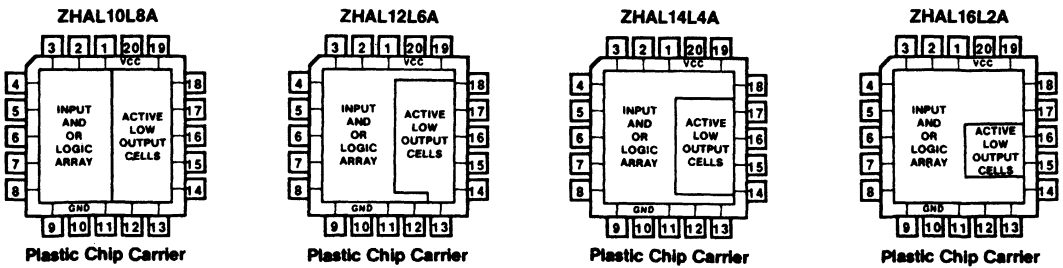
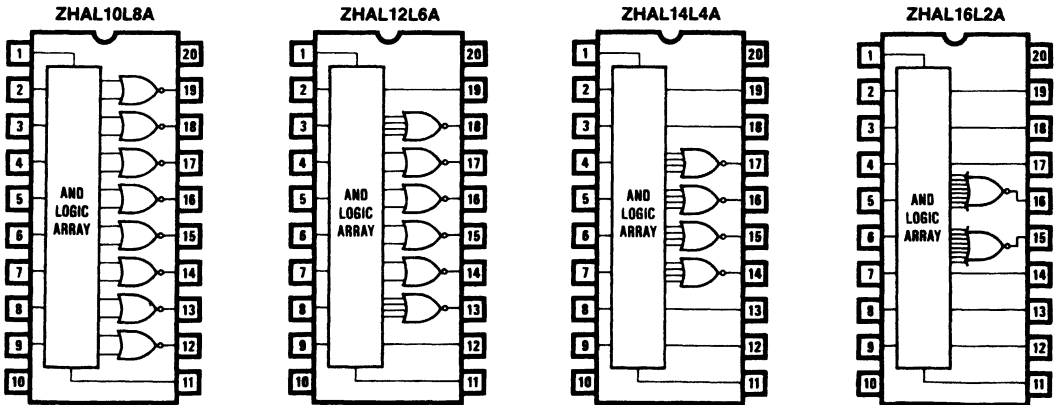
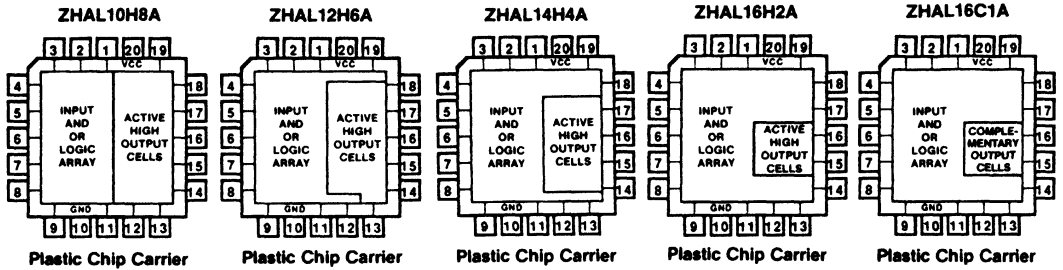
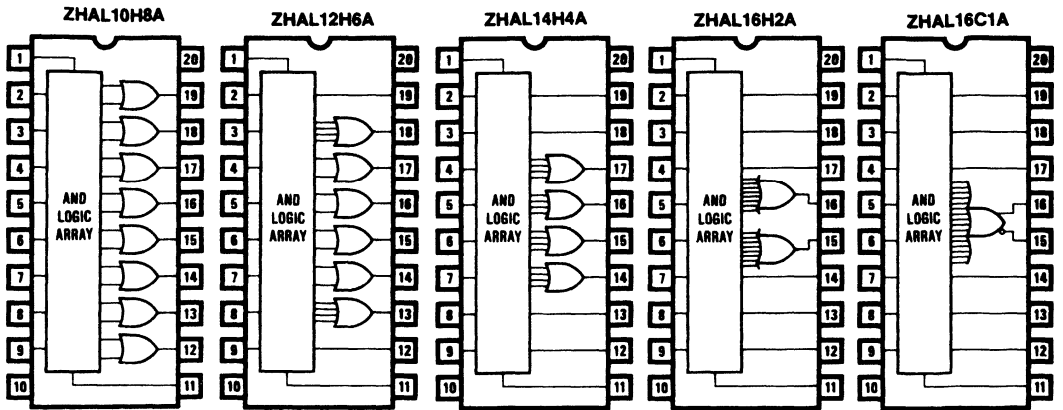
## Ordering Information

| PART NUMBER | PACKAGE | ARRAY | OUTPUTS |     |
|-------------|---------|-------|---------|-----|
|             |         |       | COMB    | REG |
| ZHAL10H8A   | N, NL   | 10    | 8       | —   |
| ZHAL12H6A   |         | 12    | 6       | —   |
| ZHAL14H4A   |         | 14    | 4       | —   |
| ZHAL16H2A   |         | 16    | 2       | —   |
| ZHAL16C1A   |         | 16    | 2       | —   |
| ZHAL10L8A   |         | 10    | 8       | —   |
| ZHAL12L6A   |         | 12    | 6       | —   |
| ZHAL14L4A   |         | 14    | 4       | —   |
| ZHAL16L2A   | 16      | 2     | —       |     |
| ZHAL16L8A   | N, NL   | 16    | 8       | —   |
| ZHAL16R8A   |         | 16    | —       | 8   |
| ZHAL16R6A   |         | 16    | 2       | 6   |
| ZHAL16R4A   |         | 16    | 4       | 4   |
| ZHAL16P8A   | N, NL   | 16    | 8       | —   |
| ZHAL16RP8A  |         | 16    | —       | 8   |
| ZHAL16RP6A  |         | 16    | 2       | 6   |
| ZHAL16RP4A  |         | 16    | 4       | 4   |

4

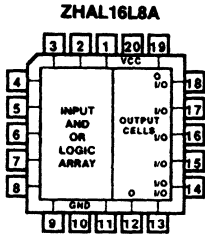
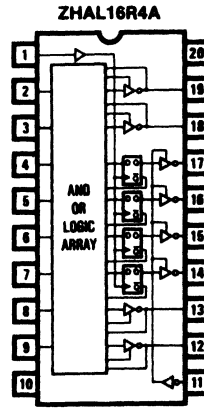
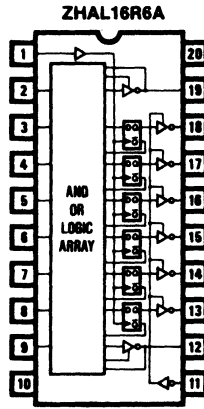
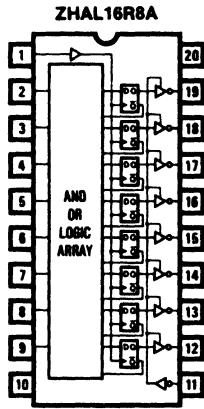
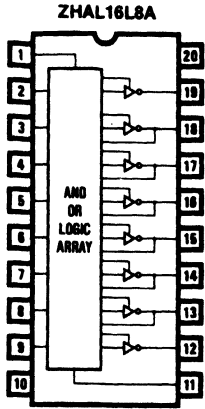


**Zero Power CMOS Hard Array Logic  
ZHAL™ 20A Series**

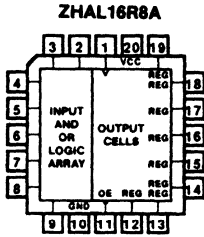


CD01030M

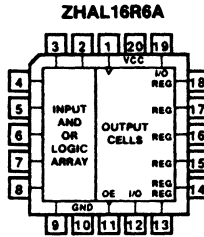
**Zero Power CMOS Hard Array Logic  
ZHAL™ 20A Series**



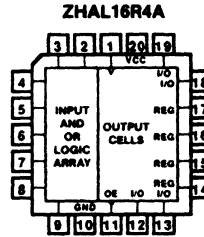
Plastic Chip Carrier



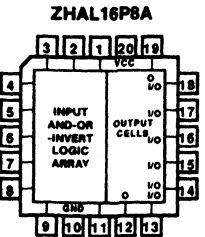
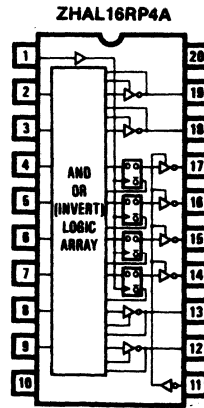
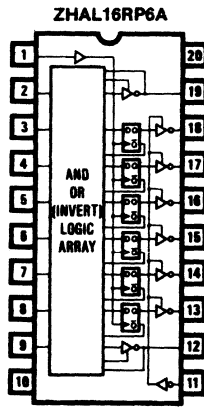
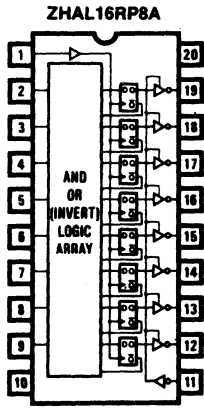
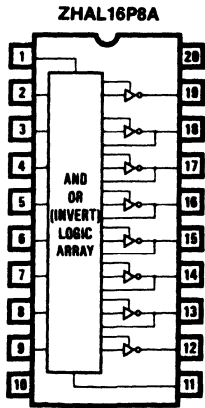
Plastic Chip Carrier



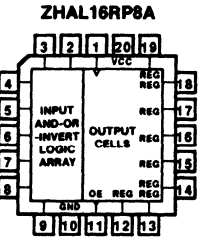
Plastic Chip Carrier



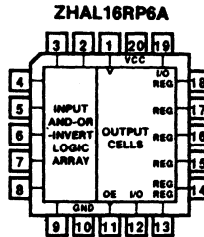
Plastic Chip Carrier



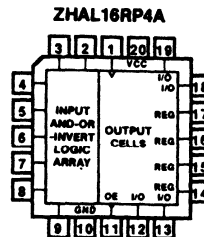
Plastic Chip Carrier



Plastic Chip Carrier



Plastic Chip Carrier



Plastic Chip Carrier

**4**

CC01040M

**Zero Power CMOS Hard Array Logic  
ZHAL™ 20A Series**

**Absolute Maximum Ratings**

|  |                          |
|--|--------------------------|
| Supply voltage, $V_{CC}$ .....                             | -0.5V to 7V              |
| DC input voltage, $V_I$ .....                              | -0.5V to $V_{CC} + 0.5V$ |
| DC output voltage, $V_O$ .....                             | -0.5V to $V_{CC} + 0.5V$ |
| DC output source/sink current per output pin, $I_O$ .....  | ± 35mA                   |
| DC $V_{CC}$ or ground current, $I_{CC}$ or $I_{GND}$ ..... | ± 100mA                  |
| Input diode current, $I_{IK}$ :                            |                          |
| $V_I < 0$ .....  | -20mA                    |
| $V_I > V_{CC}$ .....                                       | + 20mA                   |
| Output diode current, $I_{OK}$ :                           |                          |
| $V_O < 0$ .....  | -20mA                    |
| $V_O > V_{CC}$ .....                                       | + 20mA                   |
| Storage temperature.....                                   | -65°C to 150°C           |

**Operating Conditions**

| SYMBOL   | PARAMETER                                  |   | INDUSTRIAL |     |     | COMMERCIAL |     |      | UNIT |
|----------|--|---|------------|-----|-----|------------|-----|------|------|
|          |  |   | MIN        | TYP | MAX | MIN        | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                             |   | 4.5        | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| $t_w$    | Width of clock                             | 16R4A, 16R6A, 16R8A,<br>16RP4A, 16RP6A,<br>16RP8A | 15         | 10  |     | 15         | 10  |      | ns   |
| $t_{su}$ | Setup time from input or feedback to clock |   | 20         | 13  |     | 20         | 13  |      | ns   |
| $t_h$    | Hold time                                  |   | 0          | -10 |     | 0          | -10 |      | ns   |
| $t_A$    | Operating free-air temperature             |   | -40        | 25  | 85  | 0          | 25  | 75   | °C   |

**Electrical Characteristics Over Operating Conditions**

| SYMBOL      | PARAMETER                           | TEST CONDITIONS                              |                               | MIN               | TYP | MAX            | UNIT    |
|-------------|-------------------------------------|--|-------------------------------|-------------------|-----|----------------|---------|
| $V_{IL}^1$  | Low-level input voltage             |  |                               | 0                 |     | 0.8            | V       |
| $V_{IH}^1$  | High-level input voltage            |  |                               | 2                 |     | $V_{CC}$       | V       |
| $I_{IL}$    | Low-level input current             | $V_{CC} = MAX$                               | $V_I = GND$                   |                   |     | -1             | $\mu A$ |
| $I_{IH}$    | High-level input current            | Pin 8 <sup>2</sup>                           | $V_{CC} = MAX$<br>$V_I = GND$ |                   | 1   | 10             | $\mu A$ |
|             |                                     | All other pins                               |                               |                   |     | 1              | $\mu A$ |
| $V_{OL}$    | Low-level output voltage            | $V_{CC} = MIN$                               | $I_{OL} = 8mA$                |                   | 0.1 | 0.4            | V       |
|             |                                     | $V_{CC} = 5V$                                | $I_{OL} = 1\mu A$             |                   |     | 0.05           |         |
| $V_{OH}$    | High-level output voltage           | $V_{CC} = MIN$                               | $I_{OH} = -6mA$               | 3.76 <sup>3</sup> | 4.1 |                | V       |
|             |                                     | $V_{CC} = 5V$                                | $I_{OH} = -1\mu A$            | 4.95              |     |                |         |
| $I_{OZL}^4$ | Off-state output current            | $V_{CC} = MAX$                               | $V_O = GND$                   |                   | 0   | -10            | $\mu A$ |
| $I_{OZH}^4$ |                                     |  | $V_O = V_{CC}$                |                   | 0   | 10             | $\mu A$ |
| $I_{CC}$    | Standby supply current <sup>5</sup> | $I_O = 0mA, V_I = GND$ or $V_{CC}$           |                               |                   | 0   | 100            | $\mu A$ |
|             | Operating supply current            | $f = 1MHz, I_O = 0mA, V_I = GND$ or $V_{CC}$ |                               |                   | 2   | 5 <sup>6</sup> | mA      |

**Zero Power CMOS Hard Array Logic  
ZHAL™ 20A Series**

**Switching Characteristics** Over Operating Conditions

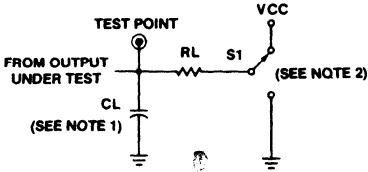
| SYMBOL                   | PARAMETER   |   | TEST CONDITIONS<br>(See Test Load) | INDUSTRIAL |      |     | COMMERCIAL |      |     | UNIT |
|--------------------------|---|---|------------------------------------|------------|------|-----|------------|------|-----|------|
|                          |   |   |                                    | MIN        | TYP  | MAX | MIN        | TYP  | MAX |      |
| $t_{PD}$                 | Input or feedback to output<br>10H8A, 12H6A, 14H4A, 16H2A,<br>16C1A, 10L8A, 12L6A, 14L4A,<br>16L2A, 16L8A, 16R6A, 16R4A,<br>16P8A, 16RP6A, 16RP8A |   | $R_L = 1K\Omega$<br>$C_L = 50pF$   |            | 15   | 25  |            | 15   | 25  | ns   |
| $t_{CLK}$                | Clock to output or feedback<br>16R4A, 16R6A, 16R8A,<br>16RP4A, 16RP6A, 16RP8A   |   |                                    |            | 10   | 15  |            | 10   | 15  | ns   |
| $t_{PZX}$                | Input to output enable  | 16L8A, 16R4A,<br>16R6A, 16P8A,<br>16RP4A,<br>16RP6A     |                                    |            | 12   | 25  |            | 12   | 25  | ns   |
| $t_{PXZ}^7$              | Input to output disable   |   |                                    |            | 14   | 25  |            | 14   | 25  | ns   |
| $t_{PZX}^7$<br>$t_{PZX}$ | Pin 11 to output disable/enable   | 16R4A, 16R6A,<br>16R8A,<br>16RP4A,<br>16RP6A,<br>16RP8A |                                    |            | 12   | 15  |            | 12   | 15  | ns   |
| $f_{MAX}$                | Maximum frequency   |   |                                    |            | 28.5 | 40  |            | 28.5 | 40  | MHz  |

Notes: Apply to electrical and switching characteristics.

1. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.
2. Pin 8 (PRELOAD pin). Applies to all devices whether registered or non-registered.
3. JEDEC standard no. 7 for high-speed CMOS devices.
4. Applies to pins 12 to 19.
5. Disable output pins =  $V_{CC}$  or GND.
6. Add 3mA per additional 1.0MHz of operation over 1MHz.
7.  $C_L = 5pF$ .

**4**

### Switching Test Load



TC00040M

- Notes:
1. CL includes probe and jig capacitance.
  2. When measuring  $t_{PLZ}$  and  $t_{PZL}$ , S1 is tied to  $V_{CC}$ . When measuring  $t_{PHZ}$  and  $t_{PZH}$ , S1 is tied to ground.  $t_{PZX}$  is measured with  $C_L = 50\text{pF}$ .  $t_{PXZ}$  is measured with  $C_L = 5\text{pF}$ . When measuring propagation delay times of 3-state outputs, S1 is open, i.e., not connected to  $V_{CC}$  or ground.
  3. Waveform 1 is for an output with internal conditions such that the output is Low except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is High except when disabled by the output control.

### Output Register PRELOAD†

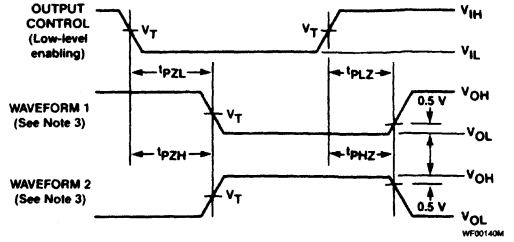
The PRELOAD function allows the register to be loaded from data placed on the output pins. This feature aids functional testing of state sequencer designs by allowing direct setting of output states for improved test coverage. The procedure for PRELOAD is as follows:

1. Raise  $V_{CC}$  to 4.5V.
2. Disable output registers by setting pin 11 to  $V_{IH}$ . Set pin 1 to 0V.
3. Apply  $V_{IL}/V_{IH}$  to all registered output pins.
4. Pulse pin 8 to  $V_p$  (12V), then back to 0V.
5. Remove  $V_{IL}/V_{IH}$  from all registered output pins.
6. Lower pin 11 to  $V_{IL}$  to enable the output registers.
7. Verify for  $V_{OL}/V_{OH}$  at all registered output pins.

† Note: Only applies to parts with output registers.

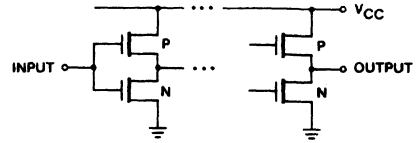
- Typical
- $t_{sup} = 50\text{ns}$
  - $t_{wp} = 100\text{ns}$
  - $t_{hp} = 50\text{ns}$
  - $I_{IH} = 30\mu\text{A}$  (Pin 8)

### Enable/Disable Delay

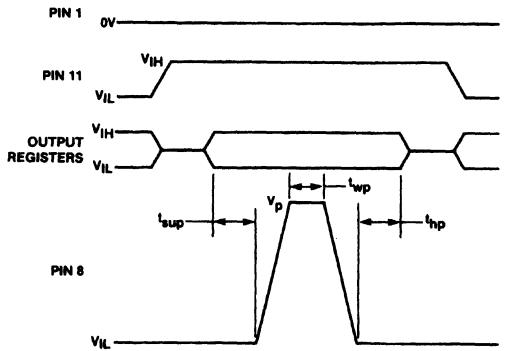


WF00140M

### Schematic of Inputs and Outputs



TC00030M



WF00131M

## ZHAL20A Evaluation #3

### Features/Benefits

- Demonstrates all features of ZHAL20A product
- 4-bit up/down counter with reset
- 3-bit shifter
- 25-ns maximum propagation delay
- Zero standby power

### Description

The ZHAL20A Evaluation Pattern is provided as an example of the features and characteristics of the ZHAL20A Series products.

This design consists of two functionally independent patterns: a 4-bit up/down counter and a 3-bit shifter. The 4-bit counter can count up or count down and has reset capability. These features are controlled by two control signals: UP and CNTRSET (Count Reset). When UP is high, the counter counts up. When UP is low, the counter counts down. CNTRSET overrides the count function and resets the counter to all ones, synchronous with the clock.

The 3-bit shifter shifts data bits by 0, 1 or 2 positions. The three bits of the shifter are enabled when EN (enable) is high, and are disabled (high-Z) when EN is low.

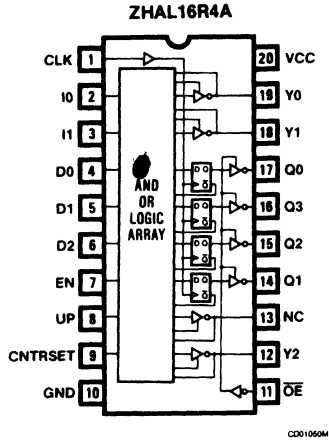
The PALASM<sup>®2</sup> software file and simulation results are shown on the next page. Below are the function tables that summarize the functions of the counter and the shifter.

### Counter Function Table

| $\overline{OE}$ | UP | CNTRSET | CLK | Q3-Q0     | OPERATION |
|-----------------|----|---------|-----|-----------|-----------|
| H               | X  | X       | X   | Z         | High-Z    |
| L               | H  | L       | ↑   | Q plus 1  | Increment |
| L               | L  | L       | ↑   | Q minus 1 | Decrement |
| L               | X  | H       | ↑   | High      | Reset     |

H=HIGH voltage level  
 L=LOW voltage level  
 X=Don't care  
 Z=High impedance (off) state  
 ↑=LOW-to-HIGH clock transition

### Logic Symbol



CD01000M

4

### Shifter Function Table

| EN | I1 | I0 | Y2              | Y1              | Y0              | OPERATION    |
|----|----|----|-----------------|-----------------|-----------------|--------------|
| L  | X  | X  | Z               | Z               | Z               | High-Z       |
| H  | L  | L  | $\overline{D2}$ | $\overline{D1}$ | $\overline{D0}$ | No operation |
| H  | L  | H  | $\overline{D0}$ | $\overline{D2}$ | $\overline{D1}$ | Shift by one |
| H  | H  | L  | $\overline{D1}$ | $\overline{D0}$ | $\overline{D2}$ | Shift by two |

**PALASM Design Specification**

TITLE PDS CONVERSION FILE  
 PATTERN EXAMPLE  
 REVISION 1.00  
 AUTHOR JOHN DOE  
 COMPANY MONOLITHIC MEMORIES, INC  
 DATE 9/23/85  
 CHIP zzz PAL16RP4 CLK I0 I1 D0 D1 D2 EN UP CTRSET GND  
 /OE Y2 NC Q1 Q2 Q3 Q0 Y1 Y0 VCC

**EQUATIONS**

Y0 = /I1\*/I0\*/D0  
 + /I1\* I0\*/D1  
 + I1\*/I0\*/D2  
 Y0.TRST = EN  
 Y1 = /I1\*/I0\*/D1  
 + /I1\* I0\*/D2  
 + I1\*/I0\*/D0  
 Y1.TRST = EN  
 Y2 = /I1\*/I0\*/D2  
 + /I1\* I0\*/D0  
 + I1\*/I0\*/D1  
 Y2.TRST = EN

Q0 := /Q0  
 + CTRSET

Q1 := /Q1\* Q0\* UP  
 + Q1\* Q0\*/UP  
 + Q1\*/Q0\* UP  
 + /Q1\*/Q0\*/UP  
 + CTRSET

Q2 := CTRSET  
 + /Q2\*/Q1\*/Q0\*/UP  
 + Q2\*/Q1\* UP  
 + Q2\* Q1\*/Q0  
 + /Q2\* Q1\* Q0\* UP  
 + Q2\* Q0\*/UP

Q3 := CTRSET  
 + Q3\* Q0\*/UP  
 + /Q3\*/Q2\*/Q1\*/Q0\*/UP  
 + /Q3\* Q2\* Q1\* Q0\* UP  
 + Q3\* Q2\*/Q1  
 + Q3\* /Q1\* UP  
 + Q3\*/Q2\* Q1  
 + Q3\* Q1\*/Q0

**Simulation Results**

**PALASM SIMULATION HISTORY LISTING**

zzz  
 Page : 1  
 CLK g g cg cg cg cgcgcg cgcgcgcgcg cgcgcgcgcg  
 I0 LLLLLLHLL LLLLHLLLH LLLLHLLLH LLLLHLLLH  
 I1 XXXLLLLLH HLLLLLLLL LLLLLLLLL LLLLLLLLL  
 D0 XXXLLLLLH HLLLLLLLL LLLLLLLLL LLLLLLLLL  
 D1 XXXLLLLLH LLLLLLLLL LLLLLLLLL LLLLLLLLL  
 D2 XXXLLLLLH HLLLLLLLL LLLLLLLLL LLLLLLLLL  
 EN LLLLLLLLLH HLLLLLLLLH HLLLLLLLLH HLLLLLLLLH  
 UP XXXXXHHHH HHHHHHHHH HHHHHHHHH HHHHHHHHH  
 CTRSET XXXHHHLLL LLLLLLLLL LLLLLLLLL LLLLLLLLL  
 GND LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL  
 /OE HLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL  
 Y2 XZHNNHHHML LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL  
 Q1 ZZXHHHHML LLLLLHHLL LHHHHHLLL HHHHHLLLH  
 Q2 ZZXHHHHML LLLLLLHLL HHHHHHLLL LLLLHHHHH  
 Q3 ZZXHHHHML LLLLLLLLL LLLLLLHLL HHHHHHHHH  
 Q0 ZZXHHHHML LHHHLLHLL HHHHLLHLL LHHHLLHLL  
 Y1 XZHNNHHHML LHHHHHHHH HHHHHHHHH HHHHHHHHH  
 Y0 XZHNNHHHH HHHHHHHHH HHHHHHHHH HHHHHHHHH  
 VCC HHHHHHHHH HHHHHHHHH HHHHHHHHH HHHHHHHHH

**Simulation File**

SIMULATION  
 TRACE\_ON CLK I0 I1 D0 D1 D2 EN UP CTRSET /OE Y2 Q1 Q2 Q3 Q0 Y1 Y0  
 SETF /CLK /OE /EN  
 SETF OE EN /I1 /I0 /D2 /D1 /D0 Y2 Y1 Y0 CTRSET  
 CLOCKF CLK  
 CHECK Q3 Q2 Q1 Q0  
 SETF /I1 /I0 /D2 /D1 /D0 Y2 Y1 Y0 /CTRSET UP  
 CLOCKF CLK  
 CHECK /Q3 /Q2 /Q1 /Q0  
 SETF /I1 I0 D2 /D1 D0 /Y2 /Y1 Y0  
 CLOCKF CLK  
 CHECK /Q3 /Q2 /Q1 Q0  
 SETF I1 /I0 /D2 D1 /D0 /Y2 Y1 Y0  
 CLOCKF CLK  
 CHECK /Q3 /Q2 Q1 /Q0  
 SETF OE /CTRSET UP  
 CLOCKF CLK  
 CHECK /Q3 /Q2 Q1 Q0  
 SETF OE /CTRSET UP  
 CLOCKF CLK  
 CHECK /Q3 Q2 /Q1 /Q0  
 SETF OE /CTRSET UP  
 CLOCKF CLK  
 CHECK /Q3 Q2 Q1 Q0  
 SETF OE /CTRSET UP  
 CLOCKF CLK  
 CHECK Q3 /Q2 /Q1 /Q0  
 SETF OE /CTRSET UP  
 CLOCKF CLK  
 CHECK Q3 /Q2 /Q1 Q0  
 SETF OE /CTRSET UP  
 CLOCKF CLK  
 CHECK Q3 /Q2 Q1 /Q0  
 SETF OE /CTRSET UP  
 CLOCKF CLK  
 CHECK Q3 /Q2 Q1 /Q0  
 SETF OE /CTRSET UP  
 CLOCKF CLK  
 CHECK Q3 Q2 Q1 /Q0  
 TRACE\_OFF



## Zero Power CMOS Hard Array Logic ZHAL64R32

### Features/Benefits

- Cost-effective mask-programmable complement to PAL64R32 user-programmable device
- CMOS technology provides zero standby power
- High speed with 55ns maximum propagation delay
- High density with 32 highly-flexible macrocells and global connectivity
- Product term sharing, selectable output polarity, and register bypass for high logic efficiency
- Individual clocks for 4 banks of 8 registers
- Register preload for easier test generation
- HC/HCT level compatible for use in CMOS/TTL systems

### Description

The ZHAL64R32 circuit is a high-density logic device with thirty-two flexible macrocells. Each macrocell consists of a registered sum of products with feedback, forming a one-bit state machine. The PAL/ZHAL64R32 device can implement over 1500 equivalent logic gates.

The MegaHAL™ circuit features product term sharing between output pairs. This allows sixteen product terms to be shared mutually exclusively between outputs. Selectable polarity allows the output to be either active low or active high, depending on the sense of the equation. Registers can be bypassed in banks of eight, leaving combinatorial outputs. Each register bank has its own clock, preset, preload, and enable controls for independent operation. The register pre-

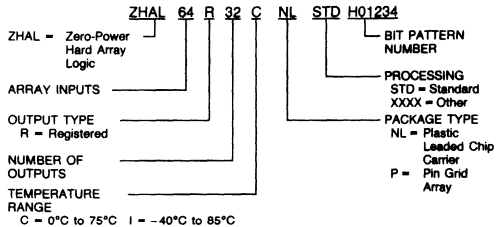
load pin allows test vectors to be loaded directly into the registers for control of present state conditions for testing.

### Design Procedures

The zero-power ZHAL64R32 device is a CMOS, mask-programmable version of the bipolar PAL64R32 circuit. Prototyping can be done with the user-programmable PAL® circuit before committing to a dedicated mask. Thus the MegaPAL™/MegaHAL products combine the instant prototyping of the PAL circuit with the cost-effective, zero power ZHAL™ circuit.

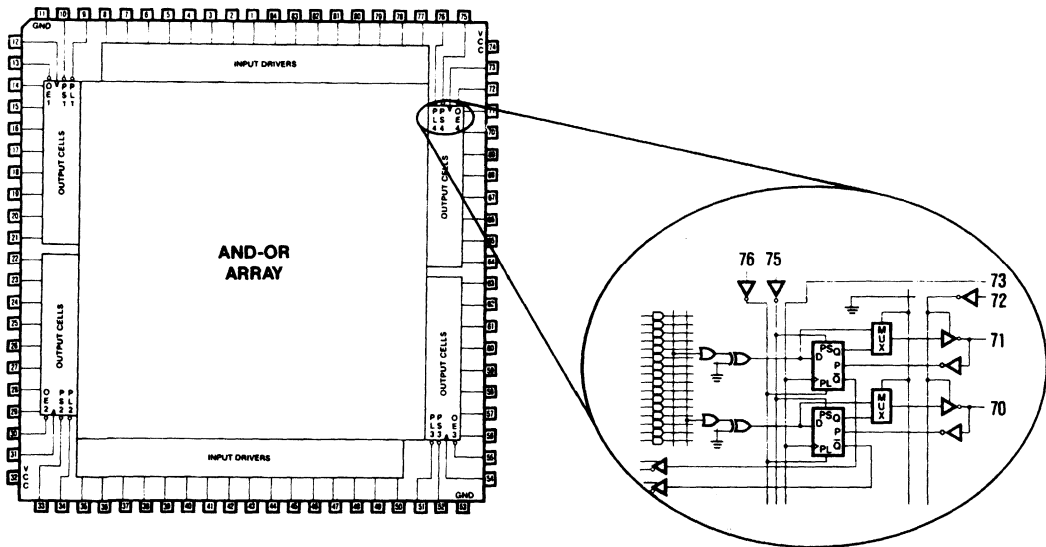
To initiate a design with the ZHAL64R32 device, the PAL64R32 circuit is used to program and debug the design with PALASM®2 software. The resulting "PAL Device Design Specification" is submitted to Monolithic Memories, and the ZHAL circuit option is produced. A ZHAL32R16 option is also available. For details contact a Monolithic Memories representative.

### Ordering Information



4

### Pin Configuration — PLCC



CD01080M



## ZHAL64R32

### Operating Conditions

| SYMBOL     | PARAMETER                                  |      | COMMERCIAL |     |      | INDUSTRIAL |     |     | UNIT |
|------------|--|------|------------|-----|------|------------|-----|-----|------|
|            |  |      | MIN        | TYP | MAX  | MIN        | TYP | MAX |      |
| $V_{CC}$   | Supply voltage                             |      | 4.75       | 5   | 5.25 | 4.5        | 5   | 5.5 | V    |
| $t_w$      | Width of clock                             | Low  | 20         | 10  |      | 20         | 10  |     | ns   |
|            |  | High |            |     |      |            |     |     |      |
| $t_{su}^1$ | Setup time from input or feedback to clock |      | 40         | 24  |      | 45         | 24  |     | ns   |
| $t_h$      | Hold time                                  |      | 0          | -10 |      | 0          | -10 |     | ns   |
| $T_A$      | Operating free-air temperature             |      | 0          | 25  | 75   | -40        | 25  | 85  | °C   |

### Electrical Characteristics Over Operating Conditions

| SYMBOL      | PARAMETER                           | TEST CONDITIONS                                       | MIN                    | TYP | MAX      | UNIT          |
|-------------|-------------------------------------|---|------------------------|-----|----------|---------------|
| $V_{IL}^2$  | Low-level input voltage             |   | 0                      |     | 0.8      | V             |
| $V_{IH}^2$  | High-level input voltage            |   | 2                      |     | $V_{CC}$ | V             |
| $I_{IL}^5$  | Low-level input current             | $V_{CC} = \text{MAX}$<br>$V_I = \text{GND}$           |                        |     | -1       | $\mu\text{A}$ |
| $I_{IH}^5$  | High-level input current            | $V_{CC} = \text{MAX}$<br>$V_I = V_{CC}$               |                        |     | 1        | $\mu\text{A}$ |
| $V_{OL}$    | Low-level output voltage            | $V_{CC} = \text{MIN}$<br>$I_{OL} = 4\text{mA}$        |                        | 0.1 | 0.4      | V             |
|             |                                     | $V_{CC} = 5\text{V}$<br>$I_{OL} = 1\mu\text{A}$       |                        |     | 0.05     |               |
| $V_{OH}$    | High-level output voltage           | $V_{CC} = \text{MIN}$<br>$I_{OH} = -4\text{mA}$       | 3.76 <sup>3</sup>      | 4.1 |          | V             |
|             |                                     | $V_{CC} = 5\text{V}$<br>$I_{OH} = -1\mu\text{A}$      | 4.95                   |     |          |               |
| $I_{OZL}^5$ | Off-state output current            | $V_{CC} = \text{MAX}$<br>$V_O = \text{GND}$           |                        | 0   | -10      | $\mu\text{A}$ |
| $I_{OZH}^5$ |                                     |   |                        | 0   | 10       |               |
| $I_{CC}$    | Standby supply current <sup>4</sup> | $I_O = 0\text{mA}$ , $V_I = \text{GND}$ or $V_{CC}^4$ |                        | 0   | 100      |               |
|             | Operating supply current            | $I_O = 0\text{mA}$ , $V_I = \text{GND}$ or $V_{CC}$   | See graph on page 4-20 |     |          |               |

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### Switching Characteristics Over Operating Conditions

| SYMBOL      | PARAMETER  |             | TEST CONDITIONS<br>(See Test Load)             | COMMERCIAL |     |     | INDUSTRIAL |     |     | UNIT |
|-------------|--|-------------|--|------------|-----|-----|------------|-----|-----|------|
|             |  |             |  | MIN        | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{PD}^1$  | Input or feedback to output                      | Active low  | $R_L = 1\text{K}\Omega$<br>$C_L = 50\text{pF}$ |            | 34  | 55  |            | 34  | 58  | ns   |
|             |  | Active high |  |            |     |     |            |     |     |      |
| $t_{CLK}$   | Clock to output or feedback                      |             |  |            | 14  | 22  |            | 14  | 25  | ns   |
| $t_{PZX}$   | Output enable                                    |             |  |            | 19  | 30  |            | 19  | 30  | ns   |
| $t_{PZX}$   | Output disable                                   |             |  |            | 18  | 30  |            | 18  | 30  | ns   |
| $t_{PRH}$   | Preset to output                                 |             |  |            | 23  | 35  |            | 23  | 40  | ns   |
| $f_{MAX}^1$ | Maximum frequency,<br>$f = 1/(t_{SU} + t_{CLK})$ |             |  |            | 16  | 25  |            | 14  | 25  | MHz  |

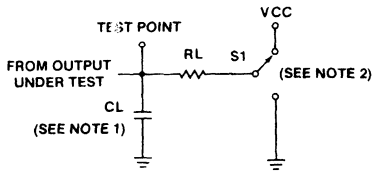
- Notes:
- Maximum 32 inputs per product term.
  - $V_{IL}$  and  $V_{IH}$  are absolute voltages with respect to the ground on the device and includes all overshoots due to system and/ or tester noise. Do not attempt to test these values without suitable equipment.
  - Per JEDEC standard no. 7 for high-speed CMOS devices.
  - Disable output pins =  $V_{CC}$  or GND.
  - I/O pin leakage is the worst case of  $I_{OZX}$  or  $I_{IX}$ , i.e.,  $I_{OZH}$  and  $I_{IL}$ .

# ZHAL64R32

## Absolute Maximum Ratings

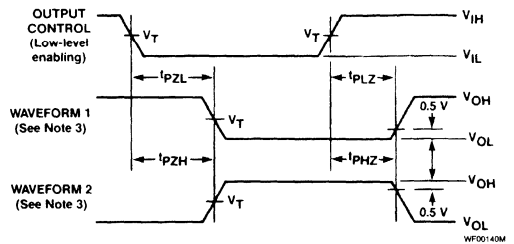
|  |                          |
|--|--------------------------|
| Supply voltage, $V_{CC}$ .....                             | -0.5V to 7.0V            |
| DC input voltage, $V_I$ .....                              | -0.5V to $V_{CC} + 0.5V$ |
| DC output voltage, $V_O$ .....                             | -0.5V to $V_{CC} + 0.5V$ |
| DC output source/sink current per output pin, $I_O$ .....  | $\pm 35mA$               |
| DC $V_{CC}$ or ground current, $I_{CC}$ or $I_{GND}$ ..... | $\pm 100mA$              |
| Input diode current, $I_{IK}$ :                            |                          |
| $V_I < 0$ .....  | -20mA                    |
| $V_I > V_{CC}$ .....                                       | +20mA                    |
| Output diode current, $I_{OK}$ :                           |                          |
| $V_O < 0$ .....  | -20mA                    |
| $V_O > V_{CC}$ .....                                       | +20mA                    |
| Storage temperature.....                                   | -65°C to +150°C          |
| Input rise and fall times.....                             | 0 to 500ns               |

## Switching Test Load



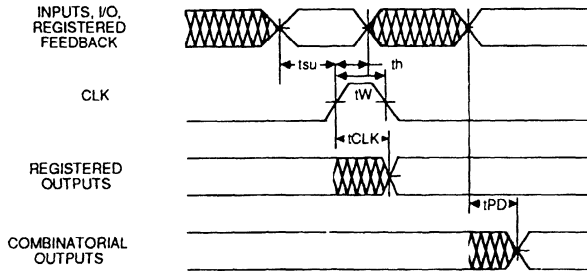
TC00050M

## Enable/Disable Delay



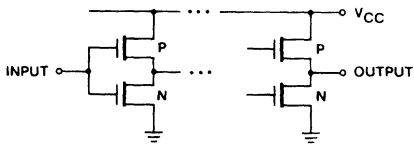
WF00145M

## Switching Waveforms



WF00160M

## Schematic of Inputs and Outputs



TC00030M

- Notes:
1. CL includes probe and jig capacitance.
  2. When measuring  $t_{PLZ}$  and  $t_{PZL}$ , S1 is tied to  $V_{CC}$ . When measuring  $t_{PHZ}$  and  $t_{PZH}$ , S1 is tied to ground. When measuring propagation delay times of 3-state outputs, S1 is open, i.e., not connected to  $V_{CC}$  or ground.
  3. Waveform 1 is for an output with internal conditions such that the output is Low except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is High except when disabled by the output control.

## ZHAL64R32

### ZHAL64R32 Testability Features Testing Conditions

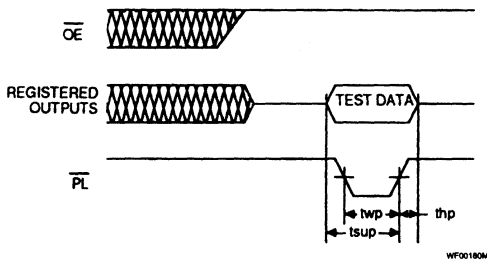
| SYMBOL      | PARAMETER            | COMMERCIAL |     |     | INDUSTRIAL |     |     | UNIT |
|-------------|----------------------|------------|-----|-----|------------|-----|-----|------|
|             |                      | MIN        | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{wp}$    | Preload pulse width  | 35         |     |     | 45         |     |     | ns   |
| $t_{sup}$   | Preload setup time   | 50         |     |     | 60         |     |     | ns   |
| $t_{hp}$    | Preload hold time    | 5          |     |     | 10         |     |     | ns   |
| $t_{PRW}$   | Preset pulse width   | 25         |     |     | 30         |     |     | ns   |
| $t_{PRR}^*$ | Preset recovery time | 45         |     |     | 50         |     |     | ns   |

\* Includes setup time for preset data feedback, Maximum 32 inputs per product term.

#### Preload Feature

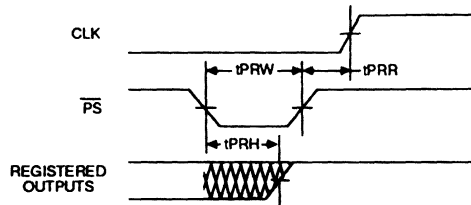
Preload pins are provided to enable the testability of each state in state-machine design. Typically for a state machine there are many unreachable states for the registers. These states, and the logic which controls them, are untestable without a way to "set-in" the desired starting state of the registers. In addition, long test sequences are sometimes needed to test a state machine simply to reach those starting states which are legal. Since complete logic verification is needed to ensure the proper exit from "illegal" or unused states, a way to enter these states must be provided. The ability to preload each bank of registers independently to any state is provided in this device.

To use the preload feature, several steps must be followed. First, a high level on an assertive-low output enable pin disables the outputs for that bank of registers. Next, the data to be loaded is presented at the output pins. This data is then loaded into the register by placing a low level on the PRELOAD pin. PRELOAD is asynchronous with respect to the clock.



#### Preset Feature

Register banks of eight may be PRESET to all highs on the outputs by setting the PRESET pin ( $\overline{PS}$ ) to a low level. Note from the Logic Diagram that when the state of an output is high, the state of the register is low due to the inverting three-state buffer.



WF00170M

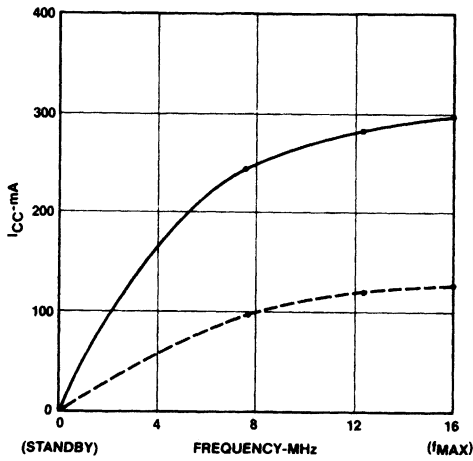
4

Preload data must be held constant while the PRELOAD pin is low.

# ZHAL64R32

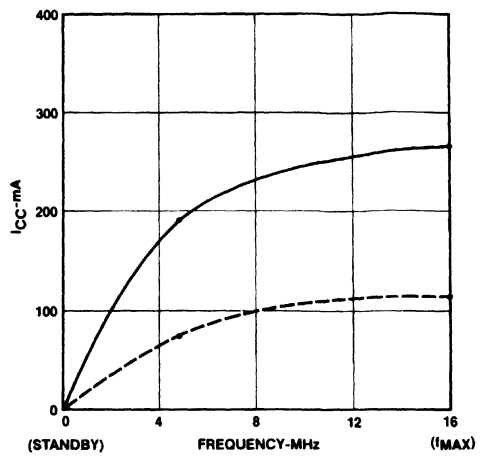
## I<sub>CC</sub> Characteristics vs. Frequency

Commercial Operating Conditions



T<sub>A</sub> = 0°C

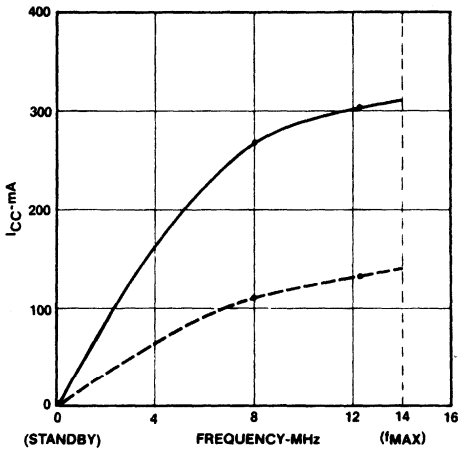
OP00020M



T<sub>A</sub> = 75°C

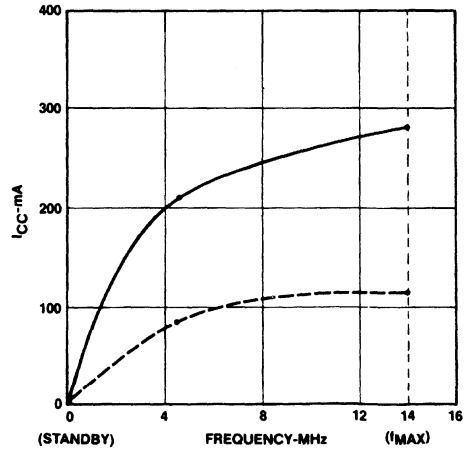
OP00020M

Industrial Operating Conditions



T<sub>A</sub> = -40°C

OP00040M



T<sub>A</sub> = 85°C

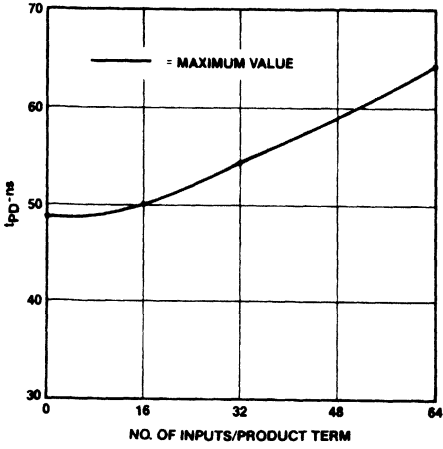
OP00050M

— = MAXIMUM VALUE  
 - - - = V<sub>CC</sub> = 5V WITH 32 INPUTS MAX PER PRODUCT TERM

# ZHAL64R32

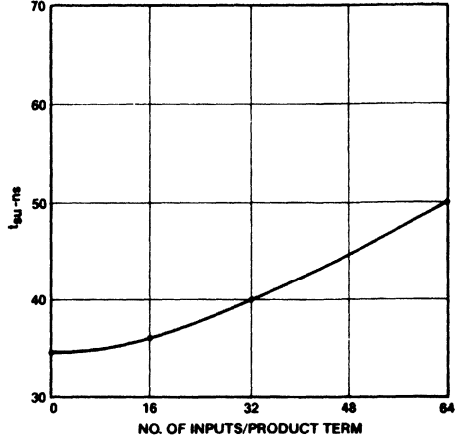
## AC Characteristics vs. Loading

Commercial Operating Conditions



$T_A = 75^\circ\text{C}$

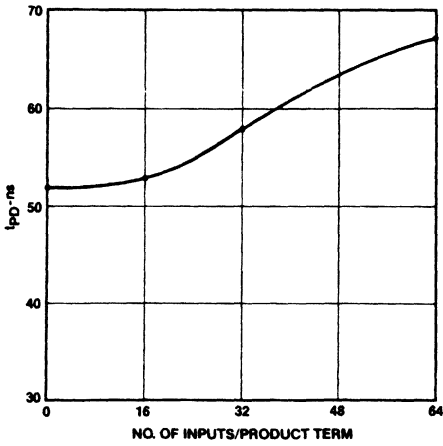
OP00080M



$T_A = 75^\circ\text{C}$

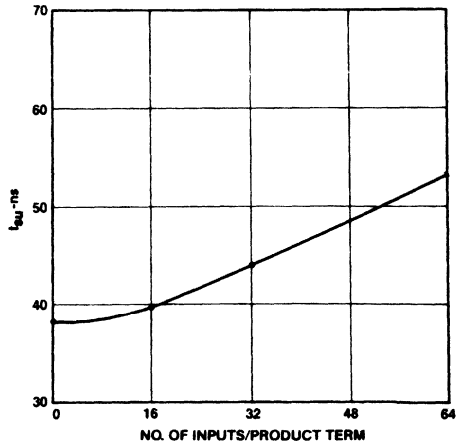
OP00070M

Industrial Operating Conditions



$T_A = 85^\circ\text{C}$

OP00080M



$T_A = 85^\circ\text{C}$

OP00080M

4

### **How To Use The PAL/ZHAL64R32**

The following description and example demonstrate the functionality of the PAL/ZHAL64R32, using PALASM 2 software. Conventions for writing equations conform with the PAL Design Specification format. Features to be programmed into the PAL device are completely specified by the equations and automatically configured by PAL device assemblers.

#### **Register Bypass**

Outputs within a bank must either be all registered or all combinatorial. Whether or not a bank of registers is bypassed depends on how the outputs are defined in the equations. A colon followed by an equal sign [:=] specifies a registered output with feedback which is updated after the low-to-high transition of the clock. An equal sign [=] defines a combinatorial output which bypasses the register. Registers are bypassed in banks of eight. Bypassing a bank of registers eliminates the feedback lines for those outputs.

#### **Output Polarity**

Output polarity is defined by comparison of the pin list and the equations. If the logic sense of a specific output in the pin list

is different from the logic sense of that output as defined by its equation, the output is inverted or active low polarity. If the logic sense of a specific output in the pin list is the same as the logic sense of that output as defined by its equation, the output is active high polarity.

#### **Product Term Sharing**

The basic configuration is sixteen product terms shared between two output cells. For a typical output pair, each product term can be used by either output; but, since product term sharing is exclusive, a product term can be used by only one output, not both. If equations call for both outputs to use the same product term, two product terms are generated, one for each output. This should be taken into account when writing equations. PAL device assemblers configure product terms automatically.

This example on the following page uses the 84-pin package. Four output equations are shown to demonstrate functionality. Pin names are arbitrary.



## ZHAL64R32

TITLE ZHAL64R32 DESIGN EXAMPLE USING PALASM 2  
 PATTERN EXAMPLE.PDS  
 REVISION PALASM 2 VERSION  
 AUTHOR NAME  
 COMPANY MONOLITHIC MEMORIES, INC.  
 DATE 1986

CHIP FUNCTIONALITY\_EXAMPLE PAL64R32

I1 I2 I3 I4 I5 I6 I7 I8 /PL1/PS1 GND CLK1 /OE1  
 Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9 Q10 Q11 Q12 Q13 Q14 Q15 Q16  
 /OE2 CLK2 VCC /PS2 /PL2  
 I9 I10 I11 I12 I13 I14 I15 I16 I17 I18 I19 I20 I21 I22 I23 I24  
 /PL3 /PS3 GND CLK3 /OE3  
 Q17 Q18 Q19 Q20 Q21 Q22 Q23 Q24 Q25 Q26 Q27 Q28 Q29 Q30 Q31 Q32  
 /OE4 CLK4 VCC /PS4 /PL4 I25 I26 I27 I28 I29 I30 I31 I32

EQUATIONS

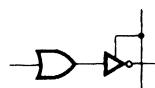
/Q1 = I1\*I2\*I3 ;ACTIVE LOW COMBINATORIAL  
 + I11\*I27\*/I32\*Q9 ;OUTPUT. SINCE THE  
 + I4\*/I9\*Q10 ;REGISTERS ARE BYPASSED  
 + I1\*I2\*I7\*/Q27\*Q15\*/Q32 ;FOR THIS BANK, THE  
 + I8\*/Q13\*/Q32 ;OUTPUTS CANNOT FEED  
 ;BACK INTO THE ARRAY.

Q2 = I1\*I2\*I3 ;ACTIVE HIGH  
 + I27\*/Q12 ;COMBINATORIAL OUTPUT.  
 + I15\*/I32\*/Q9 ;Q2 USES THE REMAINING  
 + /I1\*I2\*/I3\*I4\*Q27 ;I1 PRODUCT TERMS  
 + Q10\*Q11 ;AFTER /Q1 USED 5.  
 + /Q32 ;NOTE THAT THE FIRST  
 + I4\*I9\*I11\*Q12\*/Q27 ;PRODUCT TERM IS  
 + Q9\*Q27\*/Q15 ;CREATED TWICE.  
 + I6\*I7\*/I8\*/I9\*/I10\*/I12  
 + I6\*Q12\*Q15  
 + I11\*/Q15

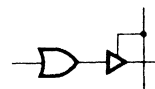
/Q9 := I2\*/I4\*Q15 ;ACTIVE LOW REGISTERED  
 + /I1\*I4\*I9\*I15\*I32 ;OUTPUT. SOME OF THE  
 + Q32\*/Q15 ;OUTPUT SIGNALS ARE FED  
 + /Q9\*I3 ;BACK INTO THE ARRAY,  
 + I8\*/Q13\*/Q32 ;SINCE THE REGISTER IS  
 + I5\*/I6\*I11\*/Q15 ;USED.  
 + I12\*I13\*I27

Q10 := I3\*/I8 ;ACTIVE HIGH REGISTERED  
 + I9\*Q15\*/Q32 ;OUTPUT.  
 + I7\*I8\*/I9\*/Q11\*/Q27\*/Q32

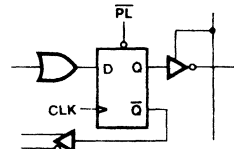
COMBINATORIAL/  
ACTIVE LOW



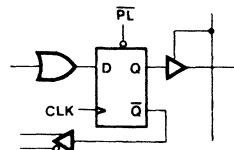
COMBINATORIAL/  
ACTIVE HIGH



REGISTERED/  
ACTIVE LOW



REGISTERED/  
ACTIVE HIGH



1802010M

4

## Zero Power CMOS Hard Array Logic ZHAL™ 24A Series

### Features/Benefits

- Zero standby power
- Low power operation
- High-speed CMOS technology
- HC and HCT compatible
- 24-pin SKINNYDIP® and 28-pin PLCC packages save space
- Low power alternative for most 24-pin PAL® devices, including 20L8/20R8/20R6/20R4

### Description

This family of Zero Power Hard Array Logic (ZHAL) devices utilizes a unique architecture that is designed for a high degree of flexibility in implementing most patterns of the listed 24-pin PAL/HAL® devices. Prototyping should be done using standard PAL devices before converting to ZHAL circuits for production. ZHAL devices are fabricated by Monolithic Memories with custom metallization masks defined by a user-supplied HAL Design Specification.

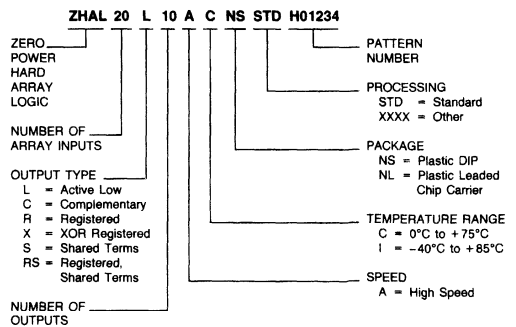
The ZHAL devices are ideal in low-power applications that require high-speed operation. These attributes are achieved through the use of Monolithic Memories' advanced high-speed CMOS process. Now system designers have the option of using a ZHAL device that matches fast PAL device speeds, but with the added feature of zero standby power. These features are needed in power-critical areas such as portable digital equipment or lap-top computers.

The procedures for designing with Monolithic Memories' ZHAL devices are shown in the flow chart on the next page. The ZHAL option in the PALASM®2 CAD package will confirm whether a design specification will fit within the ZHAL architecture. For more information on the ZHAL software, refer to the PALASM 2 User Manual.

For evaluation of the ZHAL24A circuit, sample patterns are available. See the description in this document for details.

### Ordering Information

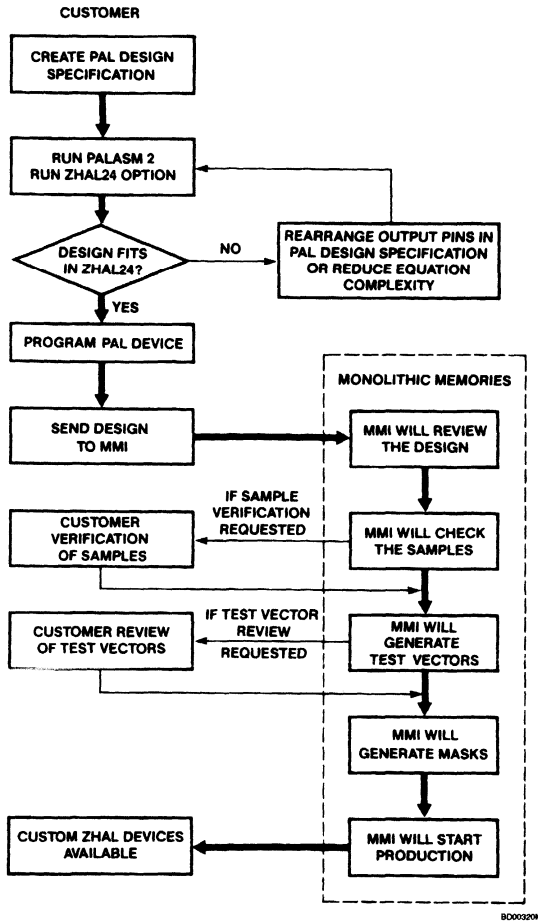
| PART NUMBER | PACKAGE | ARRAY INPUTS | OUTPUTS |     |
|-------------|---------|--------------|---------|-----|
|             |         |              | COMB    | REG |
| ZHAL12L10A  | NS, NL  | 12           | 10      | —   |
| ZHAL14L8A   | NS, NL  | 14           | 8       | —   |
| ZHAL16L6A   | NS, NL  | 16           | 6       | —   |
| ZHAL18L4A   | NS, NL  | 18           | 4       | —   |
| ZHAL20L2A   | NS, NL  | 20           | 2       | —   |
| ZHAL20C1A   | NS, NL  | 20           | 2       | —   |
| ZHAL20L8A   | NS, NL  | 20           | 8       | —   |
| ZHAL20R8A   | NS, NL  | 20           | —       | 8   |
| ZHAL20R6A   | NS, NL  | 20           | 2       | 6   |
| ZHAL20R4A   | NS, NL  | 20           | 4       | 4   |
| ZHAL20L10A  | NS, NL  | 20           | 10      | —   |
| ZHAL20X10A  | NS, NL  | 20           | —       | 10  |
| ZHAL20X8A   | NS, NL  | 20           | 2       | 8   |
| ZHAL20X4A   | NS, NL  | 20           | 6       | 4   |
| ZHAL20S10A  | NS, NL  | 20           | 10      | —   |
| ZHAL20RS10A | NS, NL  | 20           | —       | 10  |
| ZHAL20RS8A  | NS, NL  | 20           | 2       | 8   |
| ZHAL20RS4A  | NS, NL  | 20           | 6       | 4   |



# ZHAL24A Series

## ZHAL 24A Device Generation Flow

ZHAL24A DEVICE GENERATION FLOW

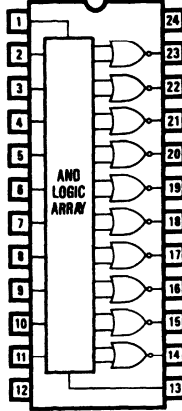


4

## ZHAL24A Series

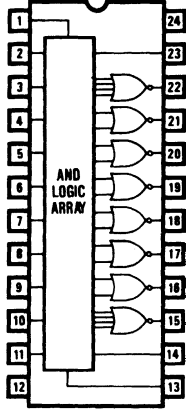
### Pin Configurations – DIP and PLCC

ZHAL12L10A



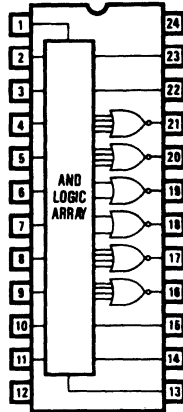
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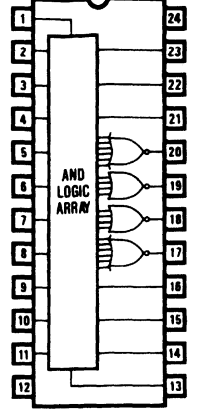
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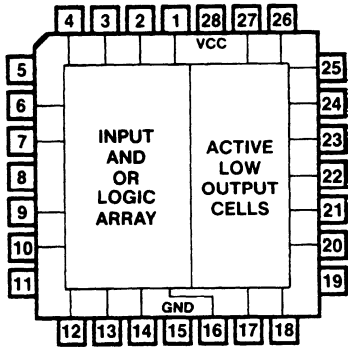
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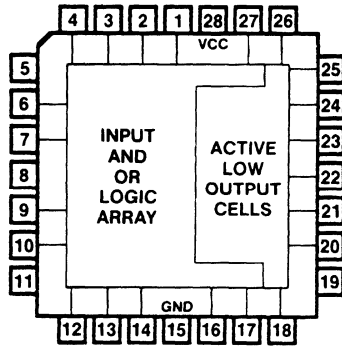
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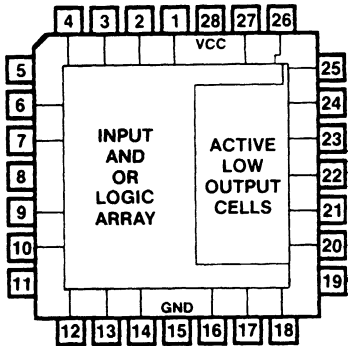
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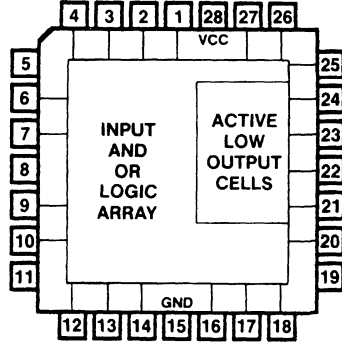
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CD01230M

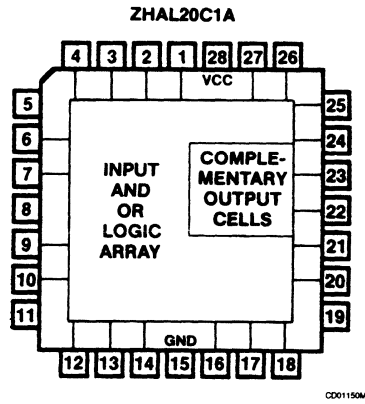
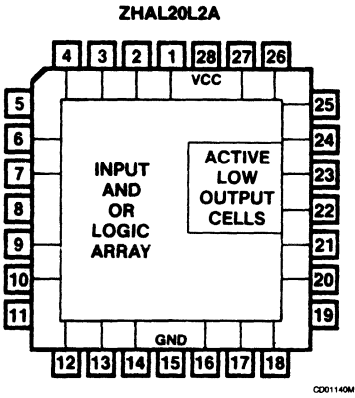
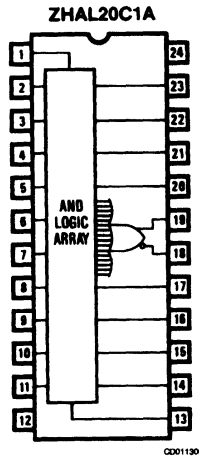
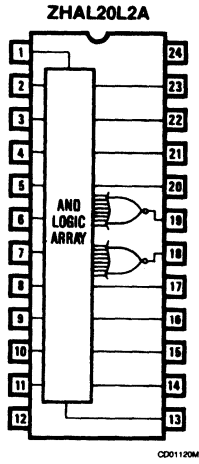
ZHAL18L4A



CD01240M

## ZHAL24A Series

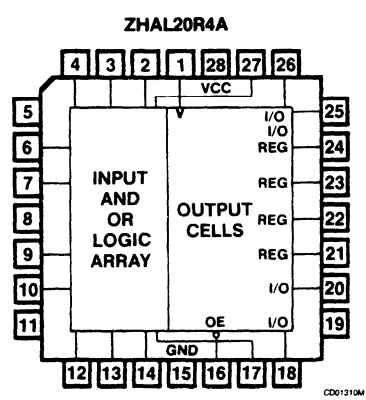
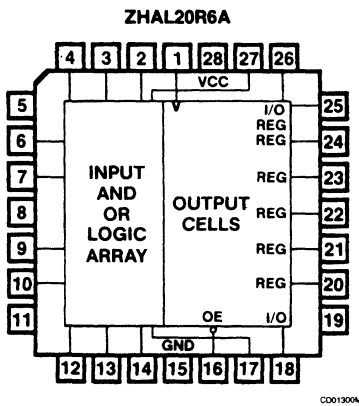
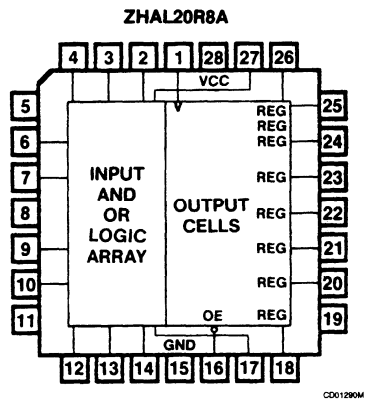
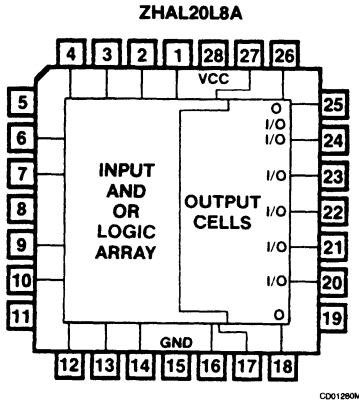
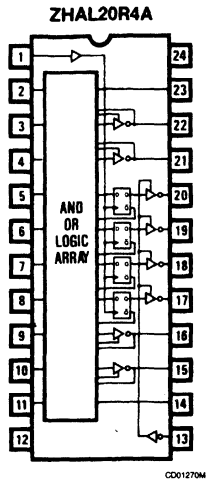
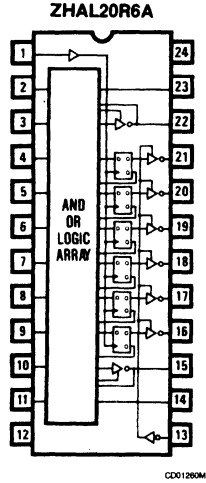
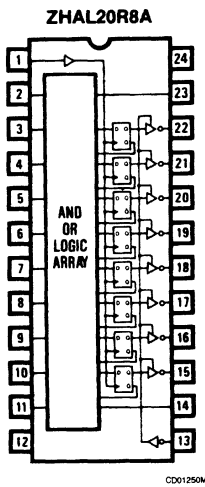
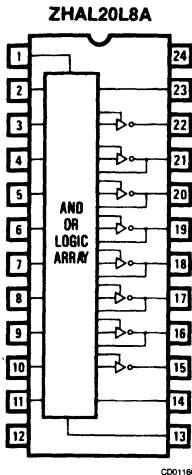
### Pin Configurations – DIP and PLCC



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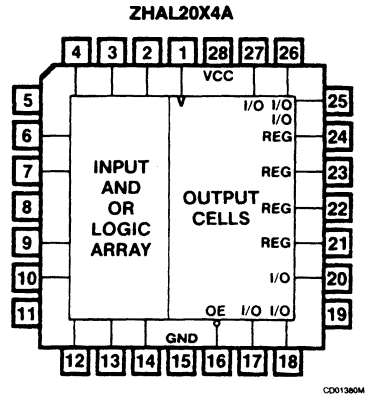
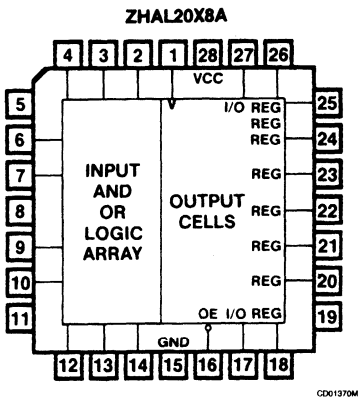
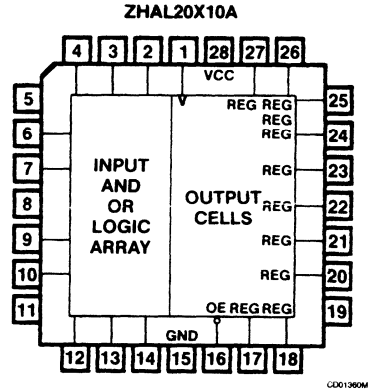
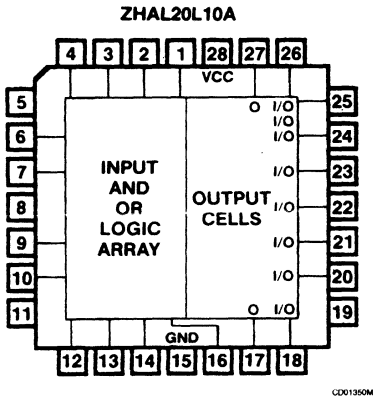
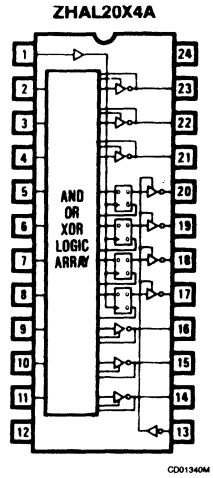
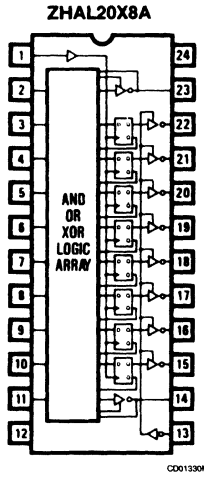
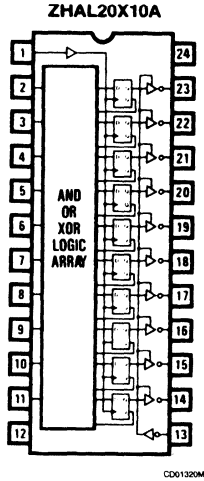
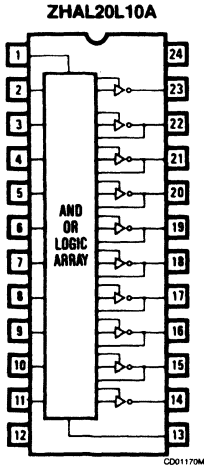
# ZHAL24A Series

## Pin Configurations – DIP and PLCC



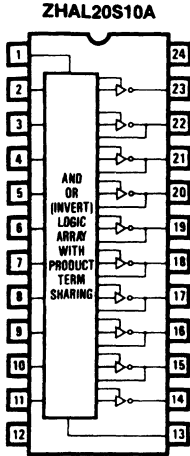
## ZHAL24A Series

### Pin Configurations - DIP and PLCC

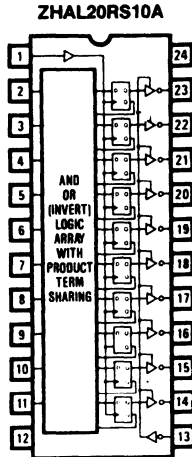


# ZHAL24A Series

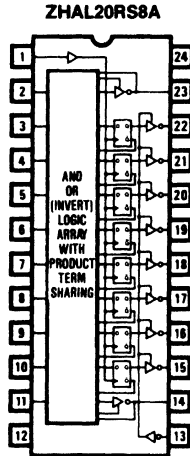
## Pin Configurations - DIP and PLCC



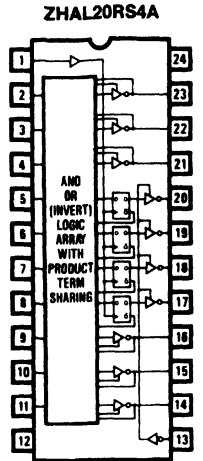
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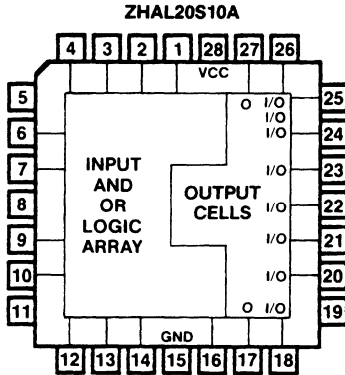
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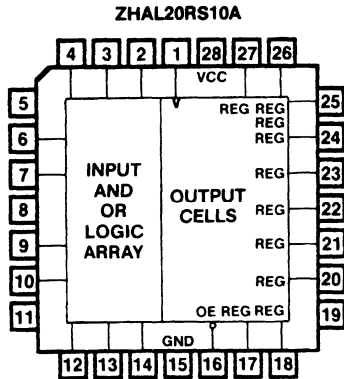
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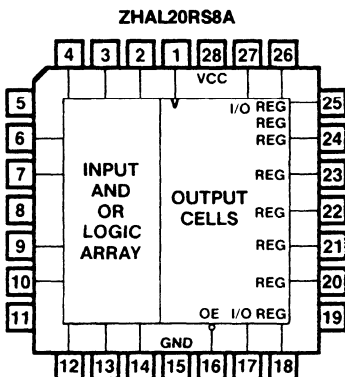
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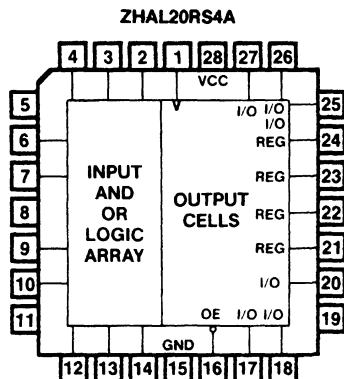
CD01420M



CD01430M



CD01440M



CD01450M



## ZHAL24A Series 12L10A, 14L8A, 16L6A, 18L4A, 20L2A, 20C1A

### Operating Conditions

| SYMBOL   | PARAMETER                      | INDUSTRIAL |     |     | COMMERCIAL |     |      | UNIT |
|----------|--------------------------------|------------|-----|-----|------------|-----|------|------|
|          |                                | MIN        | TYP | MAX | MIN        | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                 | 4.5        | 5   | 5.5 | 4.75       | 5   | 5.25 | V    |
| $T_A$    | Operating free-air temperature | -40        | 25  | 85  | 0          | 25  | 75   | °C   |

### Electrical Characteristics Over Operating Conditions

| SYMBOL      | PARAMETER                           | TEST CONDITIONS   |                          | MIN               | TYP | MAX            | UNIT          |
|-------------|-------------------------------------|---|--------------------------|-------------------|-----|----------------|---------------|
| $V_{IL}^1$  | Low-level input voltage             |   |                          | 0                 |     | 0.8            | V             |
| $V_{IH}^1$  | High-level input voltage            |   |                          | 2                 |     | $V_{CC}$       | V             |
| $I_{IL}$    | Low-level input current             | $V_{CC} = \text{MAX}$   | $V_I = \text{GND}$       |                   |     | -1             | $\mu\text{A}$ |
| $I_{IH}$    | High-level input current            | $V_{CC} = \text{MAX}$   | $V_I = V_{CC}$           |                   |     | 1              | $\mu\text{A}$ |
| $V_{OL}$    | Low-level output voltage            | $V_{CC} = \text{MIN}$   | $I_{OL} = 8\text{mA}$    |                   | 0.1 | 0.4            | V             |
|             |                                     | $V_{CC} = 5\text{V}$  | $I_{OL} = 1\mu\text{A}$  |                   |     | 0.05           |               |
| $V_{OH}$    | High-level output voltage           | $V_{CC} = \text{MIN}$   | $I_{OH} = -6\text{mA}$   | 3.76 <sup>2</sup> | 4.1 |                | V             |
|             |                                     | $V_{CC} = 5\text{V}$  | $I_{OH} = -1\mu\text{A}$ | 4.95              |     |                |               |
| $I_{OZL}^3$ | Off-state output current            | $V_{CC} = \text{MAX}$   | $V_O = \text{GND}$       |                   | 0   | -10            | $\mu\text{A}$ |
| $I_{OZH}^3$ |                                     |   | $V_O = V_{CC}$           |                   | 0   | 10             | $\mu\text{A}$ |
| $I_{CC}$    | Standby supply current <sup>4</sup> | $I_O = 0\text{mA}, V_I = \text{GND or } V_{CC}$                 |                          |                   | 0   | 100            | $\mu\text{A}$ |
|             | Operating supply current            | $f = \text{MHz}, I_O = 0\text{mA}, V_I = \text{GND or } V_{CC}$ |                          |                   | 2   | 5 <sup>5</sup> | $\text{mA}$   |

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### Switching Characteristics Over Operating Conditions

| SYMBOL   | PARAMETER       | TEST CONDITIONS<br>(See Test Load)             | INDUSTRIAL |     |                 | COMMERCIAL |     |                 | UNIT |
|----------|-----------------|--|------------|-----|-----------------|------------|-----|-----------------|------|
|          |                 |  | MIN        | TYP | MAX             | MIN        | TYP | MAX             |      |
| $t_{PD}$ | Input to output | $R_L = 1\text{K}\Omega$<br>$C_L = 50\text{pF}$ |            | 13  | 25 <sup>6</sup> |            | 13  | 25 <sup>6</sup> | ns   |

- Notes: 1. These are absolute voltages with respect to the the ground pin on the device and includes all overshoots due to system and/ or tester noise. Do not attempt to test these values without suitable equipment.
2. JEDEC standard no. 7 for high-speed CMOS devices.
3. Applies to pins 14-23 for DIP (pins 17, 18, 20-27 for PLCC).
4. Disable output pins =  $V_{CC}$  or GND.
5. Add 3mA per additional 1.0MHz of operation over 1MHz.
6. For outputs with more than 12 inputs in a product term,  $t_{PD} = 30\text{ns}$ .

## ZHAL24A Series 20L8A, 20R8A, 20R6A, 20R4A

### Operating Conditions

| SYMBOL   | PARAMETER                                  |  | INDUSTRIAL      |     |     | COMMERCIAL      |     |      | UNIT |
|----------|--|--|-----------------|-----|-----|-----------------|-----|------|------|
|          |  |  | MIN             | TYP | MAX | MIN             | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                             |  | 4.5             | 5   | 5.5 | 4.75            | 5   | 5.25 | V    |
| $t_w$    | Width of clock                             |  | 15              | 4   |     | 15              | 4   |      | ns   |
| $t_{su}$ | Setup time from input or feedback to clock |  | 20 <sup>1</sup> | 11  |     | 20 <sup>1</sup> | 11  |      | ns   |
| $t_h$    | Hold time                                  |  | 0               | -10 |     | 0               | -10 |      | ns   |
| $T_A$    | Operating free-air temperature             |  | -40             | 25  | 85  | 0               | 25  | 75   | °C   |

### Electrical Characteristics Over Operating Conditions

| SYMBOL      | PARAMETER                           |                     | TEST CONDITIONS   |                          | MIN               | TYP | MAX            | UNIT          |
|-------------|-------------------------------------|---------------------|---|--------------------------|-------------------|-----|----------------|---------------|
| $V_{IL}^2$  | Low-level input voltage             |                     |   |                          | 0                 |     | 0.8            | V             |
| $V_{IH}^2$  | High-level input voltage            |                     |   |                          | 2                 |     | $V_{CC}$       | V             |
| $I_{IL}$    | Low-level input current             |                     | $V_{CC} = \text{MAX}$   | $V_I = \text{GND}$       |                   |     | -1             | $\mu\text{A}$ |
| $I_{IH}$    | High-level input current            | Pin 10 <sup>3</sup> | $V_{CC} = \text{MAX}$   | $V_I = V_{CC}$           |                   | 8   | 30             | $\mu\text{A}$ |
|             |                                     | All other pins      |   |                          |                   |     | 1              | $\mu\text{A}$ |
| $V_{OL}$    | Low-level output voltage            |                     | $V_{CC} = \text{MIN}$   | $I_{OL} = 8\text{mA}$    |                   | 0.1 | 0.4            | V             |
|             |                                     |                     | $V_{CC} = 5\text{V}$  | $I_{OL} = 1\mu\text{A}$  |                   |     | 0.05           |               |
| $V_{OH}$    | High-level output voltage           |                     | $V_{CC} = \text{MIN}$   | $I_{OH} = -6\text{mA}$   | 3.76 <sup>4</sup> | 4.1 |                | V             |
|             |                                     |                     | $V_{CC} = 5\text{V}$  | $I_{OH} = -1\mu\text{A}$ | 4.95              |     |                |               |
| $I_{OZL}^5$ | Off-state output current            |                     | $V_{CC} = \text{MAX}$   | $V_O = \text{GND}$       |                   | 0   | -10            | $\mu\text{A}$ |
| $I_{OZH}^5$ |                                     |                     |   | $V_O = V_{CC}$           |                   | 0   | 10             | $\mu\text{A}$ |
| $I_{CC}$    | Standby supply current <sup>6</sup> |                     | $I_O = 0\text{mA}$ , $V_I = \text{GND}$ or $V_{CC}$                     |                          |                   | 0   | 100            | $\mu\text{A}$ |
|             | Operating supply current            |                     | $f = 1\text{MHz}$ , $I_O = 0\text{mA}$ , $V_I = \text{GND}$ or $V_{CC}$ |                          |                   | 2   | 5 <sup>7</sup> | mA            |

### Switching Characteristics Over Operating Conditions

| SYMBOL      | PARAMETER  |                           | TEST CONDITIONS<br>(See Test Load)             | INDUSTRIAL |      |                 | COMMERCIAL |      |                 | UNIT |
|-------------|--|---------------------------|--|------------|------|-----------------|------------|------|-----------------|------|
|             |  |                           |  | MIN        | TYP  | MAX             | MIN        | TYP  | MAX             |      |
| $t_{PD}$    | Input or feedback to output<br>20L8A, 20R6A, 20R4A |                           | $R_L = 1\text{K}\Omega$<br>$C_L = 50\text{pF}$ |            | 13   | 25 <sup>1</sup> |            | 13   | 25 <sup>1</sup> | ns   |
| $t_{CLK}$   | Clock to output or feedback<br>20R8A, 20R6A, 20R4A |                           |  |            | 8    | 15              |            | 8    | 15              | ns   |
| $t_{PZX}$   | Input to output enable                             | 20L8A,<br>20R6A,<br>20R4A |  |            | 12   | 25              |            | 12   | 25              | ns   |
| $t_{PXZ}^8$ | Input to output disable                            |                           |  |            | 12   | 25              |            | 12   | 25              | ns   |
| $t_{PXZ}^8$ | Pin 13 (DIP) to output disable/enable              | 20R8A,<br>20R6A,<br>20R4A |  |            | 10   | 20              |            | 10   | 20              | ns   |
| $t_{PZX}$   |  |                           |  |            |      |                 |            |      |                 |      |
| $f_{MAX}$   | Maximum frequency                                  |                           |  |            | 28.5 | 40              |            | 28.5 | 40              | MHz  |

- Notes: 1. For outputs with more than 12 inputs in a product term,  $t_{SU} = 25\text{ns}$  and  $t_{PD} = 30\text{ns}$ .  
2. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.  
3. Pin 10 (PRELOAD pin), pin 13PLCC (PRELOAD pin). Applies to registered devices only.  
4. JEDEC standard no. 7 for high-speed CMOS devices.  
5. Applies to pins 14-23 for DIP (pins 17, 18, 20-27 for PLCC).  
6. Disable output pins =  $V_{CC}$  or GND.  
7. Add 3mA per additional 1.0MHz of operation over 1MHz.  
8.  $C_L = 5\text{pF}$ .

## ZHAL24A Series 20L10A, 20X10A, 20X8A, 20X4A

### Operating Conditions

| SYMBOL          | PARAMETER                                  | INDUSTRIAL      |     |     | COMMERCIAL      |     |      | UNIT |
|-----------------|--|-----------------|-----|-----|-----------------|-----|------|------|
|                 |  | MIN             | TYP | MAX | MIN             | TYP | MAX  |      |
| V <sub>CC</sub> | Supply Voltage                             | 4.5             | 5   | 5.5 | 4.75            | 5   | 5.25 | V    |
| t <sub>w</sub>  | Width of clock                             | 15              | 5   |     | 15              | 5   |      | ns   |
| t <sub>su</sub> | Setup time from input or feedback to clock | 25 <sup>1</sup> | 15  |     | 25 <sup>1</sup> | 15  |      | ns   |
| t <sub>h</sub>  | Hold time                                  | 0               | -10 |     | 0               | -10 |      | ns   |
| T <sub>A</sub>  | Operating free-air temperature             | -40             | 25  | 85  | 0               | 25  | 75   | °C   |

### Electrical Characteristics Over Operating Conditions

| SYMBOL                        | PARAMETER                           | TEST CONDITIONS   |                                  | MIN                              | TYP | MAX             | UNIT |    |
|-------------------------------|-------------------------------------|---|----------------------------------|----------------------------------|-----|-----------------|------|----|
| V <sub>IL</sub> <sup>2</sup>  | Low-level input voltage             |   |                                  | 0                                |     | 0.8             | V    |    |
| V <sub>IH</sub> <sup>2</sup>  | High-level input voltage            |   |                                  | 2                                |     | V <sub>CC</sub> | V    |    |
| I <sub>IL</sub>               | Low-level input current             | V <sub>CC</sub> = MAX   | V <sub>I</sub> = GND             |                                  |     | -1              | μA   |    |
| I <sub>IH</sub>               | High-level input current            | Pin 10 <sup>3</sup>   | V <sub>CC</sub> = MAX            | V <sub>I</sub> = V <sub>CC</sub> |     | 8               | 30   | μA |
|                               |                                     | All other pins  |                                  |                                  |     |                 | 1    | μA |
| V <sub>OL</sub>               | Low-level output voltage            | V <sub>CC</sub> = MIN   | I <sub>OL</sub> = 8mA            |                                  | 0.1 | 0.4             | V    |    |
|                               |                                     | V <sub>CC</sub> = 5V  | I <sub>OL</sub> = 1μA            |                                  |     | 0.05            |      |    |
| V <sub>OH</sub>               | High-level output voltage           | V <sub>CC</sub> = MIN   | I <sub>OH</sub> = -6mA           | 3.76 <sup>4</sup>                | 4.1 |                 | V    |    |
|                               |                                     | V <sub>CC</sub> = 5V  | I <sub>OH</sub> = -1μA           | 4.95                             |     |                 |      |    |
| I <sub>OZL</sub> <sup>5</sup> | Off-state output current            | V <sub>CC</sub> = MAX   | V <sub>O</sub> = GND             |                                  | 0   | -10             | μA   |    |
| I <sub>OZH</sub> <sup>5</sup> |                                     |   | V <sub>O</sub> = V <sub>CC</sub> |                                  | 0   | 10              | μA   |    |
| I <sub>CC</sub>               | Standby supply current <sup>6</sup> | I <sub>O</sub> = 0mA, V <sub>I</sub> = GND or V <sub>CC</sub>           |                                  |                                  | 0   | 100             | μA   |    |
|                               | Operating supply current            | f = 1MHz, I <sub>O</sub> = 0mA, V <sub>I</sub> = GND or V <sub>CC</sub> |                                  |                                  | 2   | 5 <sup>7</sup>  | mA   |    |

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### Switching Characteristics Over Operating Conditions

| SYMBOL                        | PARAMETER   | TEST CONDITIONS (See Test Load)               | INDUSTRIAL                 |      |                 | COMMERCIAL |      |                 | UNIT |    |
|-------------------------------|---|---|----------------------------|------|-----------------|------------|------|-----------------|------|----|
|                               |   |   | MIN                        | TYP  | MAX             | MIN        | TYP  | MAX             |      |    |
| t <sub>PD</sub>               | Input or feedback to output<br>20L10A, 20X8A, 20X4A | R <sub>L</sub> = 1KΩ<br>C <sub>L</sub> = 50pF |                            | 13   | 25 <sup>1</sup> |            | 13   | 25 <sup>1</sup> | ns   |    |
| t <sub>CLK</sub>              | Clock to output or feedback<br>20X10A, 20X8A, 20X4A |   |                            | 10   | 15              |            | 10   | 15              | ns   |    |
| t <sub>PZX</sub>              | Input to output enable                              |   | 20L10A,<br>20X8A,<br>20X4A |      | 12              | 25         |      | 12              | 25   | ns |
| t <sub>PXZ</sub> <sup>8</sup> | Input to output disable                             |   |                            |      | 12              | 25         |      | 12              | 25   | ns |
| t <sub>PXZ</sub> <sup>8</sup> | Pin 13 (DIP) to output disable/enable               |   | 20X10A,<br>20X8A,<br>20X4A |      | 15              | 20         |      | 15              | 20   | ns |
| t <sub>PZX</sub>              |   |   |                            |      |                 |            |      |                 |      |    |
| f <sub>MAX</sub>              | Maximum frequency                                   |   |                            | 22.2 | 32              |            | 22.2 | 32              | MHz  |    |

- Notes: 1. For outputs with more than 12 inputs in a product term, t<sub>su</sub> = 30ns and t<sub>pd</sub> = 30ns.  
 2. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.  
 3. Pin 10 (PRELOAD pin), pin 13PLCC (PRELOAD pin). Applies to registered devices only.  
 4. JEDEC standard no. 7 for high-speed CMOS devices.  
 5. Applies to pins 14-23 for DIP (pins 17, 18, 20-27 for PLCC).  
 6. Disable output pins = V<sub>CC</sub> or GND.  
 7. Add 3mA per additional 1.0MHz of operation over 1MHz.  
 8. C<sub>L</sub> = 5pF.

## ZHAL24A Series 20S10A, 20RS10A, 20RS8A, 20RS4A

### Operating Conditions

| SYMBOL   | PARAMETER                      | INDUSTRIAL      |     |     | COMMERCIAL      |     |      | UNIT |
|----------|--------------------------------|-----------------|-----|-----|-----------------|-----|------|------|
|          |                                | MIN             | TYP | MAX | MIN             | TYP | MAX  |      |
| $V_{CC}$ | Supply voltage                 | 4.5             | 5   | 5.5 | 4.75            | 5   | 5.25 | V    |
| $t_w$    | Width of clock                 | 15              | 4   |     | 15              | 4   |      | ns   |
| $t_{su}$ | Setup time for input clock     | 20 <sup>1</sup> | 11  |     | 20 <sup>1</sup> | 11  |      | ns   |
| $t_h$    | Hold time                      | 0               | -10 |     | 0               | -10 |      |      |
| $T_A$    | Operating free-air temperature | -40             | 25  | 85  | 0               | 25  | 75   | °C   |

### Electrical Characteristics Over Operating Conditions

| SYMBOL      | PARAMETER                           | TEST CONDITIONS   |                          | MIN               | TYP | MAX            | UNIT          |
|-------------|-------------------------------------|---|--------------------------|-------------------|-----|----------------|---------------|
| $V_{IL}^2$  | Low-level input voltage             |   |                          | 0                 |     | 0.8            | V             |
| $V_{IH}^2$  | High-level input voltage            |   |                          | 2                 |     | $V_{CC}$       | V             |
| $I_{IL}$    | Low-level input current             | $V_{CC} = \text{MAX}$   | $V_I = \text{GND}$       |                   |     | -1             | $\mu\text{A}$ |
| $I_{IH}$    | High-level input current            | Pin 10 <sup>3</sup>   | $V_I = V_{CC}$           |                   | 8   | 30             | $\mu\text{A}$ |
|             |                                     | All other pins  |                          |                   |     | 1              | $\mu\text{A}$ |
| $V_{OL}$    | Low-level output voltage            | $V_{CC} = \text{MIN}$   | $I_{OL} = 8\text{mA}$    |                   | 0.1 | 0.4            | V             |
|             |                                     | $V_{CC} = 5\text{V}$  | $I_{OL} = 1\mu\text{A}$  |                   |     | 0.05           |               |
| $V_{OH}$    | High-level output voltage           | $V_{CC} = \text{MIN}$   | $I_{OH} = -6\text{mA}$   | 3.76 <sup>4</sup> | 4.1 |                | V             |
|             |                                     | $V_{CC} = 5\text{V}$  | $I_{OH} = -1\mu\text{A}$ | 4.95              |     |                |               |
| $I_{OZL}^5$ | Off-state output current            | $V_{CC} = \text{MAX}$   | $V_O = \text{GND}$       |                   | 0   | -10            | $\mu\text{A}$ |
| $I_{OZH}^5$ |                                     |   | $V_O = V_{CC}$           |                   | 0   | 10             | $\mu\text{A}$ |
| $I_{CC}$    | Standby supply current <sup>6</sup> | $I_O = 0\text{mA}$ , $V_I = \text{GND}$ or $V_{CC}$                     |                          |                   | 0   | 100            | $\mu\text{A}$ |
|             | Operating supply current            | $f = 1\text{MHz}$ , $I_O = 0\text{mA}$ , $V_I = \text{GND}$ or $V_{CC}$ |                          |                   | 2   | 5 <sup>7</sup> | $\text{mA}$   |

### Switching Characteristics Over Operating Conditions

| SYMBOL      | PARAMETER  | TEST CONDITIONS<br>(See Test Load)             | INDUSTRIAL                    |      |                 | COMMERCIAL |      |                 | UNIT |    |
|-------------|--|--|-------------------------------|------|-----------------|------------|------|-----------------|------|----|
|             |  |  | MIN                           | TYP  | MAX             | MIN        | TYP  | MAX             |      |    |
| $t_{PD}$    | Input or feedback to output<br>20S10A, 20RS8A, 20RS4A  | $R_L = 1\text{K}\Omega$<br>$C_L = 50\text{pF}$ |                               | 13   | 25 <sup>1</sup> |            | 13   | 25 <sup>1</sup> | ns   |    |
| $t_{CLK}$   | Clock to output or feedback<br>20RS10A, 20RS8A, 20RS4A |  |                               | 8    | 15              |            | 8    | 15              | ns   |    |
| $t_{PZX}$   | Input to output enable                                 |  | 20S10A,<br>20RS8A,<br>20RS4A  |      | 12              | 25         |      | 12              | 25   | ns |
| $t_{PXZ}^8$ | Input to output disable                                |  |                               |      | 12              | 25         |      | 12              | 25   | ns |
| $t_{PXZ}^8$ | Pin 13 (DIP) to<br>output disable/<br>enable           |  | 20RS10A,<br>20RS8A,<br>20RS4A |      | 10              | 20         |      | 10              | 20   | ns |
| $t_{PZX}$   |  |  |                               |      |                 |            |      |                 |      |    |
| $f_{MAX}$   | Maximum frequency                                      |  |                               | 28.5 | 40              |            | 28.5 | 40              | MHz  |    |

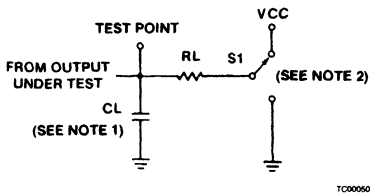
- Notes: 1. For outputs with more than 12 inputs in a product term,  $t_{SU} = 25\text{ns}$  and  $t_{PD} = 30\text{ns}$ .  
2. These are absolute voltages with respect to the ground pin on the device and include all overshoots due to system and/or tester noise. Do not attempt to test these values without suitable equipment.  
3. Pin 10 (PRELOAD pin), pin 13PLCC (PRELOAD pin). Applies to registered devices only.  
4. JEDEC standard no. 7 for high-speed CMOS devices.  
5. Applies to pins 14-23 for DIP (pins 17, 18, 20-27 for PLCC).  
6. Disable output pins =  $V_{CC}$  or GND.  
7. Add 3mA per additional 1.0MHz of operation over 1MHz.  
8.  $C_L = 5\text{pF}$ .

## ZHAL24A Series

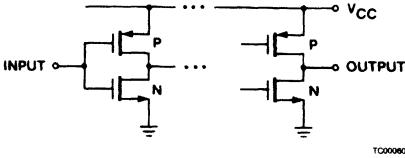
### Absolute Maximum Ratings

|  |                          |
|--|--------------------------|
| Supply voltage, $V_{CC}$ .....                             | -0.5V to 7V              |
| DC input voltage, $V_I$ .....                              | -0.5V to $V_{CC} + 0.5V$ |
| DC output voltage, $V_O$ .....                             | -0.5V to $V_{CC} + 0.5V$ |
| DC output source/sink current per output pin, $I_O$ .....  | $\pm 35mA$               |
| DC $V_{CC}$ or ground current, $I_{CC}$ or $I_{GND}$ ..... | $\pm 100mA$              |
| Input diode current, $I_{IK}$ :                            |                          |
| $V_I < 0$ .....  | -20mA                    |
| $V_I > V_{CC}$ .....                                       | +20mA                    |
| Output diode current, $I_{OK}$ :                           |                          |
| $V_O < 0$ .....  | -20mA                    |
| $V_O > V_{CC}$ .....                                       | +20mA                    |
| Storage temperature .....                                  | -65°C to +150°C          |

### Switching Test Load



### Schematic of Inputs and Outputs



### Output Register PRELOAD†

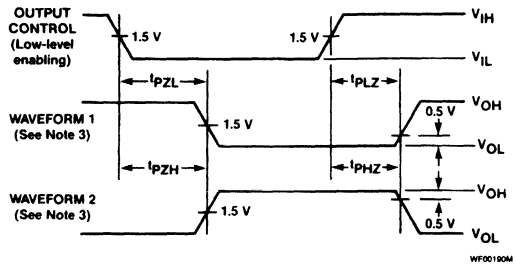
The PRELOAD function allows the register to be loaded from data placed on the output pins. This feature aids functional testing of state sequencer designs by allowing direct setting of output states for improved test coverage. The procedure for PRELOAD using DIP pin numbers, is as follows:

1. Raise  $V_{CC}$  to 4.5V.
2. Disable output registers by setting pin 13 to  $V_{IH}$ . Set pin 1 to 0V.
3. Apply  $V_{IL}/V_{IH}$  to all registered outputs.
4. Pulse pin 10 to  $V_p$  (12V), then back to 0V.
5. Remove  $V_{IL}/V_{IH}$  from all registered outputs.
6. Lower pin 13 to  $V_{IL}$  to enable the output registers.
7. Verify for  $V_{OL}/V_{OH}$  at all registered outputs.

† Note: Only applies to parts with output registers.

|                   |                       |
|-------------------|-----------------------|
| Typical $t_{sup}$ | = 50ns                |
| $t_{wp}$          | = 100ns               |
| $t_{hp}$          | = 50ns                |
| $I_{IH}$          | = 30 $\mu$ A (Pin 10) |

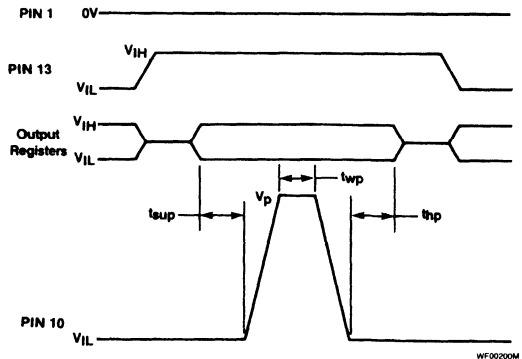
### Enable/Disable Delay



Notes: 1.  $C_L$  includes probe and jig capacitance.

2. When measuring  $t_{pLZ}$  and  $t_{pZL}$ , S1 is tied to  $V_{CC}$ . When measuring  $t_{pLH}$  and  $t_{pZH}$ , S1 is tied to ground.  $t_{pZX}$  is measured with  $C_L = 50pF$ .  $t_{pXZ}$  is measured with  $C_L = 5pF$ . When measuring propagation delay times of three-state outputs, S1 is open, i.e., not connected to  $V_{CC}$  or ground.

3. Waveform 1 is for an output with internal conditions such that the output is LOW except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is HIGH except when disabled by the output control.



4

**Features/Benefits**

- Demonstration pattern for ZHAL24A Series (ZHAL20X8A)
- 8-bit counter
- Three-state output
- Expandable in 8-bit increments
- Equivalent to 74ACT461

**Description**

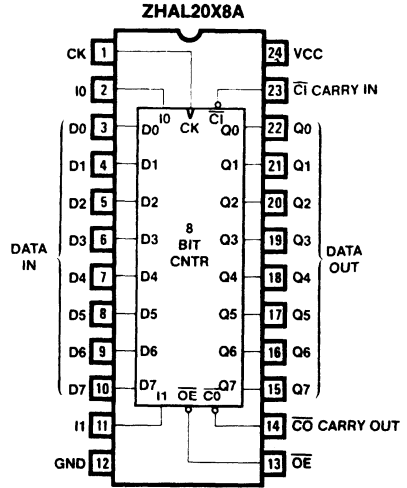
The ZHAL24A Evaluation #4 pattern is provided as an example of the features and characteristics of the ZHAL24A Series products. The design consists of an 8-bit synchronous counter with parallel load, clear, and hold capability. Two function select inputs (I0, I1) provide one of four operations which occur synchronously on the rising edge of the clock (CK).

The LOAD operation loads the inputs (D7-D0) into the output register (Q7-Q0). The CLEAR operation resets the output register to all LOWs. The HOLD operation holds the previous value regardless of clock transitions. The INCREMENT operation adds one to the output register when the carry-in input is TRUE ( $\overline{CI} = \text{LOW}$ ), otherwise the operation is a HOLD. The carry-out ( $\overline{CO}$ ) is TRUE ( $\overline{CO} = \text{LOW}$ ) when the output register (Q7-Q0) is all HIGHS, otherwise FALSE ( $\overline{CO} = \text{HIGH}$ ).

The data output pins are enabled when  $\overline{OE}$  is LOW, and disabled (HI-Z) when  $\overline{OE}$  is HIGH.

Two or more 8-bit counters may be cascaded to provide larger counters. The operation codes were chosen such that when I1 is HIGH, I0 may be used to select between LOAD and INCREMENT as in a program counter (JUMP/INCREMENT).

**Logic Symbol**



LS00100M

**Function Table**

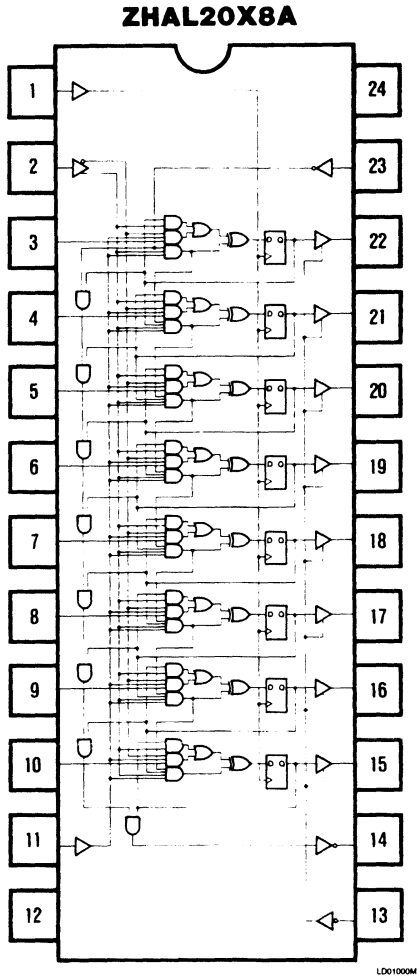
| $\overline{OE}$ | CK | I1 | I0 | $\overline{CI}$ | D7-D0 | Q7-Q0    | OPERATION |
|-----------------|----|----|----|-----------------|-------|----------|-----------|
| H               | *  | *  | *  | *               | *     | Z        | HI-Z*     |
| L               | ↑  | L  | L  | X               | X     | L        | CLEAR     |
| L               | ↑  | L  | H  | X               | X     | Q        | HOLD      |
| L               | ↑  | H  | L  | X               | D     | D        | LOAD      |
| L               | ↑  | H  | H  | H               | X     | Q        | HOLD      |
| L               | ↑  | H  | H  | L               | X     | Q plus 1 | INCREMENT |

\*When  $\overline{OE}$  is HIGH, the three-state outputs are disabled to the high-impedance states; however, sequential operation of the counter is not affected.

- H = HIGH voltage level
- L = LOW voltage level
- X = Don't care
- Z = High impedance (off) state
- ↑ = LOW-to-HIGH clock transition

ZHAL24A Evaluation #4

Logic Diagram



**4**

## ZHAL24A Evaluation #4

Title ZHAL24A Evaluation 4 (74ACT461)  
Pattern P7023  
Revision B  
Author Birkner/Kazmi/Blasco  
Company Monolithic Memories, Inc.  
Date 1986

CHIP ZHAL24A\_Evaluation\_4 PAL20X8

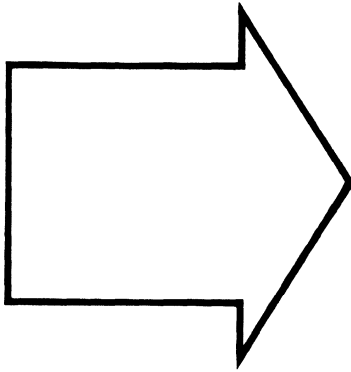
CK I0 D0 D1 D2 D3 D4 D5 D6 D7 I1 GND  
/OE /CO Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 /CI VCC

### EQUATIONS

```
/Q0 := /I1*/I0 ;CLEAR LSB  
+ I0*/Q0 ;COUNT/HOLD  
+: I1*/I0*/D0 ;LOAD D0 (LSB)  
+ I1* I0* CI ;COUNT  
  
/Q1 := /I1*/I0 ;CLEAR  
+ I0*/Q1 ;COUNT/HOLD  
+: I1*/I0*/D1 ;LOAD D1  
+ I1* I0* CI*Q0 ;COUNT  
  
/Q2 := /I1*/I0 ;CLEAR  
+ I0*/Q2 ;COUNT/HOLD  
+: I1*/I0*/D2 ;LOAD D2  
+ I1* I0* CI*Q0*Q1 ;COUNT  
  
/Q3 := /I1*/I0 ;CLEAR  
+ I0*/Q3 ;COUNT/HOLD  
+: I1*/I0*/D3 ;LOAD D3  
+ I1* I0* CI*Q0*Q1*Q2 ;COUNT  
  
/Q4 := /I1*/I0 ;CLEAR  
+ I0*/Q4 ;COUNT/HOLD  
+: I1*/I0*/D4 ;LOAD D4  
+ I1* I0* CI*Q0*Q1*Q2*Q3 ;COUNT  
  
/Q5 := /I1*/I0 ;CLEAR  
+ I0*/Q5 ;COUNT/HOLD  
+: I1*/I0*/D5 ;LOAD D5  
+ I1* I0* CI*Q0*Q1*Q2*Q3*Q4 ;COUNT  
  
/Q6 := /I1*/I0 ;CLEAR  
+ I0*/Q6 ;COUNT/HOLD  
+: I1*/I0*/D6 ;LOAD D6  
+ I1* I0* CI*Q0*Q1*Q2*Q3*Q4*Q5 ;COUNT  
  
/Q7 := /I1*/I0 ;CLEAR MSB  
+ I0*/Q7 ;COUNT/HOLD  
+: I1*/I0*/D7 ;LOAD D7 (MSB)  
+ I1* I0* CI*Q0*Q1*Q2*Q3*Q4*Q5*Q6 ;COUNT  
  
IF (VCC) CO = CI*Q0*Q1*Q2*Q3*Q4*Q5*Q6*Q7 ;CARRY OUT
```

1B02020M





|   |           |
|---|-----------|
| <b>PAL® Device Introduction</b>         | <b>1</b>  |
| <b>PAL®/HAL® Device Specifications</b>  | <b>2</b>  |
| <b>PAL Device Programmer Ref. Guide</b> | <b>3</b>  |
| <b>HAL/ZHAL™ Devices</b>                | <b>4</b>  |
| <b>Logic Cell Array™</b>                | <b>5</b>  |
| <b>PALASM® Software Syntax</b>          | <b>6</b>  |
| <b>PAL Device Applications</b>          | <b>7</b>  |
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# Logic Cell Array™

## Introduction

The Logic Cell Array (LCA)™ is a CMOS integrated circuit with a flexible, uncommitted architecture and VLSI-level density. The LCA is manufactured on Monolithic Memories' 1.6 micron CMOS process. The device architecture as is shown in Figure 1, similar to that of a gate array, with an interior matrix of programmable logic blocks, a surrounding ring of I/O interface blocks and programmable interconnect used to define the overall device structure.

Unlike gate arrays, Logic Cell Array functionality is defined by the user simply by loading the internal writable storage cells with the configuration data. An additional benefit, reprogrammability in system, allows in-circuit-emulation to be used for design verification.

The M2064 family of Logic Cell Arrays has been developed to allow Monolithic Memories to offer a device and technology that offer both the density benefits of gate arrays and the programmability benefits of user-configurable devices. These parts have been designed for maximum flexibility in system applications and are easy to use.

Using the XACT™ software development system, the designer can define and interconnect logic blocks to build larger-scale, multi-level logic functions. These are then connected to external circuitry. Interconnections throughout the Array are defined automatically by the development system, unless otherwise specified by the designer. Because the Logic Cell Array's logic functions and interconnections are established with memory cells, the array is never physically altered; instead it is simply reprogrammed.

## XACT Evaluation Kit (LCA-MEK01)

Monolithic Memories offers evaluation software and documentation that will allow a designer to determine if his or her logic design fits and assess its performance as a Logic Cell Array. All that is needed is an IBM PC-XT, AT, or compatible, a three-button Mouse System or compatible mouse.

## XACT Development System (LCA-MDS21)

The XACT Development System is the "power behind the machine." It will allow a designer to sit down with a concept and walk away with a completely tested, completely finished part.

The reason is that XACT functions as both a CAE and CAM system. The CAE part of the system allows the designer to simply draw out the design using a sophisticated graphics-based design editor. The CAM part then converts the drawing to code, similar to a PALASM-generated JEDEC file, that allows programming with conventional programming hardware of an EPSOM containing the configuration data for system prototyping.

The XACT Development System currently has 113 macros and, in addition, allows the user to define his or her own macro. To insure that internal timing constraints are satisfied, a Timing Analyzer is included to calculate propagation delays along any path within the Array.

As the design is being entered, the Automatic Design Checker insures that no design rules are violated, and when the design is completed, a final design rule check is performed.

## The XACT Development System

Contents:

- Editor
- Macro Library
- Design Checker
- Timing Analyzer
- Configuration File Generator
- Configuration File Formatter

## In-Circuit-Emulator (LCA-MDS24)

The In-Circuit-Emulator is a software/hardware package that enables a designer to connect his or her target system to the work-station where a design has just been completed. The emulator package allows:

- User control and monitoring of device function
- Interactive or file-driven setup and configuration
- Daisy-chain configuration capabilities for up to seven LCAs in a chain
- Simultaneous in-circuit emulation of up to four devices
- Single step capability for device clocks
- Readback display of device internal register states
- Dynamic reconfiguration capability.

The In-Circuit-Emulator comes with a single "pod". Up to three additional pods (LCA-MDS25) may be ordered for each emulator.

## P-SILOS Simulation Package (LCA-MDS22)

After a design is completed, the next step is to simulate. Monolithic Memories offers an integrated simulation package manufactured by Simucad, called P-SILOS.

| PART NUMBER | DESCRIPTION                 |
|-------------|-----------------------------|
| LCA-MEK01   | LCA Evaluation Kit          |
| LCA-MDS21   | LCA Development system      |
| LCA-MDS22   | LCA Simulator-P-SILOS       |
| LCA-MDS24   | LCA In-Circuit-Emulator     |
| LCA-MDS25   | LCA In-Circuit-Emulator Pod |
| LCA-MTB01   | LCA Demonstration Board     |

Table 1

The introduction of the Logic Cell Array will allow customers to reduce inventories of discrete components, reduce the time to market and development cost for new products, save money in manufacturing and spare parts inventory management, reduce test costs and improve system reliability.

## Configurable Logic Block

The core of the Logic Cell Array is an 8 x 8 matrix of Configurable Logic Blocks. Each CLB provides four logic inputs, a clock input, a combinatorial logic section, two logic outputs, and a programmable storage element.

The inputs drive a combinatorial logic section that can perform any logic function from a simple gate to a three-out-of-four majority decoder.

The combinatorial portion accepts and generates both positive- and negative-true logic, eliminating the need for inverters or the routing of complementary signals.

The storage element can serve as a flip-flop (D-type) and can be programmed to have clock enable, synchronous set and reset, and various gated inputs. In addition, since all these options can be specified independently for each logic block, designers can mix asynchronous and synchronous logic in any combination.

## Interconnect

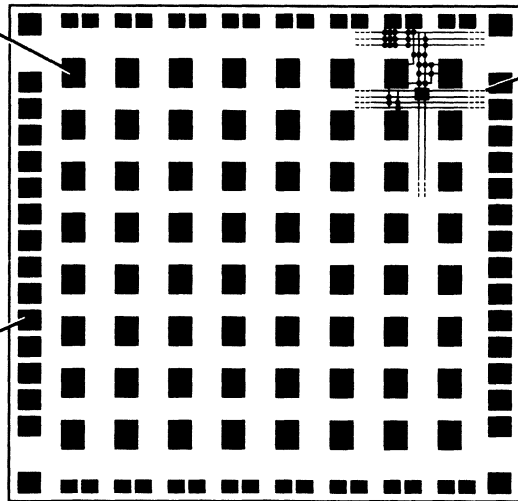
The Array's extraordinary flexibility is also the result of a two-layer metal network of lines that run horizontally and vertically between the logic and I/O blocks, and a variety of user-definable interconnection elements.

Definable interconnection points connect the inputs and outputs of logic and I/O blocks to nearby metal lines.

Crosspoint switches and interchanges are clustered at the intersection of every row and column of logic blocks. They link horizontal and vertical paths and allow signals to be switched from one path to another.

Finally, "long lines" run the length and breadth of the chip, bypassing interchanges but tying into logic blocks and other lines and distributing clocks and other critical signals with a minimum of propagation delay.

Interchanges and interconnection point assignments, as well as all routing are handled automatically by the XACT Development System Software. In addition, special graphics-based design tools are included to facilitate any necessary designer interaction.



## Configurable I/O Block

External signals enter and leave the chip through general-purpose, user-definable I/O blocks positioned around the periphery of the array. Each block can be programmed independently to be an input, output or bidirectional pin with a tristate control on the output. When configured as an input, the designer can select TTL or CMOS thresholds. In addition, each I/O block contains an input register option whose clock line is common to all the other I/O blocks along the same edge of the die.

I/O blocks can also handle more than input and output functions. For example, the input registers of unused I/O blocks can be used for read/write storage registers or as stages of a shift register.

Figure 1

# Logic Cell Array™ M2064

## Features/Benefits

- CMOS programmable Logic Cell Array (LCA™) for replacement of standard logic
- Completely reconfigurable by the user in the final system
- High performance
  - 20MHz flip-flop toggle rate (-20 speed grade)
  - 33MHz flip-flop toggle rate (-33 speed grade)
  - 50MHz flip-flop toggle rate (-50 speed grade)
- User-configurable logic functions, interconnect and I/O for maximum flexibility
- 64 user-Configurable Logic Blocks (CLBs) providing usable gate equivalency of up to 1500 gates
- 58 individually-configurable I/O pins allowing any mix of inputs, outputs or bidirectional signals (68-pin package)
- User-selectable TTL or HCMOS input threshold levels
- Multiple configuration modes for greatest flexibility and ease of use
- Verification feature allows user to check configuration data
- User-selectable security feature prevents read-back of configuration data
- Read-back of internal register states for system debug
- On-chip clock oscillator and clock buffer circuits provide flexible internal and external clocking functions
- Master reset of all internal register elements in addition to user-configurable Reset and/or Set control of individual CLB storage elements

## General Description

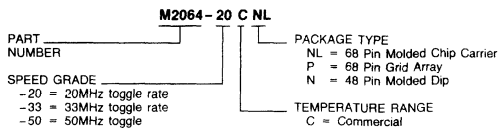
The M2064 is the first member of a family of configurable Logic Cell Arrays (LCAs) available from Monolithic Memories. These general purpose CMOS integrated circuit devices allow the user to rapidly implement complex digital logic functions directly without the requirement for masking or other vendor performed programming steps. Unique configuration circuitry allows complete reconfiguration within a user's final system to allow system changes "on-the-fly."

User configuration is controlled by internal storage elements. These are loaded with data bits which control definition of logic functions, configuration of I/O blocks, routing of internal signals, and other options. Configuration data can be loaded in one of several methods to minimize impact on overall system design.

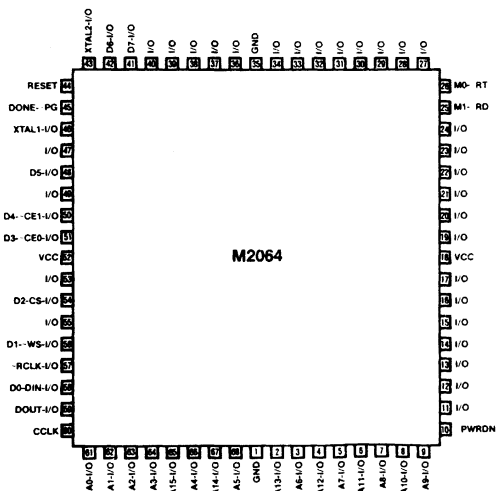
CMOS technology optimized for system level performance provides LS-TTL compatible speeds with power consumption

less than 10% of equivalent TTL systems. The use of innovative I/O buffers providing either TTL or CMOS input switching levels insures lowest possible power consumption in totally CMOS systems without any compromise in performance.

## Ordering Information



| PART NUMBER | DESCRIPTION                |
|-------------|----------------------------|
| LCA-MDS21   | XACT Development System    |
| LCA-MDS22   | P-SILOS Simulation Package |
| LCA-MDS24   | LCA In-Circuit Emulator    |
| LCA-MDS25   | In-Circuit Emulator Pod    |
| LCA-MEK01   | XACT Evaluation Kit        |



CD01470M

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## Logic Cell Array™ M2064

### Pin Description

#### I/O

User-configurable Input/Output pins.

#### ~PWRDN

Input forces device into low power mode; operation is suspended.

#### M0~RT

Dual function input. During initial power up, the state of M0 and M1 determines the configuration mode. After configuration, a rising edge on ~RT initiates a configuration read operation.

#### M1~RD

Dual function input/output. During initial power up, the state of M1 and M0 determines the configuration mode. After configuration is complete, ~RD outputs configuration data during a configuration read back operation synchronously with the toggling of the CCLK input.

#### ~RESET

Input. A low level on this input after configuration causes all register elements internal to the LCA to be forced to 0. If asserted prior to the start of configuration, causes the LCA to remain in the initialization state (configuration is not started). If asserted during configuration the LCA returns to the initialization state.

#### DONE~PG

Dual function output/input. During configuration the LCA pulls DONE low and releases it when configuration is complete (output is open drain). After configuration is complete, a falling edge on ~PG initiates an LCA programming cycle (if enabled in the current configuration). This pin has an internal user-enabled pull-up resistor.

#### XTAL1-I/O

Dual function input and I/O. This pin may be configured by the user to be a normal I/O pin equivalent to any of the general purpose I/O pins. Alternatively, this pin and XTAL2 may be used to connect a crystal for use with the internal crystal oscillator configuration.

#### XTAL2-I/O

Dual function output and I/O. This pin may be configured by the user to be a normal I/O pin equivalent to any of the general purpose I/O pins. Alternatively, this pin and XTAL1 may be used to connect a crystal for use with the internal crystal oscillator configuration.

#### CCLK

Configuration mode dependent input/output. CCLK is the master configuration clock used to configure the LCA. In slave mode it is an input; in all other modes it is an output designed to provide the input clocking of additional slave mode daisy chain connected LCA devices. During a configuration read back operation, CCLK serves as the clock input used to read the internal configuration data.

#### DOUT-I/O

Dual function output and I/O. General purpose user-configurable I/O pin during normal operation. During configuration, the serial data stream supplied from the first LCA to LCAs down the serial daisy chain is output on DOUT.

#### ~RCLK-I/O

Dual function output and I/O. General purpose user-configurable I/O pin during normal operation. During master mode configuration, a low level output on ~RCLK indicates that the external memory device is being accessed.

#### D0-DIN-I/O

Multi-function input and I/O. General purpose user-configurable I/O pin during normal operation. During master mode configuration, this pin is bit 0 of the 8-bit parallel input data bus (D0). During slave mode or peripheral mode configuration, this pin is the serial input data pin (DIN).

#### D1~WS-I/O

Multi-function input and I/O. General purpose user-configurable I/O pin during normal operation. During master mode configuration, this pin is bit 1 of the 8-bit parallel input data bus (D1). During peripheral mode configuration, a low level on ~WS indicates that a write operation is being performed by the controlling processor. See note.

#### D2-CS-I/O

Multi-function input and I/O. General purpose user-configurable I/O pin during normal operation. During master mode configuration, this pin is bit 2 of the 8-bit parallel input data bus (D2). During peripheral mode configuration, a high level on CS indicates that a write operation is being performed by the controlling processor. See note.

#### D3~CE0-I/O

Multi-function input and I/O. General purpose user-configurable I/O pin during normal operation. During master mode configuration, this pin is bit 3 of the 8-bit parallel input data bus (D3). During peripheral mode configuration, a low level on ~CE0 indicates that a write operation is being performed by the controlling processor. See note.

#### D4~CE1-I/O

Multi-function input and I/O. General purpose user-configurable I/O pin during normal operation. During master mode configuration, this pin is bit 4 of the 8-bit parallel input data bus (D4). During peripheral mode configuration, a low level on ~CE1 indicates that a write operation is being performed by the controlling processor. See note.

#### D5-I/O to D7-I/O

Input and I/O. General purpose user-configurable I/O pins during normal operation. During master mode configuration, these pins are bits 5 through 7 of the 8-bit parallel input data bus (D5-D7).

#### A0-I/O to A15-I/O

Output and I/O. General purpose user-configurable I/O pins during normal operation. During master mode configuration these pins are address output pins (A0-A15) used to address the external storage element used for configuration data.

Note: to perform a peripheral mode write, the following logical combination is necessary: ~WS·CS·CE0·CE1.

### Functional Description

The M2064 is a high-performance CMOS Logic Cell Array providing superior system performance with greatest user flexibility. Complete user-configurability provides an optimized solution to logic implementation problems.

The M2064 utilizes a unique Configurable Logic Block (CLB) structure as the basic functional building block of the device. Each CLB is a combination of a programmable logic function

and a storage element. The CLB has the capability of performing any function of its inputs with the option of the output of the storage element included in the input field. User-defined logic is implemented in a matrix of sixty-four CLBs which are interconnected with user-configurable interconnect resources. Fifty-eight independently configurable I/O Blocks; each of which can be a direct or latched input, a direct or open drain output, or a bidirectional I/O buffer; provide the interface to external circuits. Input voltage levels are user definable and may be either standard TTL or CMOS for all I/O Blocks, depending on the user's configuration choice.

User-definable path selector or multiplexers are utilized to select configuration options for the CLBs and I/O Blocks. These selectors are set in the desired state by the configuration data loaded into the device upon power up.

## Logic

User logic is implemented in one or more CLBs which are general purpose 4-input, 2-output elements. Figure 1 shows a block diagram of a single CLB. Each element is composed of a 4-input combinational logic module with two outputs, a general purpose storage element, and routing selection logic. The module can generate any combinational logic function of the four inputs, or it can generate any two independent functions of any three of the four inputs. If a function of four inputs is selected, that same function will be available on both of the outputs of the combinational module. The inputs to the combinational module are three of the four inputs to the CLB (A, B and C) and either the D input to the CLB, or the Q output of the storage element.

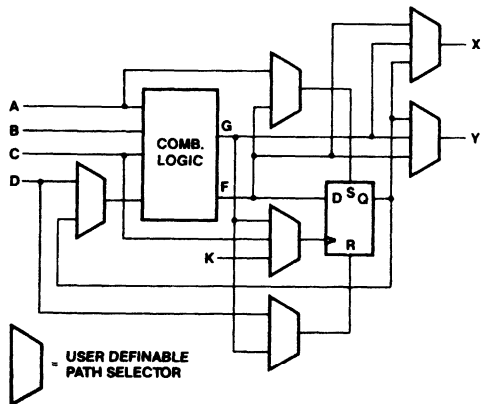


Figure 1. Block Diagram of a Single CLB

The general purpose storage element has a data input, a clock input, a set direct input, a reset direct input and an output, Q. The storage characteristic may be defined as either a transparent latch or as an edge-triggered flip-flop. The data input is connected to one of the outputs of the combinational logic module. The set direct and reset direct inputs may be individually enabled or disabled.

The reset direct input, if enabled, may come from either the D input to the CLB, or from the G output of the combinational logic module. Set direct control, if enabled, can come from

either the A input to the CLB or from the F output of the combinational logic module.

Clock for the storage element may be individually enabled or disabled and can be driven by the clock input, K, to the CLB, the C input to the CLB, or the G output of the combinational logic module. Final outputs, X and Y, from the CLB can be selected to be either of the two outputs, F and G, of the combinational logic module, or the Q output from the storage element.

## I/O Elements

The M2064 contains fifty-eight user-configurable I/O blocks for connection to external circuits. Each block is a general purpose device containing a three-state output buffer, an input buffer, and an input flip-flop as shown in Figure 2. The input buffer always reflects the status of the I/O pin or the contents of the input flip-flop. If the flip-flop is selected, data present on the I/O pin will be clocked to the input buffer by the I/O block clock signal. All I/O blocks on a particular edge of the device share a common I/O clock signal. The output buffer may be enabled, disabled, or under the control of the three-state connection.

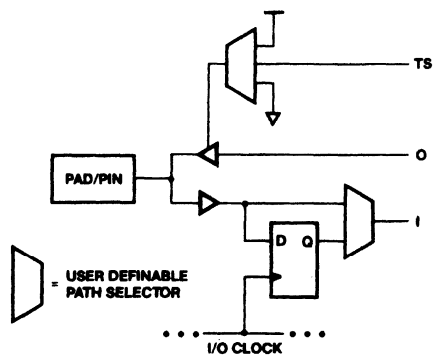


Figure 2. Block Diagram of an I/O Element

## Interconnect

There are nine rows and nine columns of metal interconnect resources with one row or column located between each row or column of CLBs or I/O blocks. Each row or column of interconnect resources contains local use lines, long lines and programmable interconnect points between I/O blocks, CLBs and interconnect resources. Local lines run either vertically from one row of resources to the adjacent row or horizontally from one column to the adjacent column. Long lines run the full height or width of the device. At the intersection of every row and column of interconnect resources are user configurable interconnect elements which allow multiple combinations of connections between local lines in adjacent rows and columns. In addition, selected intersections of local and long lines can be connected by user programmable interconnect points.

Inputs and outputs from each CLB or I/O block have programmable connections to the interconnect resources in the adjacent rows and columns. These connections allow CLBs or I/O block connections to be made for proper signal routing to or

## Logic Cell Array™ M2064

from the I/O blocks or CLBs. In addition to the programmable connections to adjacent interconnect resources, there are direct connection paths which do not utilize the general interconnect resources. These paths allow selected connection between some I/O blocks and CLBs and between adjacent CLBs. For example, the outputs of a CLB in the interior of the matrix of CLBs may be connected to adjacent CLBs without using any interconnect resources.

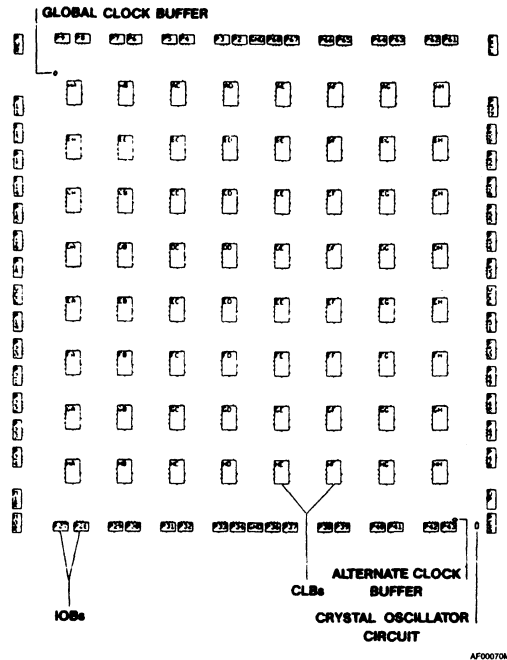


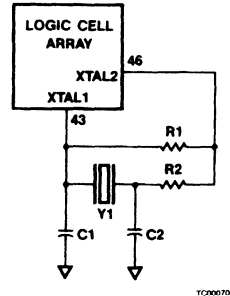
Figure 3. Overview Functional Layout of the M2064

### Clock Generation and Buffering

The M2064 contains two special purpose clock buffers for generating and driving clock signals to multiple CLBs or I/O blocks with negligible skew. The Global Clock Buffer, is dedicated to driving a matrix of long lines which have configurable connections to the K input of each CLB register. This clock buffer may be driven from an internally generated register source, or configured with a connection directly to an I/O block for driving it with an external clock signal. The output from the Global Clock Buffer may be configured to directly drive an I/O block for driving clock signals off the device.

The alternate clock buffer can be configured either as a simple buffer or as a buffer for the crystal oscillator. In the crystal oscillator mode, an externally connected crystal and optional passive components form a clock generator for use on the chip or for driving other external circuits (see Figure 4). When configured in the buffer mode, the alternate clock buffer can have either one or both of its input and output configured to directly drive, or be driven by, an I/O block. The output of

the alternate clock buffer can drive long lines in any column of CLBs as well as local interconnect.



Suggested component values:

R1 1 - 4M $\Omega$

R2 0 - 1K $\Omega$

(may be required for low frequency, phase shift and/or compensate level for crystal Q)

C1, C2 5 - 20pF

Y1 1 - 10MHz AT cut

Figure 4. Crystal Oscillator

Each CLB has a special clock input (K) which can be selected as the clock input of the storage element. Clock inputs to user selected CLBs can be configured to be driven from either the Global Clock Buffer, the oscillator/buffer or from other local interconnect. Clocks to the I/O blocks can be configured from either of the clock buffers or the local interconnect.

### Programming

Configuration of the device may be performed in any one of three modes. The desired configuration mode is set by the state of the mode pins M0 and M1 at power up (see Table 1). All configuration data relating to CLB function definition, interconnect resource utilization, and I/O block programming must be loaded into the device prior to use. In the peripheral and slave modes the data is supplied in a serial stream in conjunction with the configuration clock signal, CCLK. In master mode, the device automatically loads data from an external memory device by supplying addresses and reading bytes of data. In all modes the data patterns required to create a specific configuration are the same.

| MODE SELECT PINS | M0 | M1 |
|------------------|----|----|
| Master LOW mode  | 0  | 0  |
| Master HIGH mode | 0  | 1  |
| Peripheral mode  | 1  | 0  |
| Slave mode       | 1  | 1  |

Note: During configuration, Pin 27 on the 68-pin package or Pin 7 on the 48-pin package must be held HIGH.

Table 1. Modes

Data patterns for a specific user-configuration are created with the Monolithic Memories XACT LCA Development System and can be output to a standard EPROM programmer or saved on disk for inclusion with other software. Users who are using the Monolithic Memories XACT debugging system can directly access the configuration data and load the device directly during a debug session. Because of the complexity of the data patterns and difficulty in generating them without a thorough knowledge of the device, users are discouraged from attempting to generate data patterns on their own. Data pattern files for M2064 devices contain 1536 bytes.

## Special Features

The M2064 contains several special features which enhance its capacity for use in a wide variety of applications. Among these are the following:

### Data Security

The M2064 configuration data contains special controls bits which enable or disable configuration data security control. If enabled, the security control will prevent the read-back of configuration data after the initial configuration. There are two possible modes of operation under security control. One mode allows a single read-back after configuration to allow verification of the data. In the second mode, all access to the configuration data is prevented.

### Reprogrammability

Configuration data changes are controlled by reprogramming control bits in the configuration data supplied to the device. If reprogramming is enabled, the user may supply new configuration data at any time by asserting the correct control sequence on the DONE, ~PG and M0 and M1 mode control pins. Alternatively, the user may elect to prevent reconfiguration of the device. When operating in this mode, the only method to remove the configuration is to remove all power from the device.

### Inactive Power-down

In a system which is to remain in its current configuration through power loss, the M2064 may be forced into a low power inactive state by using the ~PWRDN pin. When held low, the LCA will retain all configuration data but will not operate. All clocks will be stopped and all outputs put into a high-impedance state. Power is reduced to a very low level, allowing a simple external battery arrangement to supply the required configuration data saving power (see electrical characteristics).

### Configuration Data Read-back

A mechanism is provided in the M2064 to provide verification of stored configuration data. The configuration read-back is initiated by toggling the ~RT pin and clocking the CCLK pin. Each clock applied to CCLK will read out a configuration data bit on the ~RD pin. When all configuration data has been read

out, the ~RD pin will return to its inactive state. The configuration data may be read at any time with no effect on the operation of the device. Once a configuration read-back has been initiated, all data must be read out of the device to insure that subsequent read-back operations will begin at the start of the configuration data.

### Master Reset

After device configuration, the ~RESET pin becomes a master reset for all CLB and IOB storage elements in the device. Asserting this control signal will asynchronously reset all of the internal storage registers regardless of the operating condition of the circuit.

## Development System

The Monolithic Memories Design System is an integrated package of design tools for developing configuration data for LCAs. All aspects of configuration are specified through interactive graphics software. Facilities to verify functionality and timing of the designed configuration insure that designs operate as desired.

XACT is a graphic design system used to specify LCA designs. It contains several standard and several optional software and hardware packages. The basic package runs on an IBM PC/XT or AT compatible computer with 640K memory, a color monitor and a mouse. The tools accessible from the executive, including the optional packages, are:

- LCA Editor and Macros
- Timing Analyzer
- Simulator (P-Silos, optional)
- Configuration-File Generator
- Configuration-File Formatter
- XACTOR 2 In-circuit-emulator (optional).

XACTOR 2 consists of a software program plus a hardware attachment that allows control of up to four LCAs. The program contains commands for:

- Loading configuration data
- Activating the Master Reset input
- Reconfiguring
- Single stepping the device clock
- Reading back configuration data and state of all 122 internal registers on any clock cycle.
- Real time system debug.

An evaluation kit is available which includes:

- Complete documentation of the Development System
- A sample LCA design
- XACT software package.

Contact your local Monolithic Memories Representative or Distributor for more information.



## Logic Cell Array™ M2064

### Absolute Maximum Ratings\*

|  |                        |
|--|------------------------|
| Supply voltage $V_{CC}$ .....                  | -0.5V to 7V            |
| Power down $V_{CC}$ .....                      | 2V to 7V               |
| Input voltage .....                            | -0.5V to $V_{CC}$ 0.5V |
| Voltage applied to three-state output .....    | -0.5V to $V_{CC}$ 0.5V |
| Storage temperature range .....                | -65°C to +150°C        |
| Lead temperature (soldering, 10 seconds) ..... | 260°C                  |

Note: Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those listed under "Recommended Operating Conditions" is not implied. Exposure to "Absolute Maximum Ratings" conditions for extended periods of time may affect device reliability.

### Operating Conditions

| SYMBOL    | PARAMETER  | MIN  | TYP | MAX  | UNIT |
|-----------|--|------|-----|------|------|
| $V_{CC}$  | Supply voltage relative to GND                     | 4.75 |     | 5.25 | V    |
| $V_{IHT}$ | High level input voltage — TTL configuration       | 2.0  |     |      | V    |
| $V_{IHC}$ | High level input voltage — CMOS configuration      | 0.7  |     |      | V    |
| $V_{ILT}$ | Low level input voltage — TTL configuration        | 0    |     | 0.8  | V    |
| $V_{ILC}$ | Low level input voltage — CMOS configuration       | 0    |     | 0.2  | V    |
| $I_{IT}$  | Input leakage current — TTL configuration          |      |     | ± 1  | μA   |
| $I_{IC}$  | Input leakage current — CMOS configuration         |      |     | ± 1  | μA   |
| $I_{OZ}$  | Three-state output off current ( $V_{CC} = 5.5V$ ) |      |     | ± 10 | μA   |
| $t_{OP}$  | Operating free-air temperature                     | 0    |     | 70   | °C   |

5

### Electrical Characteristics Over Operating Conditions

| SYMBOL     | PARAMETER                                | TEST CONDITION                     | MIN  | TYP             | MAX  | UNIT |
|------------|--|------------------------------------|------|-----------------|------|------|
| $V_{OH}$   | High level output voltage                | $V_{CC} = 4.75V$ $I_{OH} = -4.0mA$ | 3.86 |                 |      | V    |
| $V_{OL}$   | Low level output voltage                 | $V_{CC} = 4.75V$ $I_{OL} = 4.0mA$  |      |                 | 0.32 | V    |
| $I_{CCO}$  | Quiescent operating power supply current | CMOS inputs<br>$V_{CC}=5.0V$       |      |                 | 5    | mA   |
|            |  | TTL inputs<br>$V_{CC}=5.0V$        |      |                 | 10   | mA   |
| $I_{CCPD}$ | Power down supply current                | $V_{CC}=2.0V$                      |      | Consult factory |      | V    |

Note: All switching characteristics are at worst case conditions.

### Power on Timing

The M2064 contains on-chip reset timing logic for power-up operation. To insure proper master mode system operation,

$V_{CC}$  must rise from 2.0V to minimum specification level in 10ms or less. For other modes, initiation of configuration must be delayed for 60ms after  $V_{CC}$  reaches the minimum specified level.

## Logic Cell Array™ M2064

### Switching Characteristics — CLB

| ITEM      | DESCRIPTION                                   | M2064 – 50 |     |     | M2064 – 33 |     |     | M2064 – 20 |     |     | UNIT |
|-----------|---|------------|-----|-----|------------|-----|-----|------------|-----|-----|------|
|           |   | MIN        | TYP | MAX | MIN        | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{ILO}$ | Input through logic to X or Y                 |            |     | 15  |            |     | 20  |            |     | 35  | ns   |
| $t_{ITO}$ | Input through logic and latch to X or Y       |            |     | 20  |            |     | 25  |            |     | 45  | ns   |
| $t_{CKO}$ | Storage element clock from K to output        |            |     | 15  |            |     | 20  |            |     | 35  | ns   |
| $t_{CCO}$ | Storage element clock from C to output        |            |     | 19  |            |     | 25  |            |     | 45  | ns   |
| $t_{CLO}$ | Logic to storage element clock to output      |            |     | 27  |            |     | 37  |            |     | 65  | ns   |
| $t_{QLO}$ | Storage element Q to logic to output          |            |     | 8   |            |     | 13  |            |     | 30  | ns   |
| $t_{tCK}$ | Input setup to K clock to storage element     | 8          |     |     | 12         |     |     | 22         |     |     | ns   |
| $t_{CKI}$ | Input hold to K clock to storage element      | 0          |     |     | 0          |     |     | 0          |     |     | ns   |
| $t_{tCC}$ | Input setup to C clock to storage element     | 9          |     |     | 12         |     |     | 18         |     |     | ns   |
| $t_{CCI}$ | Input hold to C clock to storage element      | 0          |     |     | 6          |     |     | 10         |     |     | ns   |
| $t_{tCI}$ | Input setup to input clock to storage element | 4          |     |     | 6          |     |     | 10         |     |     | ns   |
| $t_{CII}$ | Input hold to input clock to storage element  | 5          |     |     | 9          |     |     | 15         |     |     | ns   |
| $t_{RIO}$ | Input to storage element Reset/Set to output  |            |     | 22  |            |     | 25  |            |     | 45  | ns   |
| $t_{RLO}$ | Logic to storage element Reset/Set to output  |            |     | 28  |            |     | 37  |            |     | 65  | ns   |
| $t_{RPW}$ | Reset/Set pulse width                         | 9          |     |     | 12         |     |     | 20         |     |     | ns   |
| $t_{RS}$  | Storage element control separation            | 9          |     |     | 17         |     |     | 30         |     |     | ns   |
| $t_{CH}$  | Storage element clock high time               | 9          |     |     | 12         |     |     | 20         |     |     | ns   |
| $t_{CL}$  | Storage element clock low time                | 9          |     |     | 12         |     |     | 20         |     |     | ns   |
| $f_{CLK}$ | Storage element clock frequency               |            |     | 50  |            |     | 33  |            |     | 20  | MHz  |
| $t_{MRQ}$ | Master reset to storage element Q to output   |            |     | 25  |            |     | 35  |            |     | 60  | ns   |

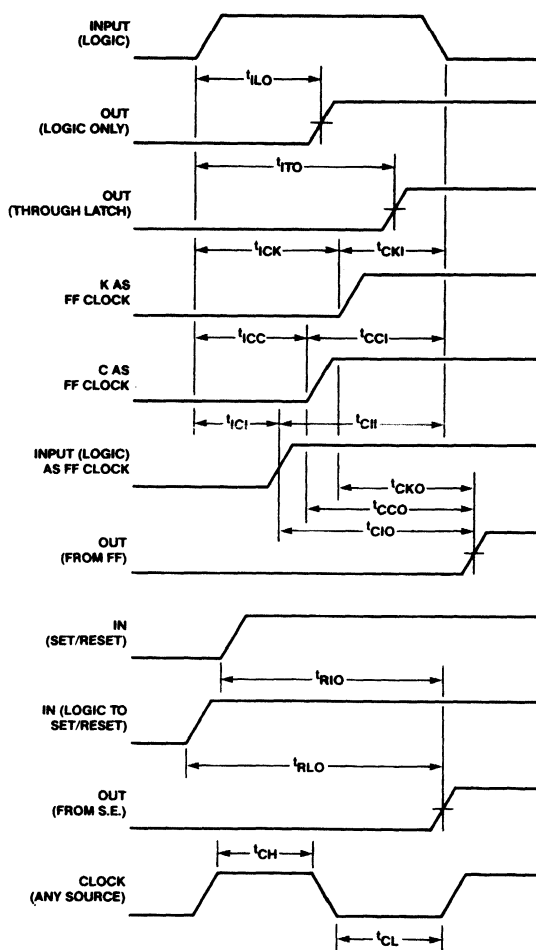
## Logic Cell Array™ M2064

### Cross Reference Guide

| XILINX     | MONOLITHIC MEMORIES | V <sub>CC</sub> |       | F <sub>MAX</sub> |
|------------|---------------------|-----------------|-------|------------------|
|            |                     | MIN             | MAX   |                  |
| XC-2064-1  |                     | 4.5V            | 5.5V  | 20MHz            |
|            | M2064-20            | 4.75V           | 5.25V | 20MHz            |
| XC-2064-2  |                     | 4.5V            | 5.5V  | 33MHz            |
| XC-2064-33 | M2064-33            | 4.75V           | 5.25V | 33MHz            |
| XC-2064-50 | M2064-50            | 4.75V           | 5.25V | 50MHz            |

\*For commercial product only.

### Switching Characteristics — CLB



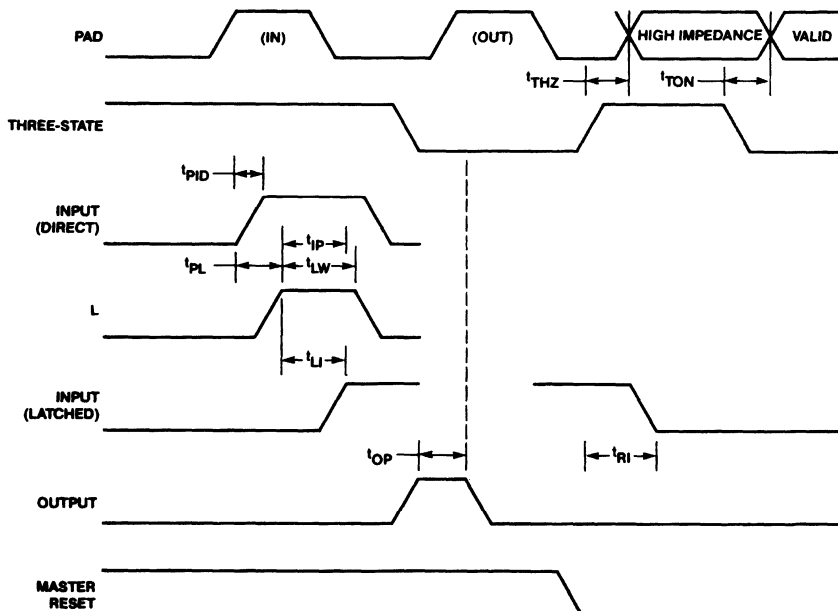
WF00210M

- Notes:
1. Input refers to CLB inputs A, B, C or D
  2. Output refers to CLB output X or Y
  3. Clock refers to the CLB storage element clock
  4. FF (Flip-Flop or L (Latch) refers to the CLB storage element
  5. Set and Reset refer to CLB storage element controls

# Logic Cell Array™ M2064

## Switching Characteristics — IOB

| ITEM      | DESCRIPTION                                | M2064 - 50 |     |     | M2064 - 33 |     |     | M2064 - 20 |     |     | UNIT |
|-----------|--|------------|-----|-----|------------|-----|-----|------------|-----|-----|------|
|           |  | MIN        | TYP | MAX | MIN        | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{PID}$ | Pad to input direct                        |            |     | 8   |            |     | 12  |            |     | 20  | ns   |
| $t_{PL}$  | Pad input setup to I/O clock               | 8          |     |     | 12         |     |     | 20         |     |     | ns   |
| $t_{LP}$  | Pad input hold to I/O clock                | 0          |     |     | 0          |     |     | 0          |     |     | ns   |
| $f_L$     | Frequency, I/O clock                       |            |     | 50  |            |     | 33  |            |     | 20  | MHz  |
| $t_{LW}$  | Pulse width input latch clock              | 9          |     |     | 12         |     |     | 20         |     |     | ns   |
| $t_{LI}$  | Input latch clock to input                 |            |     | 15  |            |     | 20  |            |     | 30  | ns   |
| $t_{OP}$  | Output to pad output (three-state enabled) |            |     | 12  |            |     | 15  |            |     | 25  | ns   |
| $t_{THZ}$ | Three-state inactive to high impedance     |            |     | 20  |            |     | 25  |            |     | 35  | ns   |
| $t_{TON}$ | Three-state active to output on            |            |     | 20  |            |     | 25  |            |     | 40  | ns   |
| $t_{RI}$  | Master Reset to latched input reset        |            |     | 25  |            |     | 30  |            |     | 50  | ns   |



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- Notes:
1. Output (O) refers to the output connection on the IOB
  2. Input (I) refers to the input connection on the IOB
  3. Three-state (T) refers to the three-state control on the IOB
  4. Pad or Pin (P) refers to the device pin connected to the IOB
  5. Latch (L) refers to the input Flip-Flop clock connection

## Logic Cell Array™ M2064

### Switching Characteristics — Programming — Slave Mode

| ITEM      | DESCRIPTION                            | M2064 - 50 |     |      | M2064 - 33 |     |      | M2064 - 20 |     |       | UNIT |
|-----------|--|------------|-----|------|------------|-----|------|------------|-----|-------|------|
|           |  | MIN        | TYP | MAX  | MIN        | TYP | MAX  | MIN        | TYP | MAX   |      |
| $t_{CCH}$ | CCLK high time                         | 300        |     |      | 3000       |     |      | 500        |     |       | ns   |
| $t_{CCL}$ | CCLK low time                          | 200        |     |      | 200        |     |      | 300        |     |       | ns   |
| $t_{CCL}$ | CCLK low time                          |            |     | 5000 |            |     | 5000 |            |     | 10000 | ns   |
| $t_{DCC}$ | DIN data setup to CCLK rising edge     | 25         |     |      | 25         |     |      | 50         |     |       | ns   |
| $t_{CCD}$ | DIN data hold from CCLK rising edge    | 40         |     |      | 40         |     |      | 75         |     |       | ns   |
| $t_{CCO}$ | DOUT data delay from CCLK falling edge |            |     | 65   |            |     | 65   |            |     | 100   | ns   |
| $f_{CC}$  | CCLK maximum frequency                 |            |     | 2    |            |     | 2    |            |     | 1     | MHz  |

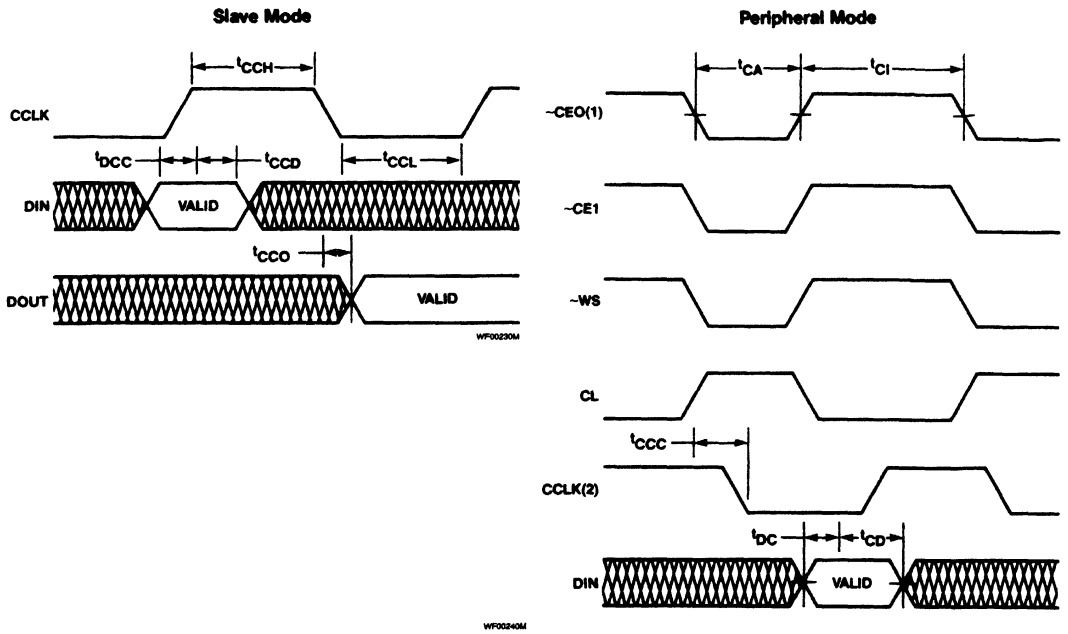
### Switching Characteristics — Programming — Peripheral Mode

| ITEM     | DESCRIPTION                        | M2064 - 50 |     |      | M2064 - 33 |     |      | M2064 - 20 |     |       | UNIT |
|----------|------------------------------------|------------|-----|------|------------|-----|------|------------|-----|-------|------|
|          |                                    | MIN        | TYP | MAX  | MIN        | TYP | MAX  | MIN        | TYP | MAX   |      |
| $t_{CA}$ | Control input active period        | 200        |     |      | 200        |     |      | 300        |     |       | ns   |
| $t_{CA}$ | Control input active period        |            |     | 5000 |            |     | 5000 |            |     | 10000 | ns   |
| $t_{CI}$ | Control input inactive period      | 150        |     |      | 150        |     |      | 250        |     |       | ns   |
| $t_{CC}$ | CCLK delay from control input edge |            |     | 75   |            |     | 75   |            |     | 100   | ns   |
| $t_{DC}$ | DIN setup to control transition    | 35         |     |      | 35         |     |      | 50         |     |       | ns   |
| $t_{CD}$ | DIN hold from control transition   | 5          |     |      | 5          |     |      | 10         |     |       | ns   |

- Notes: 1. Peripheral mode timing determined from last control signal ( $\sim$ CEO,  $\sim$ WS, CS) to transition to active or inactive state.  
 2. CCLK timing minima and maxima same as for slave mode.  
 3. CCLK and DOUT timing same as for slave mode.

5

# Logic Cell Array™ M2064

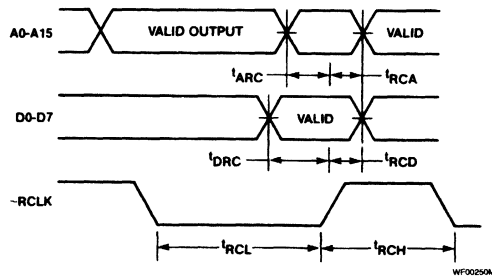


## Logic Cell Array™ M2064

### Switching Characteristics — Programming — Master Mode

| ITEM      | DESCRIPTION                               | M2064 - 50 |     |     | M2064 - 33 |     |     | M2064 - 20 |     |     | UNIT |
|-----------|---|------------|-----|-----|------------|-----|-----|------------|-----|-----|------|
|           |   | MIN        | TYP | MAX | MIN        | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{ARC}$ | Address invalid prior to $\sim$ RCLK edge |            |     | 0   |            |     | 0   |            |     | 0   | ns   |
| $t_{RCA}$ | Address valid from $\sim$ RCLK edge       |            |     | 200 |            |     | 200 |            |     | 300 | ns   |
| $t_{DRC}$ | Data bus setup to $\sim$ RCLK edge        | 60         |     |     | 60         |     |     | 100        |     |     | ns   |
| $t_{RCD}$ | Data bus hold from $\sim$ RCLK edge       | 0          |     |     | 0          |     |     | 0          |     |     | ns   |
| $t_{RCH}$ | $\sim$ RCLK high                          | 600        |     |     | 600        |     |     | 600        |     |     | ns   |
| $t_{RCL}$ | $\sim$ RCLK low                           | 4000       |     |     | 4000       |     |     | 4000       |     |     | ns   |

Note: Timing for DOUT and CCLK out is same as for slave mode.

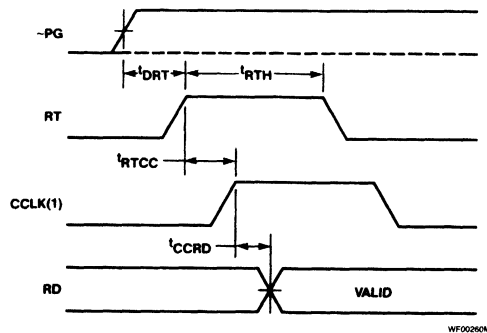


5

### Switching Characteristics — Program Readback

| ITEM       | DESCRIPTION                           | M2064 - 50 |     |     | M2064 - 33 |     |     | M2064 - 20 |     |     | UNIT |
|------------|---------------------------------------|------------|-----|-----|------------|-----|-----|------------|-----|-----|------|
|            |                                       | MIN        | TYP | MAX | MIN        | TYP | MAX | MIN        | TYP | MAX |      |
| $t_{RTH}$  | Read trigger (RT) high time           | 150        |     |     | 150        |     |     | 250        |     |     | ns   |
| $t_{RTCC}$ | Delay from RT assertion to first CCLK | 60         |     |     | 60         |     |     | 100        |     |     | ns   |
| $t_{CCRD}$ | Delay from CCLK edge to RD data valid |            |     | 60  |            |     | 60  |            |     | 100 | ns   |
| $t_{DRT}$  | Wait period from DONE to RT assertion | 75         |     |     | 175        |     |     | 300        |     |     | ns   |

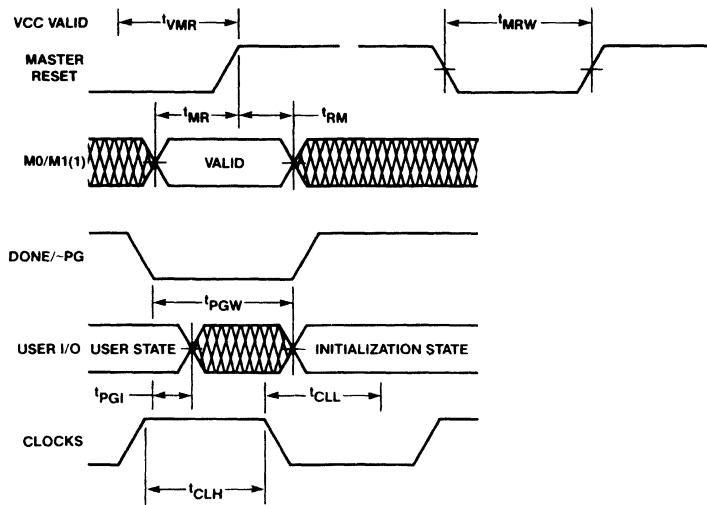
Notes: 1. Timing for CCLK is same as for slave programming mode.  
 2. DONE/ $\sim$ PG output/input must be high (device programmed) prior to assertion of  $\sim$ PG.



# Logic Cell Array™ M2064

## Switching Characteristics — General

| ITEM      | DESCRIPTION                            | M2064 - 50 |     |      | M2064 - 33 |     |      | M2064 - 20 |     |      | UNIT |
|-----------|--|------------|-----|------|------------|-----|------|------------|-----|------|------|
|           |  | MIN        | TYP | MAX  | MIN        | TYP | MAX  | MIN        | TYP | MAX  |      |
| $t_{VMR}$ | Master Reset delay from valid $V_{CC}$ | 150        |     |      | 150        |     |      | 250        |     |      | ns   |
| $t_{MRW}$ | Master Reset pulse width               | 150        |     |      | 150        |     |      | 250        |     |      | ns   |
| $t_{MR}$  | Mode control setup to Master Reset     | 60         |     |      | 60         |     |      | 100        |     |      | ns   |
| $t_{RM}$  | Mode control hold from Master Reset    | 7          |     |      | 7          |     |      | 10         |     |      | ns   |
| $t_{PGW}$ | Program control pulse width            | 6000       |     |      | 6000       |     |      | 6000       |     |      | ns   |
| $t_{PGI}$ | Program control to I/O initialized     |            |     | 7000 |            |     | 7000 |            |     | 7000 | ns   |
| $t_{CLH}$ | Clock buffer input high time           | 9          |     |      | 12         |     |      | 20         |     |      | ns   |
| $t_{CLL}$ | Clock buffer input low time            | 9          |     |      | 12         |     |      | 20         |     |      | ns   |
| $f_{CL}$  | Clock buffer input frequency           |            |     | 50   |            |     | 33   |            |     | 20   | MHz  |



WF0270M

### Test Conditions:

Outputs loaded with rated DC current and 50-pF capacitance to GND

### Design Aids

XACT™ provides complete design automation for users to specify and implement designs utilizing Monolithic Memories' LCA products. Configuration of CLBs, internal routing, I/O block definitions and global routing are all handled in an integrated, easy-to-use system.

Placement and routing of logic and I/O blocks is accomplished using interactive graphics. Final programming bit patterns are automatically produced for debugging, transfer to other systems, or downloading to standard EPROM programmers. Debugging with the XACTOR 2™ emulation system allows full device emulation and operation analysis in the target system.

The user inputs data via a graphics-oriented physical editing environment. User functions are translated into CLB logic specifications and interconnections automatically. Standard logic libraries and other macro capabilities can be utilized for rapid design entry.

Physical placement and hard connections are performed with the graphics placement and connection capabilities. Final device layout and routing are visible and can be modified without disturbing the logical arrangement. Logical connectivity and physical layout rules checking are performed automatically.

Full timing analysis and functional simulation of user configurations allows device performance and functional checking without external test hardware. In addition, point-to-point path timing calculation capability is provided to simplify general timing analysis and critical path determination.



## Logic Cell Array™ M2064

The debugging system provides full emulation in the user's target system. User configurations may be transferred directly from the design phase into the target system and tested through the emulation system.

Additional capabilities include a tool for automatic hard copy generation of the user's logic design and physical implementation and a tool for transferring programming bit patterns to EPROM programming systems.

### Recommended Sockets

The following 68-pin PLCC sockets have been evaluated by Monolithic Memories and have been found to exhibit acceptable connectivity, device retention and device extraction characteristics:

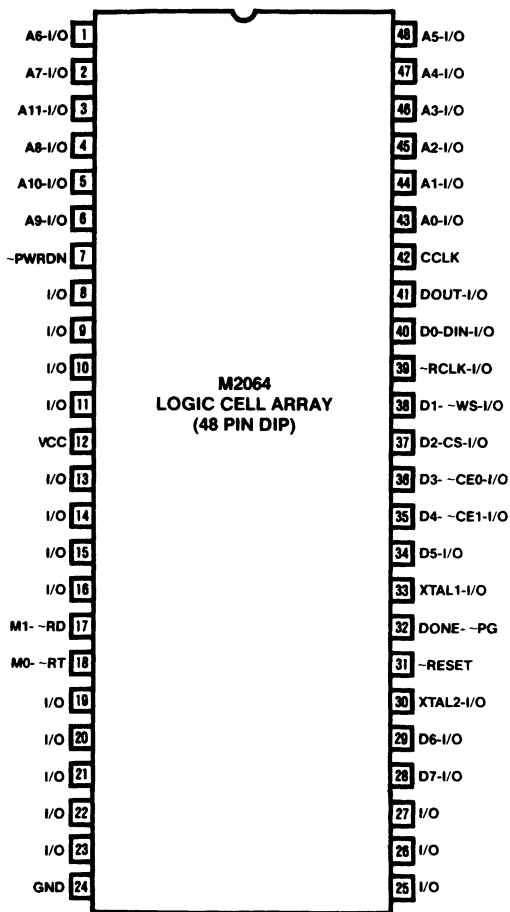
| VENDOR       | DESCRIPTION                | PART NUMBER        |
|--------------|----------------------------|--------------------|
| AMP          | PCB solder tail, tin plate | 821574-1           |
| AMP          | Surface mount, tin plate   | 821542-1           |
| Burndy       | PCB solder tail, tin plate | QILE68P-410T       |
| Midland-Ross | PCB solder tail, tin plate | 709-2000-068-4-1-1 |

The following 68-pin PLCC sockets are also available:

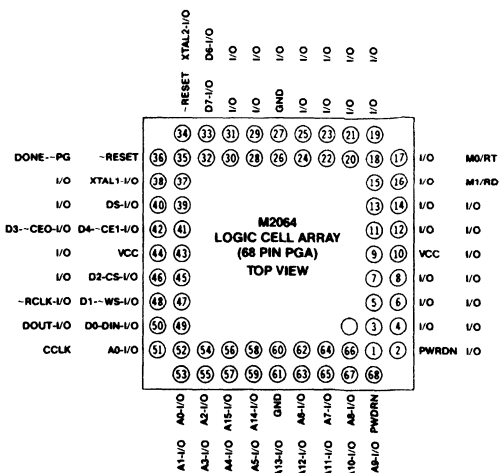
| VENDOR  | DESCRIPTION                | PART NUMBER |
|---------|----------------------------|-------------|
| Methode | PCB solder tail, tin plate | 213-068-001 |
| Methode | Surface mount, tin plate   | 213-068-002 |

- Notes:
1. The standard device extraction tools supplied with the XACT development system will work with all of the above sockets.
  2. All of the above PCB solders tail sockets have the same hold pattern and pinout.

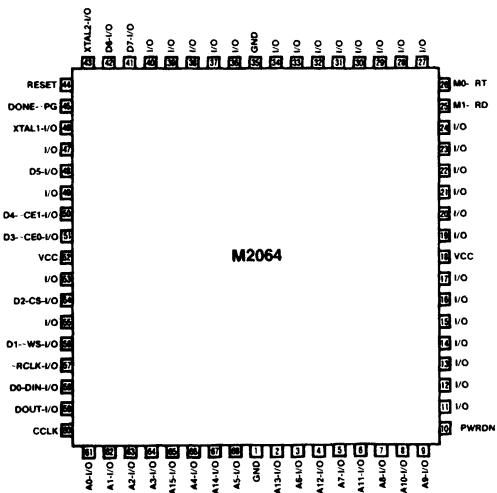
# Logic Cell Array™ M2064



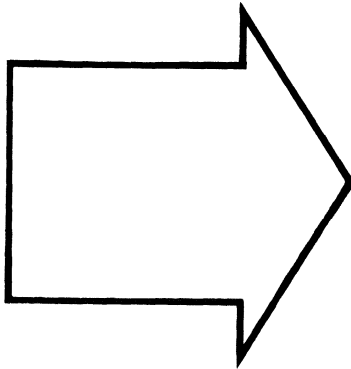
CD01480M



CD01490M



CD01470M



|   |           |
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# PALASM<sup>®</sup> 2 Software

## Introducing PALASM<sup>®</sup> 2 Software

PALASM 2 software is a package that turns PAL device Design Specification (PDS) files into input files for PAL device programmers. PDS is a format for specifying a PAL circuit and for creating inputs to a logic circuit. Using a text editor, you create a PDS file that describes a PAL circuit. PALASM 2 software accepts the file as input and performs a number of functions under your control including:

- Assembling PAL Design Specifications.
- Generating PAL device fuse patterns in JEDEC format.
- Reporting errors in syntax and assembly.
- Allowing concise mnemonic names for long, frequently used logic expressions through string substitution.

## Functional differences from PALASM 1

PALASM 2 software is quite different from PALASM 1 in implementation. It is composed of several interacting programs coupled by disk files. (Floppy based files slow interaction. We recommend RAM or hard disks for production use.) The principal benefit of the reorganization is the freedom from fixed limits within the design file.

The syntax of PALASM 2 software is significantly different from that of PALASM 1. PALASM 2 software allows description of asynchronous devices like the 20RA10 and devices of much higher complexity such as MegaPAL devices.

The current version of PALASM 2 software omits several features provided within PALASM 1. They are:

- Fault coverage prediction for test vectors.
- Automatic generation of documentation.
- Device signal/pinout display.
- Support of the security fuse.
- Printing of logic equations for each product term in a fuse plot.

Some of these omissions represent a change in philosophy; others will be provided in later versions of the program.

## Required Equipment

This section describes computers and PAL device programmers supported by PALASM 2 software and provides information about necessary and optional PALASM 2 software.

### Computers

PALASM 2 software operates with no user modification on the following CPUs, provided certain minimum system requirements are satisfied. It is usually provided as an executable program, ready to run on any of these systems:

Minicomputers: VAX<sup>™</sup> under VMS<sup>™</sup>

Microcomputers: IBM-PC<sup>™</sup>, -XT<sup>™</sup>, -AT<sup>™</sup> under MS-DOS<sup>™</sup> (256K RAM)

All systems must have a serial port (RS-232) for communication with the PAL device programmer. We also recommend that floppy disk based systems be equipped with two disk drives.

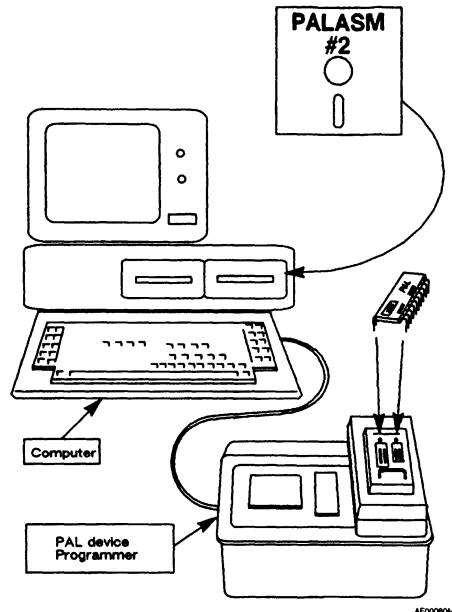


Figure 1. Typical Computer Configuration

### NOTE

Please refer to a PALASM 2 software order form for the correct part number of the version of PALASM 2 software designed for your CPU.

## PALASM 2 Software

### Software

Following is a summary of all currently available programs.

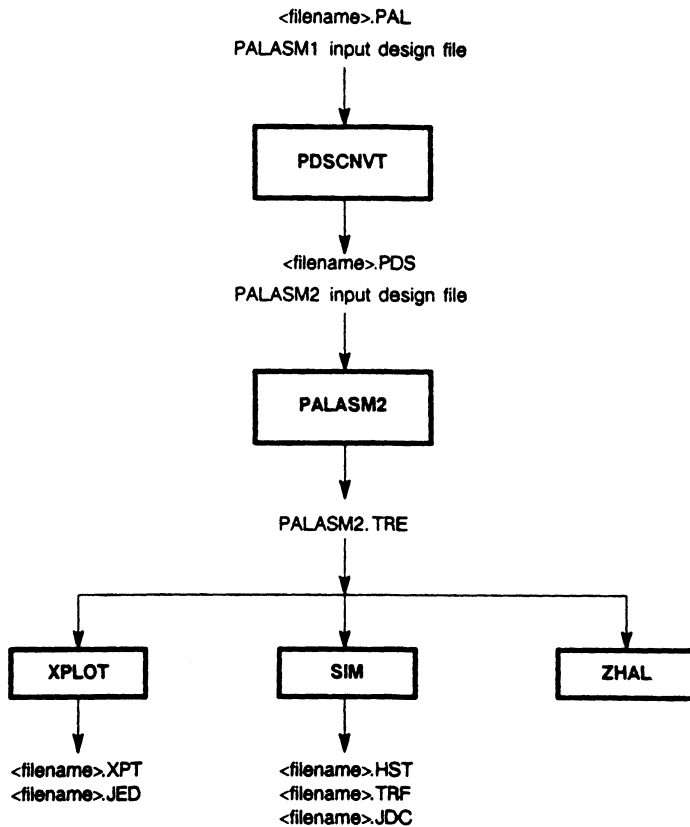
- |             |  |
|-------------|--|
| 1. PDSCNVT  | PALASM 1 to PALASM 2 syntax conversion |
| 2. PALASM 2 | PALASM 2 syntax parser                 |
| 3. XPLOT    | PALASM 2 fuse map and JEDEC output     |
| 4. SIM      | PALASM 2 simulator                     |
| 5. ZHAL     | ZHAL device fit                        |

#### Supplementary Software

- |           |                                      |
|-----------|--------------------------------------|
| 1. MENU   | Simplified PALASM 2 user interface   |
| 2. PC2    | Programmer interface program         |
| 3. VTRACE | Graph display simulator trace output |

#### Files

- |    |               |  |
|----|---------------|--|
| 1. | .PDS          | User PALASM 2 PLD design description                     |
| 2. | PALASM 2 .TRE | PLD intermediate design description                      |
| 3. | .PDF          | PLD architecture description data                        |
| 4. | .XPT          | Contains PLD fuse map data                               |
| 5. | .JED          | Contains PLD fuse JEDEC data                             |
| 6. | .HST          | Contains full simulation history data                    |
| 7. | .TRF          | Contains user simulation trace data                      |
| 8. | .JDC          | Contains both PLD fuse JEDEC data and JEDEC test vectors |



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Figure 2. PALASM Software Flow

### PDSCNVT

PDSCNVT allows you to interactively convert PAL device design specifications from the PALASM 1 format to PALASM 2 software. Input is a PALASM 1 formatted specification file, and output is the equivalent design in PALASM 2 software syntax.

### PALASM 2

PALASM 2 is the first program you will use in the PALASM 2 software suite. It reads and validates your input — a PAL device design specification — for correct design syntax. If an error is detected, the program attempts to indicate where in the input description the error has occurred. Recovery is attempted after each error in order to catch as many errors as possible on a single run. Only if no error is detected is an intermediate specification file generated. This file contains the input specification in a hierarchically structured form to enable easy processing by follow-on programs. Further, it is guaranteed to be syntactically correct. This program recognizes input descriptions for all current PAL devices.

### XPLOT

XPLOT validates the architectural design of an input PAL device description and produces fuse maps and JEDEC data for a specified PAL device. Input is a set of Boolean equations that has been preprocessed by the PALASM 2 program. XPLOT checks the equations for consistency among themselves and with the specified PAL device. When an error is detected, XPLOT attempts immediate recovery. In this way, XPLOT spots as many errors as possible on each run. Only if no errors are detected will the output fuse maps and JEDEC data be generated. The architectural information for each PAL device is read in from a file containing a profile description for the specific PAL device.

#### NOTE

XPLOT will check only valid Monolithic Memories PAL devices.

### SIM

SIM checks the functionality of a PAL device design. You will run this program after XPLOT. If the design is architecturally correct, however, you can run SIM directly after PALASM 2. SIM reads a special simulation syntax that has been preprocessed by PALASM 2. It will simulate the operation of the PAL device you specify, calculating the output values based on input signals through the Boolean equations and any feedback. Output is a history file that traces the values of every pin through a simulation sequence. A trace file, which is a subset of the history file, traces only the pins you specify in the simulation syntax. If XPLOT has been run and a JEDEC fuse address file has been created, then SIM will add test vectors to the JEDEC file that duplicate the simulation sequence when the device is tested on a programmer. All JEDEC checksums are recalculated.

#### NOTE

SIM will test only valid Monolithic Memories PAL devices.

### ZHAL

ZHAL makes sure that a PAL device description will fit into the ZHAL device architecture. ZHAL reads the description that has been preprocessed by the PALASM 2 software program, and a YES or NO answer is output. If the design fits, you must send the PAL device Design Specification to Monolithic Memories for mask processing. Before a description is rejected, the program will attempt to minimize the input equations to make use of some sharing features in the ZHAL architecture. ZHAL will also indicate what the error is before a no fit answer is output.

#### NOTE

ZHAL currently accepts designs only for valid Monolithic Memories PAL devices.

### MENU

MENU is an interactive program designed to simplify user interface to PALASM 2 software. MENU's multiple choice selection process offers you a number of options at each stage. Once you have made a selection, your choice is automatically executed. MENU makes the modular design of the PALASM 2 software system invisible to you. All you need to know is what you want to do, not how-to. For example, if you select simulation, the programs PALASM 2, XPLOT and SIM automatically run in sequence, and your need to understand the functions of the individual programs is greatly reduced.

### PC2

PC2 enables communication between PLD programmers and IBM™ PC machines (-PC, -XT, -AT, etc.). It is a menu-driven multiple-choice program that guides you through various options for programming and checking PLD devices.

### VTRACE

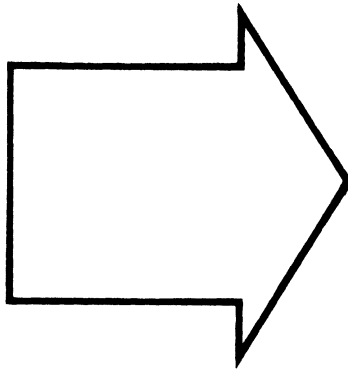
VTRACE reads the trace output of the PALASM 2 software simulator. The text-formatted data of the trace file is converted into graphic form. VTRACE output looks very much like timing diagrams of the simulation results.

### Software Customization

For software development and user customization of PALASM 2 software, you will need a Pascal compiler/linker and a second disk drive. These are necessary to create the executable version of the program. Monolithic Memories recommends the Professional Pascal compiler (Microtek Inc.) which was used to develop and test the programs on the IBM-PC. PALASM 2 software is written in nearly ISO Standard Pascal to ease porting to many computer systems.

#### CAUTION

Porting PALASM 2 software to other computer systems will require you to install and modify the original source code. Allow at least two to four weeks of software engineering time to complete this task. Monolithic Memories makes no guarantee of the portability of PALASM 2 software, and does not provide support for such efforts or other user modification.



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## 10-Bit Open Collector Buffer

Title 10-BIT OPEN COLLECTOR BUFFER  
 Pattern P7070  
 Revision A  
 Author VINCENT COLI  
 Company MMI SUNNYVALE, CALIFORNIA  
 Date 10/21/81

CHIP 10-BIT\_OPEN\_COLLECTOR\_BUFFER PAL20L10

/OC1 D0 D1 D2 D3 D4 D5 D6 D7 D8 D9 GND  
 /OC2 Y9 Y8 Y7 Y6 Y5 Y4 Y3 Y2 Y1 Y0 VCC

EQUATIONS

```
IF(OC1*/D0) /Y0 = VCC ;Y0= D0 (TRUE)
IF(OC1*/D1) /Y1 = VCC ;Y1= D1 (TRUE)
IF(OC1*/D2) /Y2 = VCC ;Y2= D2 (TRUE)
IF(OC1*/D3) /Y3 = VCC ;Y3= D3 (TRUE)
IF(OC1*/D4) /Y4 = VCC ;Y4= D4 (TRUE)
IF(OC2*/D5) /Y5 = VCC ;Y5= D5 (TRUE)
IF(OC2*/D6) /Y6 = VCC ;Y6= D6 (TRUE)
IF(OC2*/D7) /Y7 = VCC ;Y7= D7 (TRUE)
IF(OC2*/D8) /Y8 = VCC ;Y8= D8 (TRUE)
IF(OC2*/D9) /Y9 = VCC ;Y9= D9 (TRUE)
```

;FUNCTION TABLE FOR PALASM 1  
 ;/OC2 /OC1 D9 D8 D7 D6 D5 D4 D3 D2 D1 D0  
 ;Y9 Y8 Y7 Y6 Y5 Y4 Y3 Y2 Y1 Y0

| ;     | INPUT DATA | OUTPUT DATA | COMMENTS                        |
|-------|------------|-------------|---------------------------------|
| ;/OC  | DDDDDDDDDD | YYYYYYYYYY  |                                 |
| ;2 1  | 9876543210 | 9876543210  |                                 |
| ----- |            |             |                                 |
| ;L L  | LLLLLLLLLL | LLLLLLLLLL  | TEST L's (TRUE D)               |
| ;L L  | HHHHHHHHH  | ZZZZZZZZZ   | TEST H's (TRUE D)               |
| ;L L  | HLHLHLHLHL | ZLZLZLZLZL  | TEST EVEN CHECKERBOARD (TRUE D) |
| ;L L  | LHLHLHLHLH | LZLZLZLZLZ  | TEST ODD CHECKERBOARD (TRUE D)  |
| ;H L  | XXXXXLLLLL | ZZZZZLLLLL  | TEST HI-Z FOR /OC2=H            |
| ;L H  | LLLLLXXXXX | LLLLLZZZZZ  | TEST HI-Z FOR /OC1=H            |
| ----- |            |             |                                 |

TR00480M



## 10-Bit Open Collector Buffer

---

### ;DESCRIPTION

; THE 10-BIT OPEN COLLECTOR BUFFER WILL OUTPUT THE INPUT DATA (D). THE  
;OUTPUTS (Y) WILL BE EITHER L OR HI-Z.  
;CERTAIN OUTPUTS WILL BE HIGH-Z (Y=Z) IF EITHER OUTPUT CONTROL LINE  
;IS HIGH (/OC=H) REGARDLESS OF OTHER INPUTS. NOTE THAT OC2 CONTROLS  
;OUTPUTS Y9-Y5 AND OC1 CONTROLS OUTPUTS Y4-Y0. OC2 AND OC1 CONTROL  
;INDEPENDENTLY.

### ;OPERATIONS TABLE:

| ; | /OC2 | /OC1 | D9-D0 | Y9-Y5 | Y4-Y0 | OPERATION               |
|---|------|------|-------|-------|-------|-------------------------|
| ; | H    | X    | X     | Z     | X     | HI-Z FOR UPPER 5 BITS   |
| ; | X    | H    | X     | X     | Z     | HI-Z FOR LOWER 5 BITS   |
| ; | L    | L    | D     | D     | D     | OUTPUT TRUE (L or HI-Z) |

T8004604

## 10-Bit Open Collector Inverting Buffer

Title 10-BIT OPEN COLLECTOR INVERTING BUFFER  
 Pattern P7071  
 Revision A  
 Author VINCENT COLI  
 Company MMI SUNNYVALE, CALIFORNIA  
 Date 10/21/81

CHIP 10-BIT\_OPEN\_COLLECTOR\_INVERTING\_BUFFER PAL20L10

/OC1 D0 D1 D2 D3 D4 D5 D6 D7 D8 D9 GND  
 /OC2 Y9 Y8 Y7 Y6 Y5 Y4 Y3 Y2 Y1 Y0 VCC

EQUATIONS

```
IF(OC1* D0) /Y0 = VCC ;Y0= /D0 (COMP)
IF(OC1* D1) /Y1 = VCC ;Y1= /D1 (COMP)
IF(OC1* D2) /Y2 = VCC ;Y2= /D2 (COMP)
IF(OC1* D3) /Y3 = VCC ;Y3= /D3 (COMP)
IF(OC1* D4) /Y4 = VCC ;Y4= /D4 (COMP)
IF(OC2* D5) /Y5 = VCC ;Y5= /D5 (COMP)
IF(OC2* D6) /Y6 = VCC ;Y6= /D6 (COMP)
IF(OC2* D7) /Y7 = VCC ;Y7= /D7 (COMP)
IF(OC2* D8) /Y8 = VCC ;Y8= /D8 (COMP)
IF(OC2* D9) /Y9 = VCC ;Y9= /D9 (COMP)
```

;FUNCTION TABLE FOR PALASM 1

```
;/OC2 /OC1 D9 D8 D7 D6 D5 D4 D3 D2 D1 D0
; Y9 Y8 Y7 Y6 Y5 Y4 Y3 Y2 Y1 Y0
```

|       | INPUT DATA | OUTPUT DATA;/OC | DDDDDDDDDD                      | YYYYYYYYYY |
|-------|------------|-----------------|---------------------------------|------------|
| ; 2 1 | 9876543210 | 9876543210      | COMMENTS                        |            |
| ----- |            |                 |                                 |            |
| ;L L  | LLLLLLLLLL | ZZZZZZZZZZ      | TEST L's (COMP D)               |            |
| ;L L  | HHHHHHHHHH | LLLLLLLLLL      | TEST H's (COMP D)               |            |
| ;L L  | HLHLHLHLHL | LZLZLZLZLZ      | TEST EVEN CHECKERBOARD (COMP D) |            |
| ;L L  | LHLHLHLHLH | ZLZLZLZLZL      | TEST ODD CHECKERBOARD (COMP D)  |            |
| ;H L  | XXXXHHHHHH | ZZZZLLLLLL      | TEST HI-Z FOR /OC2=H            |            |
| ;L H  | HHHHHXXXXX | LLLLLZZZZZ      | TEST HI-Z FOR /OC1=H            |            |
| ----- |            |                 |                                 |            |

T800500M



## 10-Bit Open Collector Inverting Buffer

---

### ;DESCRIPTION

;THE 10-BIT INVERTING OPEN COLLECTOR BUFFER WILL OUTPUT THE  
;COMPLEMENT OF THE INPUT DATA (D). THE OUTPUTS (Y) WILL BE  
;EITHER L OR HI-Z.  
;CERTAIN OUTPUTS WILL BE HIGH-Z (Y=Z) IF EITHER OUTPUT CONTROL  
;LINE IS HIGH; (/OC=H) REGARDLESS OF OTHER INPUTS. NOTE THAT  
;OC2 CONTROLS OUTPUTS Y9-Y5 AND OC1 CONTROLS OUTPUTS Y4-Y0.  
;OC2 AND OC1 CONTROL INDEPENDENTLY.

### ;OPERATIONS TABLE:

| ; | /OC2 | /OC1 | D9-D0 | Y9-Y5 | Y4-Y0 | OPERATION               |
|---|------|------|-------|-------|-------|-------------------------|
| ; | H    | X    | X     | Z     | X     | HI-Z FOR UPPER 5 BITS   |
| ; | X    | H    | X     | X     | Z     | HI-Z FOR LOWER 5 BITS   |
| ; | L    | L    | D     | /D    | /D    | OUTPUT COMP (L or HI-Z) |

TB00510M

## 10-Bit Addressable Register

Title 10-BIT ADDRESSABLE REGISTER  
 Pattern P7072 (PMSI407)  
 Revision A  
 Author DANESH TAVANA  
 Company MMI SUNNYVALE, CALIFORNIA  
 Date 04/05/82

CHIP 10-BIT\_ADDRESSABLE\_REGISTER PAL20X10

CLK /CLR /PR A B C D E1 E2 /E3 DIN GND  
 /OC Q9 Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

### EQUATIONS

```

/Q0 := CLR ;CLEAR (LSB)
      + /PR*/Q0 ;HOLD (/Q0)
      ++ /PR*/CLR* E1* E2* E3*/D*/C*/B*/A*/Q0* DIN ;LOAD ( DIN:+:/Q0) IF /Q0=H
      + /PR*/CLR* E1* E2* E3*/D*/C*/B*/A* Q0*/DIN ;LOAD (/DIN:+:/Q0) IF /Q0=L

/Q1 := CLR ;CLEAR
      + /PR*/Q1 ;HOLD (/Q1)
      ++ /PR*/CLR* E1* E2* E3*/D*/C*/B* A*/Q1* DIN ;LOAD ( DIN:+:/Q1) IF /Q1=H
      + /PR*/CLR* E1* E2* E3*/D*/C*/B* A* Q1*/DIN ;LOAD (/DIN:+:/Q1) IF /Q1=L

/Q2 := CLR ;CLEAR
      + /PR*/Q2 ;HOLD (/Q2)
      ++ /PR*/CLR* E1* E2* E3*/D*/C* B*/A*/Q2* DIN ;LOAD ( DIN:+:/Q2) IF /Q2=H
      + /PR*/CLR* E1* E2* E3*/D*/C* B*/A* Q2*/DIN ;LOAD (/DIN:+:/Q2) IF /Q2=L

/Q3 := CLR ;CLEAR
      + /PR*/Q3 ;HOLD (/Q3)
      ++ /PR*/CLR* E1* E2* E3*/D*/C* B* A*/Q3* DIN ;LOAD ( DIN:+:/Q3) IF /Q3=H
      + /PR*/CLR* E1* E2* E3*/D*/C* B* A* Q3*/DIN ;LOAD (/DIN:+:/Q3) IF /Q3=L

/Q4 := CLR ;CLEAR
      + /PR*/Q4 ;HOLD (/Q4)
      ++ /PR*/CLR* E1* E2* E3*/D* C*/B*/A*/Q4* DIN ;LOAD ( DIN:+:/Q4) IF /Q4=H
      + /PR*/CLR* E1* E2* E3*/D* C*/B*/A* Q4*/DIN ;LOAD (/DIN:+:/Q4) IF /Q4=L

/Q5 := CLR ;CLEAR
      + /PR*/Q5 ;HOLD (/Q5)
      ++ /PR*/CLR* E1* E2* E3*/D* C*/B* A*/Q5* DIN ;LOAD ( DIN:+:/Q5) IF /Q5=H
      + /PR*/CLR* E1* E2* E3*/D* C*/B* A* Q5*/DIN ;LOAD (/DIN:+:/Q5) IF /Q5=L

/Q6 := CLR ;CLEAR
      + /PR*/Q6 ;HOLD (/Q6)
      ++ /PR*/CLR* E1* E2* E3*/D* C* B*/A*/Q6* DIN ;LOAD ( DIN:+:/Q6) IF /Q6=H
      + /PR*/CLR* E1* E2* E3*/D* C* B*/A* Q6*/DIN ;LOAD (/DIN:+:/Q6) IF /Q6=L

/Q7 := CLR ;CLEAR + /PR*/Q7
      ++ /PR*/CLR* E1* E2* E3*/D* C* B* A*/Q7* DIN ;LOAD ( DIN:+:/Q7) IF /Q7=H
      + /PR*/CLR* E1* E2* E3*/D* C* B* A* Q7*/DIN ;LOAD (/DIN:+:/Q7) IF /Q7=L

/Q8 := CLR ;CLEAR
      + /PR*/Q8 ;HOLD (/Q8)
      ++ /PR*/CLR* E1* E2* E3* D*/C*/B*/A*/Q8* DIN ;LOAD ( DIN:+:/Q8) IF /Q8=H
      + /PR*/CLR* E1* E2* E3* D*/C*/B*/A* Q8*/DIN ;LOAD (/DIN:+:/Q8) IF /Q8=L
  
```

7

7B00520M

## 10-Bit Addressable Register

```

/Q9 := CLR ;CLEAR (MSB)
+ /PR*/Q9 ;HOLD (/Q9)
+: /PR*/CLR* E1* E2* E3* D*/C*/B* A*/Q9* DIN ;LOAD (DIN:+/Q9) IF /Q9=H
+ /PR*/CLR* E1* E2* E3* D*/C*/B* A* Q9*/DIN ;LOAD (/DIN:+/Q9) IF /Q9=L
    
```

;FUNCTION TABLE FOR PALASM 1

;/OC CLK /CLR /PR /E3 E2 E1 D C B A DIN Q9 Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0

|          |   | -----FUNCTIONS----- |     |     |    |    |   |   |   |   |     | ---INPUTS--- |    |    |    |    |    |    |    |    |    | -----OUTPUTS----- |                  |  |  |  |  |  |  |  |  |          |
|----------|---|---------------------|-----|-----|----|----|---|---|---|---|-----|--------------|----|----|----|----|----|----|----|----|----|-------------------|------------------|--|--|--|--|--|--|--|--|----------|
| ;CONTROL |   | /CLR                | /PR | /E3 | E2 | E1 | D | C | B | A | DIN | Q9           | Q8 | Q7 | Q6 | Q5 | Q4 | Q3 | Q2 | Q1 | Q0 |                   |                  |  |  |  |  |  |  |  |  | COMMENTS |
| ; L      | C | L                   | L   | X   | X  | X  | X | X | X | X | X   | L            | L  | L  | L  | L  | L  | L  | L  | L  | L  | L                 | /CLR OVRRD /PR   |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | L   | X   | X  | X  | X | X | X | X | X   | H            | H  | H  | H  | H  | H  | H  | H  | H  | H  | H                 | /PR OVRRD ENABLE |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | L | L | L | L   | H            | H  | H  | H  | H  | H  | H  | H  | H  | H  | L                 | LOAD Q0 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | L | L | H | L   | H            | H  | H  | H  | H  | H  | H  | H  | H  | L  | L                 | LOAD Q1 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | L | H | L | L   | H            | H  | H  | H  | H  | H  | H  | L  | L  | L  | L                 | LOAD Q2 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | L | H | H | L   | H            | H  | H  | H  | H  | H  | L  | L  | L  | L  | L                 | LOAD Q3 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | L | L | L   | L            | H  | H  | H  | H  | L  | L  | L  | L  | L  | L                 | LOAD Q4 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | L | H | L   | H            | L  | H  | H  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q5 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | L | H | L   | H            | L  | H  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q6 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | H | L | H   | H            | L  | H  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q7 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | H | L | L | L | L   | L            | L  | L  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q8 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | H | L | L | L | L   | L            | L  | L  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q9 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | H | L | L | L | L   | L            | L  | L  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q9 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | H | L | L | L | L   | L            | L  | L  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q8 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | H | H | H   | H            | L  | L  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q7 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | H | L | H   | H            | H  | L  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q6 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | H | L | H   | H            | H  | L  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q5 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | L | L | L   | L            | H  | H  | H  | H  | H  | L  | L  | L  | L  | L                 | LOAD Q4 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | L | L | L   | L            | H  | H  | H  | H  | H  | L  | L  | L  | L  | L                 | LOAD Q3 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | H | L | H   | L            | H  | H  | H  | H  | H  | L  | L  | L  | L  | L                 | LOAD Q2 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | L | L | L | L   | L            | H  | H  | H  | H  | H  | H  | H  | H  | H  | H                 | LOAD Q1 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | L | L | L | L   | L            | L  | L  | L  | L  | L  | L  | L  | L  | L  | L                 | LOAD Q0 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | X | X | X | X | X   | H            | H  | H  | H  | H  | H  | H  | H  | H  | H  | H                 | HOLD STATE       |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | L | L | L | L   | L            | L  | H  | H  | H  | H  | H  | H  | H  | H  | L                 | LOAD Q0 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | L  | H  | X | X | X | X | X   | H            | H  | H  | H  | H  | H  | H  | H  | H  | H  | L                 | HOLD STATE       |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | L  | H  | X | X | X | X | X   | H            | H  | H  | H  | H  | H  | H  | H  | H  | H  | L                 | HOLD STATE       |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | L | L | L   | L            | L  | H  | H  | H  | H  | L  | H  | L  | H  | L                 | LOAD Q4 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | L  | L  | X | X | X | X | X   | H            | H  | H  | H  | H  | L  | H  | L  | H  | L  | L                 | HOLD STATE       |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | L | H | L | L | L   | L            | L  | H  | H  | H  | L  | H  | L  | H  | L  | L                 | LOAD Q6 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | X | X | X | X | X   | H            | H  | H  | L  | H  | L  | H  | L  | H  | L  | L                 | HOLD STATE       |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | H | L | L | L | L   | L            | L  | H  | L  | H  | L  | H  | L  | H  | L  | L                 | LOAD Q8 WITH DIN |  |  |  |  |  |  |  |  |          |
| ; L      | C | H                   | H   | L   | H  | H  | X | X | X | X | X   | H            | L  | H  | L  | H  | L  | H  | L  | H  | L  | L                 | HOLD STATE       |  |  |  |  |  |  |  |  |          |
| ; H      | X | X                   | X   | X   | X  | X  | X | X | X | X | X   | Z            | Z  | Z  | Z  | Z  | Z  | Z  | Z  | Z  | Z  | Z                 | TEST HI-Z        |  |  |  |  |  |  |  |  |          |

1900530M

## 10-Bit Addressable Register

**;DESCRIPTION**

;THE 10-BIT ADDRESSABLE REGISTER IS A SYNCHRONOUS GENERAL PURPOSE ADDRESSABLE REGISTER WITH CLEAR, PRESET, AND ENABLE. THE OUTPUT REGISTER (Q) IS SELECTED BY THE INPUT ADDRESS PINS (A,B,C,D). THE DATA (DIN) IS LOADED INTO THE SELECTED OUTPUT REGISTER ON THE RISING EDGE OF THE CLOCK (CLK) IF THE CHIP IS ENABLED (E1=HIGH,E2=HIGH,/E3=LOW). ALL OTHER OUTPUTS HOLD THEIR PREVIOUS STATES DURING THE LOAD OPERATION. ANY OTHER COMBINATION OF THE ENABLE PINS (E1,E2,/E3) WILL DISABLE THE REGISTER AND ALL OUTPUTS WILL HOLD THEIR PREVIOUS STATES. CLEAR (/CLR) AND PRESET (/PR) ARE ACTIVE LOW PINS WHICH SET THE REGISTERS TO ALL HIGH OR LOW RESPECTIVELY.

;CLEAR OVERRIDES PRESET AND ENABLE, PRESET OVERRIDES ENABLE.

;THESE FUNCTIONS ARE EXERCISED IN THE FUNCTION TABLE AND SUMMARIZED IN THE OPERATIONS TABLE:

| ;/OC | CLK | /CLR | /PR | /E3 | E2 | E1 | D | C | B | A | DIN | Q9-Q0 | OPERATION                    |
|------|-----|------|-----|-----|----|----|---|---|---|---|-----|-------|------------------------------|
| ; H  | X   | X    | X   | X   | X  | X  | X | X | X | X | X   | Z     | HI-Z                         |
| ; L  | C   | L    | L   | X   | X  | X  | X | X | X | X | X   | L     | CLEAR                        |
| ; L  | C   | H    | L   | X   | X  | X  | X | X | X | X | X   | H     | PRESET                       |
| ; L  | C   | H    | H   | L   | L  | L  | X | X | X | X | X   | Q     | HOLD PREVIOUS STATES         |
| ; L  | C   | H    | H   | L   | L  | H  | X | X | X | X | X   | Q     | HOLD PREVIOUS STATES         |
| ; L  | C   | H    | H   | L   | H  | L  | X | X | X | X | X   | Q     | HOLD PREVIOUS STATES         |
| ; L  | C   | H    | H   | L   | H  | H  | D | C | B | A | DIN | DIN   | LOAD DIN TO ADDRESSED OUTPUT |
| ; L  | C   | H    | H   | H   | L  | L  | X | X | X | X | X   | Q     | HOLD PREVIOUS STATES         |
| ; L  | C   | H    | H   | H   | L  | H  | X | X | X | X | X   | Q     | HOLD PREVIOUS STATES         |
| ; L  | C   | H    | H   | H   | H  | L  | X | X | X | X | X   | Q     | HOLD PREVIOUS STATES         |
| ; L  | C   | H    | H   | H   | H  | H  | X | X | X | X | X   | Q     | HOLD PREVIOUS STATES         |



**; OUTPUT SELECT TABLE;**

|     | D | C | B | A | DIN | Q9  | Q8  | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |
|-----|---|---|---|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| ; L | L | L | L | L | DIN | Q9  | Q8  | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | DIN |
| ; L | L | L | L | H | DIN | Q9  | Q8  | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | DIN | Q0  |
| ; L | L | H | L | L | DIN | Q9  | Q8  | Q7  | Q6  | Q5  | Q4  | Q3  | DIN | Q1  | Q0  |
| ; L | L | H | H | L | DIN | Q9  | Q8  | Q7  | Q6  | Q5  | Q4  | DIN | Q2  | Q1  | Q0  |
| ; L | H | L | L | L | DIN | Q9  | Q8  | Q7  | Q6  | Q5  | DIN | Q3  | Q2  | Q1  | Q0  |
| ; L | H | L | H | L | DIN | Q9  | Q8  | Q7  | Q6  | DIN | Q4  | Q3  | Q2  | Q1  | Q0  |
| ; L | H | H | L | L | DIN | Q9  | Q8  | Q7  | DIN | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |
| ; L | H | H | H | L | DIN | Q9  | Q8  | DIN | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |
| ; H | L | L | L | L | DIN | Q9  | DIN | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |
| ; H | L | L | H | L | DIN | DIN | Q8  | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |
| ; H | L | H | L | L | DIN | Q9  | Q8  | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |
| ; H | L | H | H | L | DIN | Q9  | Q8  | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |
| ; H | H | X | X | X | DIN | Q9  | Q8  | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |

TB00540M

## MC6800 Microprocessor Interface

Title MC6800 MICROPROCESSOR INTERFACE  
 Pattern P7073  
 Revision A  
 Author COLI/SACKETT  
 Company MMI SUNNYVALE, CALIFORNIA  
 Date 09/14/82

CHIP MC6800\_MICROPROCESSOR\_INTERFACE PAL20L10

A15 A14 A13 A12 A11 NC /S /R PH2 VMA /AR GND  
 ENIN EN /IO /RAM4 /RAM3 /RAM2 /RAM1 /PROM2 /PROM1 /RSET VUA VCC

EQUATIONS

```
IF(VCC) PROM1 = A15* A14* A13* A12 * VMA* PH2*/RSET ;PROM1, F000-FFFF
IF(VCC) PROM2 = A15* A14* A13*/A12 * VMA* PH2*/RSET ;PROM2, E000-EFFF
IF(VCC) RAM1 = /A15*/A14*/A13*/A12*/A11* VMA* PH2*/RSET ;RAM1, 0000-07FF
IF(VCC) RAM2 = /A15*/A14*/A13*/A12* A11* VMA* PH2*/RSET ;RAM2, 0800-0FFF
IF(VCC) RAM3 = /A15*/A14*/A13* A12*/A11* VMA* PH2*/RSET ;RAM3, 1000-17FF
IF(VCC) RAM4 = /A15*/A14*/A13* A12* A11* VMA* PH2*/RSET ;RAM4, 1800-1FFF
IF(VCC) IO = A15* A14*/A13* A12* A11* VMA* PH2*/RSET ;I/O, D800-DFFF
IF(VCC) /EN = /PROM1*/PROM2*/RAM1*/RAM2*/RAM3*/RAM4*/IO* VMA*/RSET ;EN=/VUA
IF(VCC) /VUA = ENIN ;ASSERTIVE HIGH VUA SIGNAL (INVERT EN FEEDBACK)
IF(VCC) RSET = S ;SET
                + /R * RSET ;RESET
                + /AR* RSET ;AUTO RESET
```

;FUNCTION TABLE FOR PALASM 1

;A15 A14 A13 A12 A11 /S /R /AR /RSET PH2 VMA /PROM1 /PROM2 /RAM1 /RAM2 /RAM3  
 ;/RAM4 /IO EN ENIN VUA

| ;ADDR1 | S-R       | /RE | PROM |     |   |   | --RAM-- |   |   |   | ENABLE |     |    | COMMENT |                 |
|--------|-----------|-----|------|-----|---|---|---------|---|---|---|--------|-----|----|---------|-----------------|
| ;54321 | /S /R /AR | SET | PH2  | VMA | 1 | 2 | 1       | 2 | 3 | 4 | I/O    | OUT | IN | VUA     |                 |
| ;HHHX  | L H L     | L   | L    | H   | H | H | H       | H | H | H | H      | H   | H  | L       | RESET (/S=L)    |
| ;HHHX  | H L H     | L   | L    | H   | H | H | H       | H | H | H | H      | H   | H  | L       | AUTO-RESET      |
| ;HHHX  | H L L     | H   | L    | H   | H | H | H       | H | H | H | H      | L   | L  | H       | NO SELECT PH2=L |
| ;HHHX  | H L L     | H   | H    | L   | H | H | H       | H | H | H | H      | H   | H  | L       | NO SELECT VMA=L |
| ;HHHX  | H L L     | H   | H    | H   | L | H | H       | H | H | H | H      | H   | H  | L       | SELECT PROM1    |
| ;HHHX  | H L L     | H   | H    | H   | H | L | H       | H | H | H | H      | H   | H  | L       | SELECT PROM2    |
| ;LLLL  | H L L     | H   | H    | H   | H | H | L       | H | H | H | H      | H   | H  | L       | SELECT RAM1     |
| ;LLLL  | H L L     | H   | H    | H   | H | H | H       | L | H | H | H      | H   | H  | L       | SELECT RAM2     |
| ;LLLL  | H L L     | H   | H    | H   | H | H | H       | H | L | H | H      | H   | H  | L       | SELECT RAM3     |
| ;LLLL  | H L L     | H   | H    | H   | H | H | H       | H | H | L | H      | H   | H  | L       | SELECT RAM4     |
| ;HHLH  | H L L     | H   | H    | H   | H | H | H       | H | H | H | L      | H   | H  | L       | SELECT I/O PORT |

T000550M



## MC6800 Microprocessor Interface

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;DESCRIPTION

;THIS PAL20L10 INTERFACES BETWEEN THE MOTOROLA MC6800 MICROPROCESSOR AND ITS  
;SYSTEM COMPONENTS ON A SINGLE BOARD COMPUTER. THE FUNCTIONS IT PERFORMS,  
;PREVIOUSLY DONE WITH RANDOM LOGIC ARE: ADDRESS DECODING, MEMORY AND I/O  
;SELECT, RESET SIGNAL GENERATION, AND CONTROL OF THE BUFFER WHICH INTERFACES  
;THE DATA BUS TO OTHER BOARDS IN THE SYSTEM.

T800600M

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## MC6800 Microprocessor Interface

;FUNCTION TABLE FOR PALASM 1

;B A 1C0 1C1 1C2 2C0 2C1 2C2 3C0 3C1 3C2 4C0 4C1 4C2 1Y 2Y 3Y 4Y

```

; SEL  -----INPUTS-----  --OUTPUTS--          COMMENTS
;      1C    2C    3C    4C
; B A  012   012   012   012   1Y 2Y 3Y 4Y
;-----
; L L  LHH  HHH  HHH  HHH  L  H  H  H          1C0=0
; L L  HHH  LHH  HHH  HHH  H  L  H  H          2C0=0
; L L  HHH  HHH  LHH  HHH  H  H  L  H          3C0=0
; L L  HHH  HHH  HHH  LHH  H  H  H  L          4C0=0
; L L  HLL  LLL  LLL  LLL  H  L  L  L          1C0=1
; L L  LLL  HLL  LLL  LLL  L  H  L  L          2C0=1
; L L  LLL  LLL  HLL  LLL  L  L  H  L          3C0=1
; L L  LLL  LLL  LLL  HLL  L  L  L  H          4C0=1
; L L  HHH  HHH  HHH  HHH  H  H  H  H          TOGGLE LINES
; L H  HLH  HHH  HHH  HHH  L  H  H  H          1C1=0
; L H  HHH  HLH  HHH  HHH  H  L  H  H          2C1=0
; L H  HHH  HHH  HLH  HHH  H  H  L  H          3C1=0
; L H  HHH  HHH  HHH  HLH  H  H  H  L          4C1=0
; L H  LHL  LLL  LLL  LLL  H  L  L  L          1C1=1
; L H  LLL  LHL  LLL  LLL  L  H  L  L          2C1=1
; L H  LLL  LLL  LHL  LLL  L  L  H  L          3C1=1
; L H  LLL  LLL  LLL  LHL  L  L  L  H          4C1=1
; L H  HHH  HHH  HHH  HHH  H  H  H  H          TOGGLE LINES
; H L  HHL  HHH  HHH  HHH  L  H  H  H          1C2=0
; H L  HHH  HHL  HHH  HHH  H  L  H  H          2C2=0
; H L  HHH  HHH  HHL  HHH  H  H  L  H          3C2=0
; H L  HHH  HHH  HHH  HHL  H  H  H  L          4C2=0
; H L  LLH  LLL  LLL  LLL  H  L  L  L          1C2=1
; H L  LLL  LLH  LLL  LLL  L  H  L  L          2C2=1
; H L  LLL  LLL  LLH  LLL  L  L  H  L          3C2=1
; H L  LLL  LLL  LLL  LLH  L  L  L  H          4C2=1
; H L  HHH  HHH  HHH  HHH  H  H  H  H          TOGGLE LINES
; H H  LLL  LLL  LLL  LLL  H  H  H  H          SELECT = 4
; H H  HHH  HHH  HHH  HHH  H  H  H  H          TOGGLE LINES
;-----

```

;DESCRIPTION

;THIS IS AN EXAMPLE OF A QUAD 3-TO-1 MULTIPLEXER USING A PAL18L4. SELECT  
;LINES A,B ARE ENCODED IN BINARY, WITH A REPRESENTING THE LSB. THE OUTPUTS  
;(Y) ARE ALL HIGH IF THE SELECT LINES ARE BOTH HIGH (B,A=H).

; OPERATIONS TABLE:

```

; INPUT   OUTPUTS
; SELECT
;   B  A       Y
;-----
;   L  L       C0
;   L  H       C1
;   H  L       C2
;   H  H       H
;-----

```

T800570M

## Quad 3:1 Multiplexer

Title QUAD 3:1 MULTIPLEXER  
Pattern P7074  
Revision A  
Author VINCENT COLI  
Company MMI SUNNYVALE, CALIFORNIA  
Date 01/05/82

CHIP QUAD\_3:1\_MULTIPLEXER PAL14L4

1C0 1C1 1C2 2C0 2C1 2C2 3C0 3C1 3C2 GND  
4C0 4C1 4C2 4Y 3Y 2Y 1Y B A VCC

### EQUATIONS

```
/1Y = /B*/A * /1C0 ;SELECT INPUT 1C0  
+ /B* A * /1C1 ;SELECT INPUT 1C1  
+ B*/A * /1C2 ;SELECT INPUT 1C2  
  
/2Y = /B*/A * /2C0 ;SELECT INPUT 2C0  
+ /B* A * /2C1 ;SELECT INPUT 2C1  
+ B*/A * /2C2 ;SELECT INPUT 2C2  
  
/3Y = /B*/A * /3C0 ;SELECT INPUT 3C0  
+ /B* A * /3C1 ;SELECT INPUT 3C1  
+ B*/A * /3C2 ;SELECT INPUT 3C2  
  
/4Y = /B*/A * /4C0 ;SELECT INPUT 4C0  
+ /B* A * /4C1 ;SELECT INPUT 4C1  
+ B*/A * /4C2 ;SELECT INPUT 4C2
```

TB00080A

## 4-Bit Counter With Register

Title 4-BIT COUNTER WITH REGISTER  
Pattern P7075  
Revision A  
Author MIKE VOLPIGNO  
Company MONOLITHIC MEMORIES INC NEWTON, MASSACHUSETTS  
Date 11/20/81

CHIP 4-BIT\_COUNTER\_WITH\_REGISTER PAL20X8

CLK D0 D1 D2 D3 /RCLR /RLD SEL /CCLR /CLD EP GND  
/OC RCO C3 C2 C1 C0 R3 R2 R1 R0 ET VCC

### EQUATIONS

```
/C0 := CCLR ;CLEAR COUNTER
      + /CLD*/CCLR* EP* ET ;COUNT
      +: /CLD*/CCLR*/C0 ;COUNT
      + CLD*/CCLR*/R0 ;LOAD COUNTER FROM REGISTER

/C1 := CCLR ;CLEAR COUNTER
      + /CLD*/CCLR* EP* ET* C0 ;COUNT
      +: /CLD*/CCLR*/C1 ;COUNT
      + CLD*/CCLR*/R1 ;LOAD COUNTER FROM REGISTER

/C2 := CCLR ;CLEAR COUNTER
      + /CLD*/CCLR* EP* ET* C0* C1 ;COUNT
      +: /CLD*/CCLR*/C2 ;COUNT
      + CLD*/CCLR*/R2 ;LOAD COUNTER FROM REGISTER

/C3 := CCLR ;CLEAR COUNTER
      + /CLD*/CCLR* EP* ET* C0* C1* C2 ;COUNT
      +: /CLD*/CCLR*/C3 ;COUNT
      + CLD*/CCLR*/R3 ;LOAD COUNTER FROM REGISTER

/R0 := RCLR ;CLEAR REGISTER
      + /RCLR* RLD*/SEL*/D0 ;LOAD REGISTER FROM DATA
      +: /RCLR* RLD* SEL*/C0 ;LOAD REGISTER FROM COUNTER
      + /RCLR*/RLD*/R0 ;HOLD

/R1 := RCLR ;CLEAR REGISTER
      + /RCLR* RLD*/SEL*/D1 ;LOAD REGISTER FROM DATA
      +: /RCLR* RLD* SEL*/C1 ;LOAD REGISTER FROM COUNTER
      + /RCLR*/RLD*/R1 ;HOLD

/R2 := RCLR ;CLEAR REGISTER
      + /RCLR* RLD*/SEL*/D2 ;LOAD REGISTER FROM DATA
      +: /RCLR* RLD* SEL*/C2 ;LOAD REGISTER FROM COUNTER
      + /RCLR*/RLD*/R2 ;HOLD

/R3 := RCLR ;CLEAR REGISTER
      + /RCLR* RLD*/SEL*/D3 ;LOAD REGISTER FROM DATA
      +: /RCLR* RLD* SEL*/C3 ;LOAD REGISTER FROM COUNTER
      + /RCLR*/RLD*/R3 ;HOLD

IF(VCC) /RCO = ET* C0* C1* C2* C3 ;TERMINAL COUNT
```

780090M

## 4-Bit Counter With Register

;FUNCTION TABLE FOR PALASM 1

;CLK /RCLR /RLD SEL /CCLR /CLD EP ET D3 D2 D1 D0  
;R3 R2 R1 R0 C3 C2 C1 C0 /RCO

| ; / / /           | ; R / C / | ; C C R S C C | ; R  | ; L L L E L L E E D--D R--R C--C C | ; K R D L R D P T 3 0 3 0 3 0 0 | COMMENTS                     |
|-------------------|-----------|---------------|------|------------------------------------|---------------------------------|------------------------------|
| ; C L X X X X X X |           | XXXX          | LLLL | XXXX                               | X                               | CLEAR REGISTER               |
| ; C H L L X X X X |           | HHHH          | HHHH | XXXX                               | X                               | LOAD REGISTER HI FROM DATA   |
| ; C H H X H L X X |           | XXXX          | HHHH | HHHH                               | X                               | LOAD COUNTER FROM REGISTER   |
| ; C H H X H H L H |           | XXXX          | HHHH | HHHH                               | H                               | ENABLE RCO AND HOLD COUNT    |
| ; C H H X H H H H |           | XXXX          | HHHH | LLLL                               | L                               | COUNT AND ROLLOVER           |
| ; C H H X H H H H |           | XXXX          | HHHH | LLHL                               | L                               | INCREMENT COUNTER            |
| ; C H H X H H H H |           | XXXX          | HHHH | LLHL                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | LLHH                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | LHLL                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | LHLH                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | LHHL                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | LHHH                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | HLLL                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | HLLH                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | HLHL                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | HLHH                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | HLLL                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | HHLH                               | L                               | " "                          |
| ; C H H X H H H H |           | XXXX          | HHHH | HHHL                               | L                               | " "                          |
| ; C H L H H H H L |           | XXXX          | HHHL | HHHL                               | L                               | LOAD REGISTER FROM COUNTER   |
| ; C H H X L X X X |           | XXXX          | HHHL | LLLL                               | L                               | HOLD REGISTER, CLEAR COUNTER |

;DESCRIPTION

;THIS PAL DESIGN SPECIFICATION DESCRIBES A 4-BIT SYNCHRONOUS COUNTER WITH  
;4-BIT REGISTER. DATA CAN BE LOADED TO THE COUNTER FROM THE REGISTER. IT  
;CAN ALSO BE SYNCHRONOUSLY CLEARED. THE REGISTER CAN BE LOADED FROM EITHER  
;THE COUNTER OR THE DATA INPUTS UNDER CONTROL OF THE SEL INPUT. THE REGISTER  
;CAN ALSO BE SYNCHRONOUSLY CLEARED. THE COUNTER AND REGISTER HAVE A COMMON  
;CLOCK FOR SYNCHRONOUS OPERATION.

180000M



## 9-Bit Down Counter

Title 9-BIT DOWN COUNTER  
Pattern P7076  
Revision A  
Author BIRKNER/COLI/LEE  
Company MMI SUNNYVALE, CALIFORNIA  
Date 01/12/83

CHIP 9-BIT\_DOWN\_COUNTER PAL20X10

CLK D0 D1 D2 D3 D4 D5 D6 D7 D8 /LD GND  
/OC /BO Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

### EQUATIONS

```
/Q0 := /LD*/Q0 ;HOLD Q0
      + LD*/D0 ;LOAD D0 (LSB)
      :+: /LD ;COUNT DOWN

/Q1 := /LD*/Q1 ;HOLD Q1
      + LD*/D1 ;LOAD D1
      :+: /LD*/Q0 ;COUNT DOWN

/Q2 := /LD*/Q2 ;HOLD Q2
      + LD*/D2 ;LOAD D2
      :+: /LD*/Q0*/Q1 ;COUNT DOWN

/Q3 := /LD*/Q3 ;HOLD Q3
      + LD*/D3 ;LOAD D3
      :+: /LD*/Q0*/Q1*/Q2 ;COUNT DOWN

/Q4 := /LD*/Q4 ;HOLD Q4
      + LD*/D4 ;LOAD D4
      :+: /LD*/Q0*/Q1*/Q2*/Q3 ;COUNT DOWN

/Q5 := /LD*/Q5 ;HOLD Q5
      + LD*/D5 ;LOAD D5
      :+: /LD*/Q0*/Q1*/Q2*/Q3*/Q4 ;COUNT DOWN

/Q6 := /LD*/Q6 ;HOLD Q6
      + LD*/D6 ;LOAD D6
      :+: /LD*/Q0*/Q1*/Q2*/Q3*/Q4*/Q5 ;COUNT DOWN

/Q7 := /LD*/Q7 ;HOLD Q7
      + LD*/D7 ;LOAD D7
      :+: /LD*/Q0*/Q1*/Q2*/Q3*/Q4*/Q5*/Q6 ;COUNT DOWN

/Q8 := /LD*/Q8 ;HOLD Q8
      + LD*/D8 ;LOAD D8 (MSB)
      :+: /LD*/Q0*/Q1*/Q2*/Q3*/Q4*/Q5*/Q6*/Q7 ;COUNT DOWN

BO := /LD* Q0*/Q1*/Q2*/Q3*/Q4*/Q5*/Q6*/Q7*/Q8 ;CARRY OUT (ANTICIPATE COUNT)
      + LD*/D0*/D1*/D2*/D3*/D4*/D5*/D6*/D7*/D8 ;CARRY OUT (ANTICIPATE LOAD)
```

T800610M

## 9-Bit Down Counter

;F

;CLK /OC /LD D8 D7 D6 D5 D4 D3 D2 D1 D0 /BO Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0

|              |   |   | DATA IN   |     |           |                    | DATA OUT |  |  |  |  |
|--------------|---|---|-----------|-----|-----------|--------------------|----------|--|--|--|--|
| ; CONTROL    |   |   | DDDDDDDD  |     |           |                    | QQQQQQQQ |  |  |  |  |
| ;CLK /OC /LD |   |   | 876543210 | /BO | 876543210 | COMMENT            |          |  |  |  |  |
| -----        |   |   |           |     |           |                    |          |  |  |  |  |
| ; C          | L | L | LLLLLLLLL | L   | LLLLLLLLL | LOAD (BORROW)      |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | HHHHHHHHH | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | LLLLLLLLL | H   | LLLLLLLLL | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | L   | LLLLLLLLL | DECREMENT (BORROW) |          |  |  |  |  |
| ; C          | L | L | LLLLLLLLH | H   | LLLLLLLLH | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | LLLLLLLLH | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | LLLLLLLLH | H   | LLLLLLLLH | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | LLLLLLHHL | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | LLLLLLHHL | H   | LLLLLLHHL | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | LLLLLLHHL | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | LLLLHHHHH | H   | LLLLHHHHH | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | LLLLHHHHH | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | LLLLHHHHH | H   | LLLLHHHHH | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | LLLLHHHHH | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | LLLHHHHHH | H   | LLLHHHHHH | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | LLLHHHHHH | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | LLHHHHHHH | H   | LLHHHHHHH | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | LLHHHHHHH | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | LHHHHHHHH | H   | LHHHHHHHH | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | LHHHHHHHH | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | HHHHHHHHH | H   | HHHHHHHHH | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | HHHHHHHHH | DECREMENT          |          |  |  |  |  |
| ; C          | L | L | HHHHHHHLL | H   | HHHHHHHLL | LOAD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | HHHHHHLHH | DECREMENT          |          |  |  |  |  |
| ; L          | L | H | XXXXXXXXX | H   | HHHHHLLHH | HOLD               |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | HHHHHLLHL | DECREMENT          |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | HHHHHLLH  | DECREMENT          |          |  |  |  |  |
| ; C          | L | H | XXXXXXXXX | H   | HHHHHLLL  | DECREMENT          |          |  |  |  |  |
| ; X          | H | X | XXXXXXXXX | Z   | ZZZZZZZZZ | TEST HI-Z          |          |  |  |  |  |

;DESCRIPTION

;THE 9-BIT SYNCHRONOUS COUNTER HAS PARALLEL LOAD, DECREMENT, AND HOLD CAPABILITIES. DATA (D8-D0) IS LOADED INTO THE OUTPUT REGISTER (Q8-Q0) WHEN THE LOAD INPUT IS TRUE (/LD=L) AND A POSITIVE EDGE PULSE IS RECEIVED ON THE CLOCK PIN (CLK). THE COUNTER WILL DECREMENT IF A CLOCK PULSE IS RECEIVED WITH THE LOAD INPUT BEING FALSE (/LD=H). THE OPERATION IS A HOLD IF NO CLOCK PULSE IS RECEIVED REGARDLESS OF ANY OTHER INPUTS.

;THE BORROW OUT PIN (/BO) SHOWS HOW TO IMPLEMENT A BORROW OUT USING A REGISTER BY ANTICIPATED ONE COUNT BEFORE THE TERMINAL COUNT IF COUNTING AND THE TERMINAL COUNT IF LOADING.

;OPERATIONS TABLE:

|       | /OC | CLK | /LD | D8-D0 | Q8-Q0     | OPERATION |
|-------|-----|-----|-----|-------|-----------|-----------|
| ----- |     |     |     |       |           |           |
| ; H   | X   | X   | X   | X     | Z         | HI-Z      |
| ; L   | L   | X   | X   | X     | /Q        | HOLD      |
| ; L   | C   | L   | D   | D     | D         | LOAD      |
| ; L   | C   | H   | X   | X     | Q MINUS 1 | DECREMENT |

T80020M



## Refresh Clock Generator

Title REFRESH CLOCK GENERATOR  
Pattern P7077  
Revision A  
Author FRANK LEE  
Company MMI SUNNYVALE, CALIFORNIA  
Date 08/03/82

CHIP REFRESH CLOCK GENERATOR PAL20X10

CLK /LD F3 F2 F1 F0 M3 M2 M1 M0 /HOLD GND  
/OC RFCK Q0 Q1 Q2 Q3 Q4 Q5 Q6 Q7 /INIT VCC

### EQUATIONS

```
INIT := /Q7*/Q6*/Q5*/Q4*/Q3*/Q2*/Q1*/Q0 ;END OF COUNT
      + LD ;LOAD

/Q0 := /INIT*/Q0 ;DECREMENT
     :+ /INIT*/HOLD ;HOLD

/Q1 := /INIT*/Q1 ;DECREMENT
     :+ /INIT*/HOLD*/Q0 ;HOLD

/Q2 := INIT ;LOAD IN 0
     + /INIT*/Q2 ;DECREMENT
     :+ /INIT*/HOLD*/Q0*/Q1 ;HOLD

/Q3 := /INIT*/Q3 ;DECREMENT
     :+ /INIT*/HOLD*/Q0*/Q1*/Q2 ;HOLD

/Q4 := INIT*/F0 ;LOAD IN F0
     + /INIT*/Q4 ;DECREMENT
     :+ /INIT*/HOLD*/Q0*/Q1*/Q2*/Q3 ;HOLD

/Q5 := INIT*/F1 ;LOAD IN F1
     + /INIT*/Q5 ;DECREMENT
     :+ /INIT*/HOLD*/Q0*/Q1*/Q2*/Q3*/Q4 ;HOLD

/Q6 := INIT*/F2 ;LOAD IN F2
     + /INIT*/Q6 ;DECREMENT
     :+ /INIT*/HOLD*/Q0*/Q1*/Q2*/Q3*/Q4*/Q5 ;HOLD

/Q7 := INIT*/F3 ;LOAD IN F3
     + /INIT*/Q7 ;DECREMENT
     :+ /INIT*/HOLD*/Q0*/Q1*/Q2*/Q3*/Q4*/Q5*/Q6 ;HOLD

/RFCK := M3*/Q7*/Q6* Q5 ;32 LOW STATES
       + M2*/Q7*/Q6*/Q5* Q4 ;16 LOW STATES
       :+ M1*/Q7*/Q6*/Q5*/Q4* Q3 ;8 LOW STATES
       + M0*/Q7*/Q6*/Q5*/Q4*/Q3* Q2 ;4 LOW STATES
```

T800030M



## Refresh Clock Generator

;FUNCTION TABLE FOR PALASM 1

;CLK /OC /LD /HOLD F3 F2 F1 F0 M3 M2 M1 M0 /INIT Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 RFCK

```

;      /      /
;      H      I      R
;C / / O      N      F
;L O L L FFFF MMMM I QQQQQQQQ C
;K C D D 3210 3210 T 76543210 K      COMMENTS
-----
;C L L X LLHH LLHH L XXXXXXXX X      READY TO LOAD COUNTER
;C L L H LLHH LLHH L LLHHHLHH X      READY TO LOAD COUNTER
;C L H H LLHH LLHH H LLHHHLHH H      COUNTER LOADED, READY TO COUNT DOWN
;C L H H LLHH LLHH H LLHHHLHL H      COUNT DOWN
;C L H H LLHH LLHH H LLHHHLHL H      COUNT DOWN
;C L L H LLLH LHHL L LLHHHLLL H      READY TO LOAD COUNTER, COUNT DOWN
;C L H H LLLH LHHL H LLLHHLHH H      COUNTER LOADED
;C L H H LLLH LHHL H LLLHHLHL L      COUNT DOWN
;C L H H LLLH LHHL H LLLHHLHL L      COUNT DOWN
;C L H H LLLH LHHL H LLLHHLHL L      COUNT DOWN
;C L L H LLLH LHHL L LLLHLHHH L      READY TO LOAD COUNTER, COUNT DOWN
;C L H H LLLL LHHL H LLLLHLHH L      COUNTER LOADED
;C L H H LLLL LHHL H LLLLHLHL L      COUNT DOWN
;C L H H LLLL LHHL H LLLLHLHL L      COUNT DOWN
;C L H H LLLL LHHL H LLLLHLHL L      COUNT DOWN
;C L H H LLLL LHHL H LLLLHLHL L      COUNT DOWN
;C L H H LLLL LHHL H LLLLHLHL H      COUNT DOWN, RFCK HIGH
;C L H H LLLL LHHL H LLLLHLHL H      COUNT DOWN, RFCK HIGH
;C L H L LLLL LHHL H LLLLHLHL H      HOLD
;C L H H LLLL LHHL H LLLLHLHL H      COUNT DOWN
;C L H H LLLL LHHL H LLLLHLHL H      COUNT DOWN
;C L H H LLLL LHHL H LLLLHLHL H      COUNT DOWN
;C L H H LLLL LHHL H LLLLHLHL H      COUNT DOWN
;C L H H LLLL LHHL H LLLLHLHL H      COUNT DOWN
;C L H H LLLL LHHL L HHHHHHHH H      COUNT DOWN, READY TO LOAD COUNTER
;C H X X XXXX XXXX Z ZZZZZZZZ Z      HIGH IMPEDANCE TEST
-----

```

T800640M

7

## Refresh Clock Generator

;DESCRIPTION

;THE REFRESH CLOCK GENERATOR CAN GENERATE REFRESH CLOCK (RFCK) FOR THE DYNAMIC  
;RAM CONTROLLERS. THE PERIOD OF RFCK DEPENDS ON F3-F0 WHILE THE DURATION OF  
;RFCK BEING LOW DEPENDS ON M3-M0.

| ; FFFF  | RFCK PERIOD | MMM   | RFCK LOW DURATION |
|---------|-------------|-------|-------------------|
| ; 3210  | (CYCLES)    | 3210  | (CYCLES)          |
| ; ----- |             | ----- |                   |
| ; 0000  | 12          | 0000  | 0                 |
| ; 0001  | 28          | 0001  | 4                 |
| ; 0010  | 44          | 0010  | 8                 |
| ; 0011  | 60          | 0011  | 12                |
| ; 0100  | 76          | 0100  | 16                |
| ; 0101  | 92          | 0101  | 20*               |
| ; 0110  | 108         | 0110  | 24                |
| ; 0111  | 124         | 0111  | 28                |
| ; 1000  | 140         | 1000  | 32                |
| ; 1001  | 156         | 1001  | 36*               |
| ; 1010  | 172         | 1010  | 40*               |
| ; 1011  | 188         | 1011  | 44*               |
| ; 1100  | 204         | 1100  | 48                |
| ; 1101  | 220         | 1101  | 52*               |
| ; 1110  | 236         | 1110  | 56                |
| ; 1111  | 252         | 1111  | 60                |
| ; ----- |             | ----- |                   |

;\*NOT ALLOWED DUE TO BAD WAVEFORMS

T800650M

## Octal Addressable Register

Title OCTAL ADDRESSABLE REGISTER  
Pattern P7078  
Revision A  
Author DANESH TAVANA  
Company MMI SUNNYVALE, CALIFORNIA  
Date 02/02/82

CHIP OCTAL\_ADDRESSABLE\_REGISTER PAL16R8

CLK /CLR /PR A B C E1 /E2 DIN GND  
/OC Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

### EQUATIONS

```
/Q0 := CLR ;CLEAR (LSB)
+ /PR* E1* E2*/DIN*/C*/B*/A ;DATA IN ADDRESS 0
+ /PR* E1* E2*/Q0 * A ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q0 * B ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q0 * C ;LOAD PREVIOUS STATES
+ /PR* E1*/E2*/Q0 ;HOLD IF NOT LOADING (E1=H,/E2=H)
+ /PR*/E1*/E2*/Q0 ;HOLD IF NOT LOADING (E1=L,/E2=H)
+ /PR*/E1* E2*/Q0 ;HOLD IF NOT LOADING (E1=L,/E2=L)

/Q1 := CLR ;CLEAR
+ /PR* E1* E2*/DIN*/C*/B* A ;DATA IN ADDRESS 1
+ /PR* E1* E2*/Q1 * /A ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q1 * B ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q1 * C ;LOAD PREVIOUS STATES
+ /PR* E1*/E2*/Q1 ;HOLD IF NOT LOADING (E1=H,/E2=H)
+ /PR*/E1*/E2*/Q1 ;HOLD IF NOT LOADING (E1=L,/E2=H)
+ /PR*/E1* E2*/Q1 ;HOLD IF NOT LOADING (E1=L,/E2=L)

/Q2 := CLR ;CLEAR
+ /PR* E1* E2*/DIN*/C* B*/A ;DATA IN ADDRESS 2
+ /PR* E1* E2*/Q2 * A ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q2 * /B ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q2 * C ;LOAD PREVIOUS STATES
+ /PR* E1*/E2*/Q2 ;HOLD IF NOT LOADING (E1=H,/E2=H)
+ /PR*/E1*/E2*/Q2 ;HOLD IF NOT LOADING (E1=L,/E2=H)
+ /PR*/E1* E2*/Q2 ;HOLD IF NOT LOADING (E1=L,/E2=L)

/Q3 := CLR ;CLEAR
+ /PR* E1* E2*/DIN*/C* B* A ;DATA IN ADDRESS 3
+ /PR* E1* E2*/Q3 * /A ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q3 * /B ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q3 * C ;LOAD PREVIOUS STATES
+ /PR* E1*/E2*/Q3 ;HOLD IF NOT LOADING (E1=H,/E2=H)
+ /PR*/E1*/E2*/Q3 ;HOLD IF NOT LOADING (E1=L,/E2=H)
+ /PR*/E1* E2*/Q3 ;HOLD IF NOT LOADING (E1=L,/E2=L)

/Q4 := CLR ;CLEAR
+ /PR* E1* E2*/DIN* C*/B*/A ;DATA IN ADDRESS 4
+ /PR* E1* E2*/Q4 * A ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q4 * B ;LOAD PREVIOUS STATES
+ /PR* E1* E2*/Q4 */C ;LOAD PREVIOUS STATES
+ /PR* E1*/E2*/Q4 ;HOLD IF NOT LOADING (E1=H,/E2=H)
+ /PR*/E1*/E2*/Q4 ;HOLD IF NOT LOADING (E1=L,/E2=H)
+ /PR*/E1* E2*/Q4 ;HOLD IF NOT LOADING (E1=L,/E2=L)
```

TB00660M



## Octal Addressable Register

;DESCRIPTION

;THE 8-BIT ADDRESSABLE REGISTER LOADS THE DATA (DIN) INTO THE APPROPRIATE  
 ;ADDRESS LINE REGISTER (Q) ON THE RISING EDGE OF THE CLOCK (CLK).  
 ;THE INPUT ADDRESSING PINS (C,B,A) CHANNEL THE DATA (DIN) INTO ITS CORRESPONDING  
 ;OUTPUT REGISTER (Q) WHEN THE ENABLE PINS (/E2,E1) ARE (LOW,HIGH) RESPECTIVELY;  
 ;ANY OTHER COMBINATION OF INPUTS FOR THE ENABLE PINS HOLDS THE PREVIOUS STATE OF  
 ;THE REGISTERS (Q).

;CLEAR OVERRIDES PRESET, PRESET OVERRIDES LOAD ENABLE.

;THESE FUNCTIONS ARE EXERCISED IN THE FUNCTION TABLE AND SUMMARIZED IN THE  
 ;OPERATIONS TABLE:

|   | /OC | CLK | /CLR | /PR | E1 | /E2 | C | B | A | DIN | Q7-Q0 | OPERATION |
|---|-----|-----|------|-----|----|-----|---|---|---|-----|-------|-----------|
| H | X   | X   | X    | X   | X  | X   | X | X | X | X   | Z     | HI-Z      |
| L | C   | L   | X    | X   | X  | X   | X | X | X | X   | L     | CLEAR     |
| L | C   | H   | L    | X   | X  | X   | X | X | X | X   | H     | PRESET    |
| L | C   | H   | H    | H   | L  | L   | C | B | A | D   | D     | ENABLE    |
| L | C   | H   | H    | H   | H  | X   | X | X | X | X   | Q     | HOLD      |
| L | C   | H   | H    | L   | H  | X   | X | X | X | X   | Q     | HOLD      |
| L | C   | H   | H    | L   | L  | X   | X | X | X | X   | Q     | HOLD      |

TS00680M

## Octal Addressable Register With Demux/Enables

Title      OCTAL ADDRESSABLE REGISTER WITH DEMULTIPLEXER/ENABLES  
 Pattern    P7079  
 Revision   A  
 Author     DANESH TAVANA  
 Company    MMI SUNNYVALE, CALIFORNIA  
 Date       02/08/82

CHIP OCTAL\_ADDRESSABLE\_REGISTER\_WITH\_DEMULTIPLEXER/ENABLES PAL16R8

CLK MODE /PR A B C E1 /E2 DIN GND  
 /OC Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

### EQUATIONS

```

/Q0 := /PR* E1* E2*/DIN*/C*/B*/A* MODE ;LOAD /Q0 WITH /DIN (MODE=H)
      + /PR* E1* E2* /C*/B*/A*/MODE ;LOAD /Q0 WITH HIGH (MODE=L)
      + /PR* E1* E2*/Q0 * A* MODE ;/Q0 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q0 * B * MODE ;/Q0 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q0 * C * MODE ;/Q0 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1*/E2*/Q0 ;HOLD IF NOT LOADING (E1=H,/E2=H)
      + /PR*/E1*/E2*/Q0 ;HOLD IF NOT LOADING (E1=L,/E2=H)

/Q1 := /PR* E1* E2*/DIN*/C*/B* A* MODE ;LOAD /Q1 WITH /DIN (MODE=H)
      + /PR* E1* E2* /C*/B* A*/MODE ;LOAD /Q1 WITH HIGH (MODE=L)
      + /PR* E1* E2*/Q1 * /A* MODE ;/Q1 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q1 * B * MODE ;/Q1 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q1 * C * MODE ;/Q1 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1*/E2*/Q1 ;HOLD IF NOT LOADING (E1=H,/E2=H)
      + /PR*/E1*/E2*/Q1 ;HOLD IF NOT LOADING (E1=L,/E2=H)

/Q2 := /PR* E1* E2*/DIN*/C* B*/A* MODE ;LOAD /Q2 WITH /DIN (MODE=H)
      + /PR* E1* E2* /C* B*/A*/MODE ;LOAD /Q2 WITH HIGH (MODE=L)
      + /PR* E1* E2*/Q2 * A* MODE ;/Q2 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q2 * /B * MODE ;/Q2 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q2 * C * MODE ;/Q2 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1*/E2*/Q2 ;HOLD IF NOT LOADING (E1=H,/E2=H)
      + /PR*/E1*/E2*/Q2 ;HOLD IF NOT LOADING (E1=L,/E2=H)

/Q3 := /PR* E1* E2*/DIN*/C* B* A* MODE ;LOAD /Q3 WITH /DIN (MODE=H)
      + /PR* E1* E2* /C* B* A*/MODE ;LOAD /Q3 WITH HIGH (MODE=L)
      + /PR* E1* E2*/Q3 * /A* MODE ;/Q3 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q3 * /B * MODE ;/Q3 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q3 * C * MODE ;/Q3 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1*/E2*/Q3 ;HOLD IF NOT LOADING (E1=H,/E2=H)
      + /PR*/E1*/E2*/Q3 ;HOLD IF NOT LOADING (E1=L,/E2=H)

/Q4 := /PR* E1* E2*/DIN* C*/B*/A* MODE ;LOAD /Q4 WITH /DIN (MODE=H)
      + /PR* E1* E2* C*/B*/A*/MODE ;LOAD /Q4 WITH HIGH (MODE=L)
      + /PR* E1* E2*/Q4 * A* MODE ;/Q4 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q4 * B * MODE ;/Q4 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1* E2*/Q4 */C * MODE ;/Q4 IS EITHER PREVIOUS STATE OR LOW
      + /PR* E1*/E2*/Q4 ;HOLD IF NOT LOADING (E1=H,/E2=H)
      + /PR*/E1*/E2*/Q4 ;HOLD IF NOT LOADING (E1=L,/E2=H)
  
```

T80090M

## Octal Addressable Register With Demux/Enables

```

/Q5 := /PR* E1* E2*/DIN* C*/B* A* MODE ;LOAD /Q5 WITH /DIN (MODE=H)
+ /PR* E1* E2* C*/B* A*/MODE ;LOAD /Q5 WITH HIGH (MODE=L)
+ /PR* E1* E2*/Q5 * /A* MODE ;/Q5 IS EITHER PREVIOUS STATE OR LOW
+ /PR* E1* E2*/Q5 * B * MODE ;/Q5 IS EITHER PREVIOUS STATE OR LOW
+ /PR* E1* E2*/Q5 */C * MODE ;/Q5 IS EITHER PREVIOUS STATE OR LOW
+ /PR* E1*/E2*/Q5 ;HOLD IF NOT LOADING (E1=H,/E2=H)
+ /PR*/E1*/E2*/Q5 ;HOLD IF NOT LOADING (E1=L,/E2=H)
+ /PR*/E1* E2*/Q5 ;HOLD IF NOT LOADING (E1=L,/E2=L)

/Q6 := /PR* E1* E2*/DIN* C* B*/A* MODE ;LOAD /Q6 WITH /DIN (MODE=H)
+ /PR* E1* E2* C* B*/A*/MODE ;LOAD /Q6 WITH HIGH (MODE=L)
+ /PR* E1* E2*/Q6 * A* MODE ;/Q6 IS EITHER PREVIOUS STATE OR LOW
+ /PR* E1* E2*/Q6 * /B * MODE ;/Q6 IS EITHER PREVIOUS STATE OR LOW
+ /PR* E1* E2*/Q6 */C * MODE ;/Q6 IS EITHER PREVIOUS STATE OR LOW
+ /PR* E1*/E2*/Q6 ;HOLD IF NOT LOADING (E1=H,/E2=H)
+ /PR*/E1*/E2*/Q6 ;HOLD IF NOT LOADING (E1=L,/E2=H)
+ /PR*/E1* E2*/Q6 ;HOLD IF NOT LOADING (E1=L,/E2=L)

/Q7 := /PR* E1* E2*/DIN* C* B* A* MODE ;LOAD /Q7 WITH /DIN (MODE=H)
+ /PR* E1* E2* C* B* A*/MODE ;LOAD /Q7 WITH HIGH (MODE=L)
+ /PR* E1* E2*/Q7 * /A* MODE ;/Q7 IS EITHER PREVIOUS STATE OR LOW
+ /PR* E1* E2*/Q7 * /B * MODE ;/Q7 IS EITHER PREVIOUS STATE OR LOW
+ /PR* E1* E2*/Q7 */C * MODE ;/Q7 IS EITHER PREVIOUS STATE OR LOW
+ /PR* E1*/E2*/Q7 ;HOLD IF NOT LOADING (E1=H,/E2=H)
+ /PR*/E1*/E2*/Q7 ;HOLD IF NOT LOADING (E1=L,/E2=H)
+ /PR*/E1* E2*/Q7 ;HOLD IF NOT LOADING (E1=L,/E2=L)

```

T800100M

## Octal Addressable Register With Demux/Enables

;FUNCTION TABLE

;/OC CLK MODE /PR /E2 E1 C B A DIN Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0

| ;CONTROL |     | FUNCTIONS |     |     | INPUTS |   |   |   | OUTPUTS |   |   |   |   |   |   |   | COMMENTS |                         |
|----------|-----|-----------|-----|-----|--------|---|---|---|---------|---|---|---|---|---|---|---|----------|-------------------------|
| ;/OC     | CLK | MODE      | /PR | /E2 | E1     | C | B | A | DIN     | Q | Q | Q | Q | Q | Q | Q |          | Q                       |
|          |     |           |     |     |        |   |   |   |         | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0        |                         |
| ; L      | C   | X         | L   | X   | X      | X | X | X | X       | H | H | H | H | H | H | H | H        | PRESET (OVERRD ENABLES) |
| ; L      | C   | H         | H   | L   | H      | L | L | L | L       | H | H | H | H | H | H | H | L        | LOAD Q0 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | L | L | H | L       | H | H | H | H | H | L | L | L        | LOAD Q1 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | L | H | L | L       | L | H | H | H | L | L | L | L        | LOAD Q2 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | L | H | H | L       | L | H | H | H | L | L | L | L        | LOAD Q3 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | H | L | L | L       | L | H | H | L | L | L | L | L        | LOAD Q4 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | H | L | H | L       | L | H | H | L | L | L | L | L        | LOAD Q5 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | H | L | L | L       | L | H | L | L | L | L | L | L        | LOAD Q6 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | H | H | H | L       | L | L | L | L | L | L | L | L        | LOAD Q7 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | H | H | L | H       | L | L | L | L | L | L | L | L        | LOAD Q6 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | H | L | H | H       | L | L | L | L | L | L | L | L        | LOAD Q5 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | H | L | L | L       | L | L | L | L | L | L | L | L        | LOAD Q4 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | L | H | H | H       | L | L | L | L | L | L | L | L        | LOAD Q3 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | L | H | L | L       | L | L | L | L | L | L | L | L        | LOAD Q2 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | L | L | L | H       | H | H | H | H | H | H | H | H        | LOAD Q1 WITH DIN        |
| ; L      | C   | H         | H   | L   | H      | L | L | L | H       | H | H | H | H | H | H | H | H        | LOAD Q0 WITH DIN        |
| ; L      | C   | L         | H   | L   | H      | L | L | L | X       | H | H | H | H | H | H | L | L        | DECODE ADDRESS LINE 0   |
| ; L      | C   | L         | H   | L   | H      | L | L | H | X       | H | H | H | H | H | L | H | H        | DECODE ADDRESS LINE 1   |
| ; L      | C   | L         | H   | L   | H      | L | H | L | X       | H | H | H | H | L | H | H | H        | DECODE ADDRESS LINE 2   |
| ; L      | C   | L         | H   | L   | H      | L | H | H | X       | H | H | H | L | H | H | H | H        | DECODE ADDRESS LINE 3   |
| ; L      | C   | L         | H   | L   | H      | H | L | L | X       | H | H | L | H | H | H | H | H        | DECODE ADDRESS LINE 4   |
| ; L      | C   | L         | H   | L   | H      | H | L | H | X       | H | L | H | H | H | H | H | H        | DECODE ADDRESS LINE 5   |
| ; L      | C   | L         | H   | L   | H      | H | H | L | X       | H | L | H | H | H | H | H | H        | DECODE ADDRESS LINE 6   |
| ; L      | C   | L         | H   | L   | H      | H | H | X | X       | L | H | H | H | H | H | H | H        | DECODE ADDRESS LINE 7   |
| ; L      | C   | X         | H   | L   | L      | X | X | X | X       | L | H | H | H | H | H | H | H        | HOLD PREVIOUS STATE     |
| ; L      | C   | H         | H   | L   | H      | H | L | H | L       | L | H | L | H | H | H | H | H        | LOAD Q5 WITH DIN        |
| ; L      | C   | X         | H   | H   | L      | X | X | X | X       | L | H | L | H | H | H | H | H        | HOLD PREVIOUS STATE     |
| ; L      | C   | H         | H   | L   | H      | L | H | H | L       | L | H | L | H | L | H | H | H        | LOAD Q3 WITH DIN        |
| ; L      | C   | X         | H   | H   | H      | X | X | X | X       | L | H | L | H | L | H | H | H        | HOLD PREVIOUS STATE     |
| ; L      | C   | L         | H   | L   | H      | L | L | H | X       | H | H | H | H | H | L | H | H        | DECODE ADDRESS LINE 1   |
| ; H      | X   | X         | X   | X   | X      | X | X | X | X       | Z | Z | Z | Z | Z | Z | Z | Z        | HI-Z                    |

1800710M



## Octal Addressable Register With Demux/Enables

;DESCRIPTION

;THE 8-BIT ADDRESSABLE REGISTER AND DEMULTIPLEXER PERFORMS TWO FUNCTIONS ON ONE  
 ;MSI PACKAGE. IF MODE=0 THE PART PERFORMS A 3 TO 8 DE-MULTIPLEXER FUNCTION WITH  
 ;PRESET, LOAD, AND HOLD; IF MODE=1 IT IS AN 8-BIT ADDRESSABLE REGISTER WITH  
 ;PRESET, LOAD, AND HOLD.

;WHEN THE CONTROL PINS (/E2,E1) ARE (LOW,HIGH) THE UNIT IS ENABLED AND THE INPUT  
 ;ADDRESS PINS (C,B,A) EITHER CHANNEL THE INPUT DATA (DIN) TO ITS APPROPRIATE  
 ;OUTPUT REGISTER (Q) WITH MODE=1, OR SELECT THE ADDRESSED OUTPUT REGISTER (Q)  
 ;WITH MODE=0. ANY OTHER COMBINATION FOR THE INPUT CONTROL PINS HOLDS THE  
 ;PREVIOUS STATE OF THE OUTPUTS.

;PRESET OVERRIDES ENABLE.

;THESE FUNCTIONS ARE EXERCISED IN THE FUNCTION TABLE AND SUMMARIZED IN THE  
 ;OPERATIONS TABLE:

| ; | /OC | CLK | MODE | /PR | /E2 | E1 | C | B | A | DIN | Q7-Q0 | OPERATION            |
|---|-----|-----|------|-----|-----|----|---|---|---|-----|-------|----------------------|
| ; | H   | X   | X    | X   | X   | X  | X | X | X | X   | Z     | HI-Z                 |
| ; | L   | C   | X    | L   | X   | X  | X | X | X | X   | H     | PRESET               |
| ; | L   | C   | L    | H   | L   | H  | C | B | A | X   | MUX   | ADDRESSED OUTPUT=LOW |
| ; | L   | C   | H    | H   | L   | H  | C | B | A | D   | REG   | ADDRESSED OUTPUT=D   |
| ; | L   | C   | X    | H   | H   | L  | X | X | X | X   | Q     | HOLD                 |
| ; | L   | C   | X    | H   | L   | L  | X | X | X | X   | Q     | HOLD                 |
| ; | L   | C   | X    | H   | H   | H  | X | X | X | X   | Q     | HOLD                 |

18007204

7

## Octal Addressable Register With Demux/Clear

Title      OCTAL ADDRESSABLE REGISTER WITH DEMULTIPLEXER/CLEAR  
 Pattern   P7080 (PMSI002)  
 Revision   A  
 Author     DANESH TAVANA  
 Company   MMI SUNNYVALE, CALIFORNIA  
 Date      04/27/82

CHIP OCTAL\_ADDRESSABLE\_REGISTER\_WITH\_DEMULTIPLEXER/CLEAR PAL16R8

### EQUATIONS

CLK /CLR /PR A B C MODE /E DIN GND  
 /OC Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

```

/Q0 := CLR                                ;CLEAR (LSB)
      + /PR* E*/MODE*/C*/B*/A            ;DEMULTIPLEX OUTPUT /Q0=H
      + /PR* E* MODE*/C*/B*/A*/DIN      ;REGISTER OUTPUT /Q0=/DIN
      + /PR* E* MODE*                      A*/Q0    ;LOAD PREVIOUS STATE (/Q0) OR A LOW
      + /PR* E* MODE*                      B      */Q0    ;LOAD PREVIOUS STATE (/Q0) OR A LOW
      + /PR* E* MODE* C                      */Q0    ;LOAD PREVIOUS STATE (/Q0) OR A LOW
      + /PR*/E                              */Q0    ;HOLD IF NOT LOADING (/E=H)

/Q1 := CLR                                ;CLEAR
      + /PR* E*/MODE*/C*/B* A            ;DEMULTIPLEX OUTPUT /Q1=H
      + /PR* E* MODE*/C*/B* A*/DIN      ;REGISTER OUTPUT /Q1=/DIN
      + /PR* E* MODE*                      /A*/Q1    ;LOAD PREVIOUS STATE (/Q1) OR A LOW
      + /PR* E* MODE*                      B      */Q1    ;LOAD PREVIOUS STATE (/Q1) OR A LOW
      + /PR* E* MODE* C                      */Q1    ;LOAD PREVIOUS STATE (/Q1) OR A LOW
      + /PR*/E                              */Q1    ;HOLD IF NOT LOADING (/E=H)

/Q2 := CLR                                ;CLEAR
      + /PR* E*/MODE*/C* B*/A            ;DEMULTIPLEX OUTPUT /Q2=H
      + /PR* E* MODE*/C* B*/A*/DIN      ;REGISTER OUTPUT /Q2=/DIN
      + /PR* E* MODE*                      A*/Q2    ;LOAD PREVIOUS STATE (/Q2) OR A LOW
      + /PR* E* MODE*                      /B      */Q2    ;LOAD PREVIOUS STATE (/Q2) OR A LOW
      + /PR* E* MODE* C                      */Q2    ;LOAD PREVIOUS STATE (/Q2) OR A LOW
      + /PR*/E                              */Q2    ;HOLD IF NOT LOADING (/E=H)

/Q3 := CLR                                ;CLEAR
      + /PR* E*/MODE*/C* B* A            ;DEMULTIPLEX OUTPUT /Q3=H
      + /PR* E* MODE*/C* B* A*/DIN      ;REGISTER OUTPUT /Q3=/DIN
      + /PR* E* MODE*                      /A*/Q3    ;LOAD PREVIOUS STATE (/Q3) OR A LOW
      + /PR* E* MODE*                      /B      */Q3    ;LOAD PREVIOUS STATE (/Q3) OR A LOW
      + /PR* E* MODE* C                      */Q3    ;LOAD PREVIOUS STATE (/Q3) OR A LOW
      + /PR*/E                              */Q3    ;HOLD IF NOT LOADING (/E=H)

/Q4 := CLR                                ;CLEAR
      + /PR* E*/MODE* C*/B*/A            ;DEMULTIPLEX OUTPUT /Q4=H
      + /PR* E* MODE* C*/B*/A*/DIN      ;REGISTER OUTPUT /Q4=/DIN
      + /PR* E* MODE*                      A*/Q4    ;LOAD PREVIOUS STATE (/Q4) OR A LOW
      + /PR* E* MODE*                      B      */Q4    ;LOAD PREVIOUS STATE (/Q4) OR A LOW
      + /PR* E* MODE*/C                      */Q4    ;LOAD PREVIOUS STATE (/Q4) OR A LOW
      + /PR*/E                              */Q4    ;HOLD IF NOT LOADING (/E=H)
  
```

TR00130M

## Octal Addressable Register With Demux/Clear

```

/Q5 := CLR ;CLEAR
+ /PR* E*/MODE* C*/B* A ;DEMULPLEX OUTPUT /Q5=H
+ /PR* E* MODE* C*/B* A*/DIN ;REGISTER OUTPUT /Q5=/DIN
+ /PR* E* MODE* /A*/Q5 ;LOAD PREVIOUS STATE (/Q5) OR A LOW
+ /PR* E* MODE* B */Q5 ;LOAD PREVIOUS STATE (/Q5) OR A LOW
+ /PR* E* MODE*/C */Q5 ;LOAD PREVIOUS STATE (/Q5) OR A LOW
+ /PR*/E */Q5 ;HOLD IF NOT LOADING (/E=H)

/Q6 := CLR ;CLEAR
+ /PR* E*/MODE* C* B*/A ;DEMULPLEX OUTPUT /Q6=H
+ /PR* E* MODE* C* B*/A*/DIN ;REGISTER OUTPUT /Q5=/DIN
+ /PR* E* MODE* A*/Q6 ;LOAD PREVIOUS STATE (/Q6) OR A LOW
+ /PR* E* MODE* /B */Q6 ;LOAD PREVIOUS STATE (/Q6) OR A LOW
+ /PR* E* MODE*/C */Q6 ;LOAD PREVIOUS STATE (/Q6) OR A LOW
+ /PR*/E */Q6 ;HOLD IF NOT LOADING (/E=H)

/Q7 := CLR ;CLEAR (MSB)
+ /PR* E*/MODE* C* B* A ;DEMULPLEX OUTPUT /Q7=H
+ /PR* E* MODE* C* B* A*/DIN ;REGISTER OUTPUT /Q7=/DIN
+ /PR* E* MODE* /A*/Q7 ;LOAD PREVIOUS STATE (/Q7) OR A LOW
+ /PR* E* MODE* /B */Q7 ;LOAD PREVIOUS STATE (/Q7) OR A LOW
+ /PR* E* MODE*/C */Q7 ;LOAD PREVIOUS STATE (/Q7) OR A LOW
+ /PR*/E */Q7 ;HOLD IF NOT LOADING (/E=H)

```

### FUNCTION TABLE FOR PALASM 1

| ;FUNCTION TABLE FOR PALASM 1  |  |  |  |  |  |  |  |  |  |
|---|--|--|--|--|--|--|--|--|--|
| ;/OC CLK /CLR /PR /E MODE C B A DIN Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0                                 |  |  |  |  |  |  |  |  |  |
| ;   |  |  |  |  |  |  |  |  |  |
| ;CONTROL ---FUNCTIONS--- -INPUTS-- --OUTPUTS---   |  |  |  |  |  |  |  |  |  |
| ;/OC CLK /CLR /PR /E MODE C B A DIN 7 6 5 4 3 2 1 0 COMMENTS                                |  |  |  |  |  |  |  |  |  |
| -----   |  |  |  |  |  |  |  |  |  |
| ; L C L L X X X X X X L L L L L L L L CLEAR (OVERRD /PR)                                    |  |  |  |  |  |  |  |  |  |
| ; L C H L X X X X X H H H H H H H H PRESET (OVERRD ENABLES)                                 |  |  |  |  |  |  |  |  |  |
| ; L C H H L H L L L L H H H H H H H L LOAD Q0 WITH DIN                                      |  |  |  |  |  |  |  |  |  |
| ; L C H H L H L H L L H H H H H L L L LOAD Q1 WITH DIN                                      |  |  |  |  |  |  |  |  |  |
| ; L C H H L H L H L L H H H H L L L L LOAD Q2 WITH DIN                                      |  |  |  |  |  |  |  |  |  |
| ; L C H H L H H L L L H H H L L L L L LOAD Q3 WITH DIN                                      |  |  |  |  |  |  |  |  |  |
| ; L C H H L H H L L L H H L L L L L L LOAD Q4 WITH DIN                                      |  |  |  |  |  |  |  |  |  |
| ; L C H H L H H L L L H H L L L L L L LOAD Q5 WITH DIN                                      |  |  |  |  |  |  |  |  |  |
| ; L C H H L H H L L L H L L L L L L L L LOAD Q6 WITH DIN                                    |  |  |  |  |  |  |  |  |  |
| ; L C H H L H H H H L L L L L L L L L L LOAD Q7 WITH DIN                                    |  |  |  |  |  |  |  |  |  |
| ; L C H H L H H H H H H L L L L L L L L LOAD Q7 WITH DIN                                    |  |  |  |  |  |  |  |  |  |
| ; L C H H L H H H L L L L L L L L L L L L LOAD Q6 WITH DIN                                  |  |  |  |  |  |  |  |  |  |
| ; L C H H L H H L H H H L L L L L L L L LOAD Q5 WITH DIN                                    |  |  |  |  |  |  |  |  |  |
| ; L C H H L H H L L H H H H L L L L L L L L LOAD Q4 WITH DIN                                |  |  |  |  |  |  |  |  |  |
| ; L C H H L H L H L H H H H H L L L L L L L L LOAD Q3 WITH DIN                              |  |  |  |  |  |  |  |  |  |
| ; L C H H L H L H L L H H H H H H L L L L L L L L LOAD Q2 WITH DIN                          |  |  |  |  |  |  |  |  |  |
| ; L C H H L H L H L L L H H H H H H H H L L L L L L L L LOAD Q1 WITH DIN                    |  |  |  |  |  |  |  |  |  |
| ; L C H H L H L L L L L L X H H H H H H H H L L L L L L L L DECODE ADDRESS LINE 0           |  |  |  |  |  |  |  |  |  |
| ; L C H H L L L L L L L L X H H H H H H L H H H H H H H L L L L L L L DECODE ADDRESS LINE 1 |  |  |  |  |  |  |  |  |  |
| ; L C H H L L L L L L L L X H H H H H L H H H H H H H H H H H H DECODE ADDRESS LINE 2       |  |  |  |  |  |  |  |  |  |
| ; L C H H L L L L L L L L X H H H H L H H H H H H H H H H H H DECODE ADDRESS LINE 3         |  |  |  |  |  |  |  |  |  |
| ; L C H H L L L L L L L L X H H L H H H H H H H H H H H H H H DECODE ADDRESS LINE 4         |  |  |  |  |  |  |  |  |  |
| ; L C H H L L L L L L L L X H L H H H H H H H H H H H H H H H H H DECODE ADDRESS LINE 5     |  |  |  |  |  |  |  |  |  |
| ; L C H H L L L L L L L L X L H H H H H H H H H H H H H H H H H H DECODE ADDRESS LINE 6     |  |  |  |  |  |  |  |  |  |
| ; L C H H H X X X X X L H H H H H H H H H H H H H H H H H H DECODE ADDRESS LINE 7           |  |  |  |  |  |  |  |  |  |
| ; H X X X X X X X X Z Z Z Z Z Z Z Z TEST HI-Z   |  |  |  |  |  |  |  |  |  |



1800740M

## Octal Addressable Register With Demux/Clear

**;DESCRIPTION**

;THE OCTAL ADDRESSABLE REGISTER AND DEMULTIPLEXER PERFORMS ONE OF TWO MSI  
 ;FUNCTIONS DEPENDING ON THE STATE OF THE MODE SELECT PIN. IF MODE=HIGH THEN THE  
 ;PART PERFORMS THE FUNCTION OF AN ADDRESSABLE REGISTER WITH 8 OUTPUTS (Q7-Q0)  
 ;AND ONE DATA INPUT (DIN). THE REGISTERED OUTPUT IS SELECTED BY THREE INPUT  
 ;ADDRESS PINS (A,B,C). WITH MODE=LOW CONVERTS THIS CHIP INTO AN ACTIVE LOW  
 ;3-TO-8 DEMULTIPLEXER, WHERE THE ADDRESSED OUTPUT IS LOW AND ALL OTHER OUTPUTS  
 ;REMAIN HIGH. CLEAR (/CLR) AND PRESET (/PR) ARE ACTIVE LOW OUTPUTS WHICH SET  
 ;ALL OUTPUTS TO LOW OR HIGH RESPECTIVELY. WHEN ENABLE (/E) IS HIGH, THE CHIP IS  
 ;DISABLED AND THE OUTPUTS RETAIN THEIR PREVIOUS STATES.

;CLEAR OVERRIDES PRESET AND ENABLE, PRESET OVERRIDES ENABLE.

;THESE FUNCTIONS ARE EXERCISED IN THE FUNCTION TABLE AND SUMMARIZED IN THE  
 ;OPERATIONS TABLE:

| ;/OC | CLK | /CLR | /PR | /E | MODE | C | B | A | DIN | Q7-Q0 | OPERATION            |
|------|-----|------|-----|----|------|---|---|---|-----|-------|----------------------|
| ; H  | X   | X    | X   | X  | X    | X | X | X | X   | Z     | HI-Z                 |
| ; L  | C   | L    | X   | X  | X    | X | X | X | X   | L     | CLEAR                |
| ; L  | C   | H    | L   | X  | X    | X | X | X | X   | H     | PRESET               |
| ; L  | C   | H    | H   | L  | L    | C | B | A | X   | MUX   | ADDRESSED OUTPUT=LOW |
| ; L  | C   | H    | H   | L  | H    | C | B | A | DIN | REG   | ADDRESSED OUTPUT=DIN |
| ; L  | C   | H    | H   | H  | X    | X | X | X | X   | Q     | HOLD PREVIOUS STATES |

**OUTPUT SELECT TABLE**

| C | B | A | DIN | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |
|---|---|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| L | L | L | DIN | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | DIN |
| L | L | H | DIN | Q7  | Q6  | Q5  | Q4  | Q3  | Q2  | DIN | Q0  |
| L | H | L | DIN | Q7  | Q6  | Q5  | Q4  | Q3  | DIN | Q1  | Q0  |
| L | H | H | DIN | Q7  | Q6  | Q5  | Q4  | DIN | Q2  | Q1  | Q0  |
| H | L | L | DIN | Q7  | Q6  | Q5  | DIN | Q3  | Q2  | Q1  | Q0  |
| H | L | H | DIN | Q7  | Q6  | DIN | Q4  | Q3  | Q2  | Q1  | Q0  |
| H | H | L | DIN | Q7  | DIN | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |
| H | H | H | DIN | DIN | Q6  | Q5  | Q4  | Q3  | Q2  | Q1  | Q0  |

TB00750M

## Rounding - Control Logic

---

Title     ROUNDING-CONTROL LOGIC  
 Pattern   P7081  
 Revision   A  
 Author    VINCENT COLI  
 Company   MMI SUNNYVALE, CALIFORNIA  
 Date       03/18/82

CHIP ROUNDING-CONTROL\_LOGIC PAL16C1

D00 D01 D02 D03 D04 D05 D06 D07 D08 GND  
 D09 D10 D11 D12 TRU COM NC   NC   NC   VCC

### EQUATIONS

```

COM =  D12* D11
      +   D11* D10
      +   D11   *D09
      +   D11     * D08
      +   D11       * D07
      +   D11         * D06
      +   D11           * D05
      +   D11             * D04
      +   D11               * D03
      +   D11                 * D02
      +   D11                   * D01
      +   D11                     * D00
  
```

### ;FUNCTION TABLE

```

;D12 D11 D10 D09 D08 D07 D06 D05 D04 D03 D02 D01 D00 COM TRU
;
; COM RESULTS HAVE BEEN REMOVED FROM SIMULATION RESULTS
;
;D D D D D D D D D D D D D D ROUND-CONTROL
;12 11 10
  
```

7

T900780M

## 4-Bit Counter With Terminal Count Lock

Title 4-BIT COUNTER WITH TERMINAL COUNT LOCK  
Pattern P7082  
Revision A  
Author COLI/VOLDAN  
Company MMI SUNNYVALE, CALIFORNIA  
Date 04/05/82

CHIP 4-BIT\_COUNTER\_WITH\_TERMINAL\_COUNT\_LOCK PAL16R6

CLK NC NC D0 D1 D2 D3 CLEAR /LOAD GND  
/OC NC /EP Q3 Q2 Q1 Q0 NC NC VCC

### EQUATIONS

```
/Q0 := CLEAR ;CLEAR Q0 (LSB)
      + LOAD*/D0 ;LOAD D0
      + /LOAD*/Q0*/EP ;HOLD IF NO EP
      + /LOAD* EP* Q0 ;COUNT IF EP AND Q0=H

/Q1 := CLEAR ;CLEAR Q1
      + LOAD*/D1 ;LOAD D1
      + /LOAD*/Q1*/EP ;HOLD IF NO EP
      + /LOAD*/Q1*/Q0 ;HOLD IF Q1,Q0=L
      + /LOAD* EP* Q1* Q0 ;COUNT IF EP AND Q1,Q0=H

/Q2 := CLEAR ;CLEAR Q2
      + LOAD*/D2 ;LOAD D2
      + /LOAD*/Q2*/EP ;HOLD IF NO EP
      + /LOAD*/Q2*/Q0 ;HOLD IF Q2,Q0=L
      + /LOAD*/Q2*/Q1 ;HOLD IF Q2,Q1=L
      + /LOAD* EP* Q2* Q1* Q0 ;COUNT IF EP AND Q2,Q1,Q0=H

/Q3 := CLEAR ;CLEAR Q3 (MSB)
      + LOAD*/D3 ;LOAD D3
      + /LOAD*/Q3*/EP ;HOLD IF NO EP
      + /LOAD*/Q3*/Q0 ;HOLD IF Q3,Q0=L
      + /LOAD*/Q3*/Q1 ;HOLD IF Q3,Q1=L
      + /LOAD*/Q3*/Q2 ;HOLD IF Q3,Q2=L
      + /LOAD* EP* Q3* Q2* Q1* Q0 ;COUNT IF EP AND Q3,Q2,Q1,Q0=H

EP := CLEAR ;INITIALIZE REGISTER
     + /Q3 + /Q2 + /Q1 ;HOLD IF Q3,Q2,Q1=H
```

TB0072M

## 4-Bit Counter With Terminal Count Lock

;FUNCTION TABLE FOR PALASM 1

;CLK /OC CLEAR /LOAD /EP D3 D2 D1 D0 Q3 Q2 Q1 Q0

| ;CONTROL |     | ---OPERATION--- |       |     |      | DDDD | QQQQ                   | COMMENTS<br>(HEX VALUES) |
|----------|-----|-----------------|-------|-----|------|------|------------------------|--------------------------|
| ;CLK     | /OC | CLEAR           | /LOAD | /EP | 3210 | 3210 |                        |                          |
| ; C      | L   | H               | H     | L   | XXXX | LLLL | CLEAR (0)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | LLLH | COUNT (1)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | LLHL | COUNT (2)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | LLHH | COUNT (3)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | LHLH | COUNT (4)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | LHLH | COUNT (5)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | LHHL | COUNT (6)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | LHHH | COUNT (7)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | HLLL | COUNT (8)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | HLLH | COUNT (9)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | HLHL | COUNT (A)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | HLHH | COUNT (B)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | HHLL | COUNT (C)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | HHLH | COUNT (D)              |                          |
| ; C      | L   | L               | H     | L   | XXXX | HHHL | COUNT (E)              |                          |
| ; C      | L   | L               | H     | H   | XXXX | HHHH | COUNT (F)              |                          |
| ; C      | L   | L               | H     | H   | XXXX | HHHH | HOLD AT TERMINAL COUNT |                          |
| ; C      | L   | L               | L     | X   | LLLL | LLLL | LOAD (0)               |                          |
| ; C      | L   | L               | L     | X   | LLLH | LLLH | LOAD (1)               |                          |
| ; C      | L   | L               | L     | X   | LLHL | LLHL | LOAD (3)               |                          |
| ; C      | L   | L               | L     | X   | LHLH | LHLH | LOAD (4)               |                          |
| ; C      | L   | L               | L     | X   | HLLL | HLLL | LOAD (8)               |                          |
| ; C      | L   | L               | L     | X   | HHLH | HHLH | LOAD (C)               |                          |
| ; C      | L   | L               | L     | X   | HHHL | HHHL | LOAD (E)               |                          |
| ; C      | L   | L               | L     | X   | HHHH | HHHH | LOAD (F)               |                          |
| ; X      | H   | X               | X     | Z   | XXXX | ZZZZ | TEST HI-Z              |                          |

;DESCRIPTION

;THE 4-BIT COUNTER LOADS DATA, INCREMENTS, OR HOLDS ON THE RISING EDGE OF THE CLOCK (CLK).

;THE COUNTER WILL HOLD WHEN THE TERMINAL COUNT IS REACHED UNTIL NEW DATA IS LOADED OR THE REGISTERS ARE CLEARED.

;THESE OPERATIONS ARE EXERCISED IN THE FUNCTION TABLE AND SUMMARIZED IN THE IN THE OPERATIONS TABLE:

|     | /OC | CLK | CLEAR | /LOAD | /EP | D3-D0    | Q3-Q0 | OPERATION |
|-----|-----|-----|-------|-------|-----|----------|-------|-----------|
| ; H | X   | X   | X     | X     | X   | X        | Z     | HI-Z      |
| ; L | C   | H   | X     | X     | L   | L        | L     | CLEAR     |
| ; L | C   | L   | L     | X     | A   | A        | A     | LOAD      |
| ; L | C   | L   | H     | H     | X   | Q        | Q     | HOLD      |
| ; L | C   | L   | H     | L     | X   | Q PLUS 1 |       | INCREMENT |

T800780M

## Memory Mapped I/O

Title MEMORY MAPPED I/O  
 Pattern P7083  
 Revision A  
 Author VINCENT COLI  
 Company MMI SUNNYVALE, CALIFORNIA  
 Date 04/19/82

CHIP MEMORY\_MAPPED\_I/O PAL18L4

A0 A1 A2 A3 A4 A5 A6 A7 A8 /RD /WR GND  
 A9 A10 A11 A12 /READ /WRITE /AUX2 /AUX1 A13 A14 A15 VCC

EQUATIONS

```

READ = /A15*/A14*/A13* A12* A11* A10* A9* A8 ;SELECT PORT1
      * /A7 * A6 * A5 * A4 */A3 * A2 * A1*/A0 ; (1F76)
      * RD ;READ STROBE

WRITE = /A15*/A14*/A13* A12* A11* A10* A9* A8 ;SELECT PORT1
       * /A7 * A6 * A5 * A4 */A3 * A2 * A1* A0 ; (1F77)
       * WR ;WRITE STROBE

AUX1 = /A15*/A14*/A13* A12* A11* A10* A9* A8 ;SELECT PORT0
      * /A7 * A6 * A5 * A4 * A3 */A2 */A1*/A0 ; (1F78)

AUX2 = /A15*/A14*/A13* A12* A11* A10* A9* A8 ;SELECT PORT1
      * /A7 * A6 * A5 * A4 * A3 */A2 */A1* A0 ; (1F79)
  
```

;FUNCTION TABLE FOR PALASM 1  
 ;A15 A14 A13 A12 A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1 A0 /RD /WR  
 ;/READ /WRITE /AUX1 /AUX2

;-ADDRESS INPUTS-

;111111

|  | STROBES | --PORT ENABLE OUTPUTS--- |       |       |  | COMMENT |
|--|---------|--------------------------|-------|-------|--|---------|
|  | /RD /WR | /READ /WRITE             | /AUX1 | /AUX2 |  |         |

|                 |   |   |   |   |   |                          |
|-----------------|---|---|---|---|---|--------------------------|
| -----           |   |   |   |   |   |                          |
| ;LLLHHHHLHHHLLL | L | L | H | H | H | TEST 0F78                |
| ;LLLHHHLLHHHLLL | L | L | H | H | H | TEST 1E78                |
| ;LLLHHHHHHHLLL  | L | L | H | H | H | TEST 1F78                |
| ;LLLHHHHLHHHLLL | L | L | H | H | H | TEST 1F70                |
| ;LLLHHHHLHHHLHL | H | L | H | H | H | TEST 1F76 (NO RD STROBE) |
| ;LLLHHHHLHHHLHL | L | L | L | H | H | TEST 1F76 (READ ENABLE)  |
| ;LLLHHHHLHHHLHH | L | H | H | H | H | TEST 1F77 (NO WR STROBE) |
| ;LLLHHHHLHHHLHH | L | L | H | L | H | TEST 1F77 (WRITE ENABLE) |
| ;LLLHHHHLHHHLLL | L | L | H | H | L | TEST 1F78 (AUX1 ENABLE)  |
| ;LLLHHHHLHHHLLH | L | L | H | H | L | TEST 1F79 (AUX2 ENABLE)  |
| ;LLLHHHHLHHHLHL | L | L | H | H | H | TEST 1F7A                |
| ;LLLHHHHLHHHLLH | L | L | H | H | H | TEST 1FF9                |
| ;LLLHHHLLHHHLLH | L | L | H | H | H | TEST 1E79                |
| ;LLHHHHLHHHLLH  | L | L | H | H | H | TEST 3F79                |
| ;LLLLLLLLLLLLLL | L | L | H | H | H | TEST ALL L'S             |
| ;HHHHHHHHHHHHH  | L | L | H | H | H | TEST ALL H'S             |
| ;LHLHLHLHLHLHL  | L | L | H | H | H | TEST ODD CHECKERBOARD    |
| ;HLHLHLHLHLHL   | L | L | H | H | H | TEST EVEN CHECKERBOARD   |
| -----           |   |   |   |   |   |                          |

TB00790M



## Memory Mapped I/O

---

;DESCRIPTION

;THIS PAL PROVIDES A SINGLE CHIP DECODER FOR USE IN MEMORY MAPPED I/O OPERATIONS  
;REQUIRING FOUR ACTIVE LOW PORT ENABLES AND FULL 16-BIT DECODE WITH TWO TWO  
;STROBE LINES (/RD AND /WR). EQUATION TERMS CAN BE CHANGED TO ACCOMMODATE ANY  
;16-BIT ADDRESS.

;THE PAL WILL MONITOR THE SYSTEM MEMORY ADDRESS BUS (A15-A0) AND DECODE THE  
;SPECIFIED MEMORY ADDRESS WORD (1F76,1F77,1F78,1F79) TO PRODUCE A PORT ENABLE  
;FOR READ, WRITE, A

TB00800M

## 74S508 Memory Map Interface #1

Title SN54/74S508 MEMORY MAP INTERFACE WITH THE INTEL 8085 (DESIGN # 1)  
 Pattern P7085  
 Revision A  
 Author VINCENT COLI  
 Company MMI SUNNYVALE, CALIFORNIA  
 Date 05/15/82

CHIP SN54/74S508\_MEMORY\_MAP\_INTERFACE\_WITH\_THE\_INTEL\_8085\_(DESIGN\_#1) PAL16R4

CLK AD0 AD1 AD2 AD3 AD4 AD5 AD6 AD7 GND  
 /OE /E1 ALE I2 I1 I0 /GO E2 E3 VCC

EQUATIONS

```
GO := /AD3*/AD4*/AD5* AD6*/AD7      ;MONITOR ADDRESS/DATA BUS (AD3-AD7)
    * E1 * E2* E3                    ;MONITOR ENABLES (FROM A8-A15)
    * ALE                             ;MONITOR ADDRESS/DATA CONTROL
```

```
/I0 := /AD0      ;REGISTER INSTRUCTION INPUT I0
```

```
/I1 := /AD1      ;REGISTER INSTRUCTION INPUT I1
```

```
/I2 := /AD2      ;REGISTER INSTRUCTION INPUT I2
```

;FUNCTION TABLE FOR PALASM 1

```
;/OE CLK AD0 AD1 AD2 AD3 AD4 AD5 AD6 AD7 /E1 E2 E3 ALE I0 I1 I2 /GO
```

|      |     | A/D BUS   | ADD BUS |    |    | INSTR |     | COMMENTS |                                 |
|------|-----|-----------|---------|----|----|-------|-----|----------|---------------------------------|
| ;/OE | CLK | 01234567  | /E1     | E2 | E3 | ALE   | 012 | /GO      | (OCTAL ADDRESS)                 |
| ; L  | C   | XXXLLLLH  | L       | H  | H  | H     | XXX | H        | (200 TO 207) INACTIVE           |
| ; L  | C   | XXXLLLLH  | H       | H  | H  | H     | XXX | H        | (100 TO 107) INACTIVE (/E1=H)   |
| ; L  | C   | XXXLLLHL  | L       | L  | L  | H     | XXX | H        | (100 TO 107) INACTIVE (E2,E3=L) |
| ; L  | C   | XXXLLLHL  | L       | H  | H  | L     | XXX | H        | (100 TO 107) INACTIVE (ALE=L)   |
| ; L  | C   | XXXLLLHL  | L       | H  | H  | H     | XXX | L        | (100 TO 107) (ACTIVE RANGE)     |
| ; L  | C   | LHHLLLHL  | L       | H  | H  | H     | LHH | L        | (106) LOAD X                    |
| ; L  | C   | LHHLLLHL  | L       | H  | H  | L     | LHH | H        | (106) NOP (ALE=L)               |
| ; L  | C   | LLLLLLLHL | L       | H  | H  | H     | LLL | L        | (100) LOAD Y                    |
| ; H  | X   | XXXXXXXX  | X       | X  | X  | X     | ZZZ | Z        | TEST HI-Z                       |

## 74S508 Memory Map Interface #1

---

### :DESCRIPTION

;THIS PAL PROVIDES THE DECODE LOGIC FOR INTERFACING THE MMI SN54/74S508, 8-BIT  
;SEQUENTIAL MULTIPLIER/DIVIDER, WITH THE INTEL 8085 MICROPROCESSOR. THE PAL16R4  
;MONITORS THE LOWER 8 BIT ADDRESS/DATA BUS (A0-A7), THE ADDRESS LATCH ENABLE  
;(ALE), AND THREE OF THE UPPER 8 BIT ADDRESS BUS (A8-A15) WHICH IS LABELED  
;/E1,E2,M THE 8085 IN ORDER TO  
;DECODE AN ACTIVE LOW CHIP-ACTIVATION SIGNAL (/GO) FOR THE 74S508. THE  
;INSTRUCTION LINES AND CHIP-ACTIVATION SIGNAL ARE REGISTERED IN ORDER TO INSURE  
;THAT INSTRUCTION INPUTS WILL NOT CHANGE WHEN THE CLOCK IS LOW (CLK=L). BY  
;MONITORING THE MACHINE STATUS CYCLE, THE 74S508 CAN BE ADDRESS MAPPED BY THE  
;8085 AS IF IT WERE AN I/O DEVICE, THUS NOT USING ANY MEMORY MAP ADDRESS SPACE.  
;THE MACHINE CYCLE STATUS FROM THE 8085 IS AVAILABLE ON THE FALLING EDGE OF ALE.

;FOR THIS PARTICULAR DESIGN, THE THREE INSTRUCTION INPUTS TO THE 74S508 (I0-I2)  
;ARE ASSIGNED TO THE THREE LSB BITS OF ADDRESS BUS (A8-A10), WHILE THE REMAINING  
;ADDRESS BITS (A11-A15) ARE DECODED BY THE PAL TO DETERMINE IF THE 74S508 IS  
;SELECTED. ALSO, ADDRESS 100 TO 107 IS RESERVED FOR THE 74S508. THE ADDRESS  
;SPACE CAN BE CHANGED BY SIMPLY EDITING THE LOGIC

18006404

## 74S508 Memory Map Interface #2

Title SN54/74S508 I/O DEVICE INTERFACE WITH THE INTEL 8085 (DESIGN # 2)  
 Pattern P7086  
 Revision A  
 Author VINCENT COLI  
 Company MMI SUNNYVALE, CALIFORNIA  
 Date 05/15/82

CHIP SN54/74S508\_I/O\_DEVICE\_INTERFACE\_WITH\_THE\_INTEL\_8085\_(DESIGN\_#\_2) PAL16R4

CLK A15 A14 A13 A12 A11 A10 A9 A8 GND  
 /OE IOM ALE I2 I1 I0 /GO S1 S0 VCC

EQUATIONS

GO := /A11\*/A12\*/A13\* A14\*/A15 ;MONITOR ADDRESS BUS (A11-A15)  
 \* IOM\*/S1 \* S0 ;MONITOR MACHINE CYCLE STATUS (I/O WRITE)  
 \* /ALE ;MONITOR ADDRESS/DATA CONTROL (FALLING EDGE)

/I0 := /A8 ;REGISTER INSTRUCTION INPUT I0

/I1 := /A9 ;REGISTER INSTRUCTION INPUT I1

/I2 := /A10 ;REGISTER INSTRUCTION INPUT I2

;FUNCTION TABLE FOR PALASM 1

;/OE CLK A8 A9 A10 A11 A12 A13 A14 A15 IOM S1 S0 ALE I0 I1 I2 /GO

| ; | ;/OE | CLK      | ADDR BUS  | MACH STATUS | INSTR   | COMMENTS                      |
|---|------|----------|-----------|-------------|---------|-------------------------------|
| ; | CLK  | 89012345 | IOM S1 S0 | ALE         | 012 /GO | (OCTAL ADDRESS)               |
| ; | L    | C        | XXXLLLLH  | H L H       | L XXX H | (200 TO 207) INACTIVE         |
| ; | L    | C        | XXXLLLLH  | H H L       | L XXX H | (100 TO 107) I/O REA          |
| ; | L    | C        | XXXLLLHL  | H H H       | L XXX H | (100 TO 107) INTERRUPT ACKNOW |
| ; | L    | C        | XXXLLLHL  | L H H       | H XXX H | (100 TO 107) INACTIVE (ALE=H) |
| ; | L    | C        | XXXLLLHL  | H L H       | L XXX L | (100 TO 107) (ACTIVE RANGE)   |
| ; | L    | C        | LHHLLLHL  | H L H       | L LHH L | (106) LOAD X                  |
| ; | L    | C        | LHHLLLHL  | H L H       | H LHH H | (106) NOP (ALE=H)             |
| ; | L    | C        | LLLLLLLHL | H L H       | L LLL L | (100) LOAD Y                  |
| ; | H    | X        | XXXXXXXX  | X X X       | X ZZZ Z | TEST HI-Z                     |

;DESCRIPTION

;THIS PAL PROVIDES THE DECODE LOGIC FOR INTERFACING THE MMI SN54/74S508, 8-BIT  
 ;SEQUENTIAL MULTIPLIER/DIVIDER, WITH THE INTEL 8085 MICROPROCESSOR. THE PAL16R4  
 ;MONITORS THE UPPER 8 BIT ADDRESS BUS (A8-A15), THE ADDRESS LATCH ENABLE (ALE),  
 ;AND THE THREE MACHINE CYCLE STATUS LINES (IOM,S1,S0) FRO

7B00850M

## 16 Input Registered Priority Encoder #1

Title 16 INPUT REGISTERED PRIORITY ENCODER (CHIP No. 1)  
Pattern P7090 COLI/VOLPIGNO 10/13/82  
Revision A  
Author COLI/VOLPIGNO  
Company MMI SUNNYVALE, CALIFORNIA  
Date 10/13/82

CHIP 16\_INPUT\_REGISTERED\_PRIORITY\_ENCODER\_(CHIP\_No.\_1) PAL20R4

CLK I0 I1 I2 I3 I4 I5 I6 I7 I8 I9 GND  
/OC I10 I11 I12 Q3 Q2 Q1 Q0 I13 I14 I15 VCC

### EQUATIONS

```
/Q0 := /I0* I1
      + /I0*/I1*/I2* I3
      + /I0*/I1*/I2*/I3*/I4* I5
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6* I7
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8* I9
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10* I11
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12* I13
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13*/I14* I15
```

```
/Q1 := /I0*/I1* I2
      + /I0*/I1*/I2* I3
      + /I0*/I1*/I2*/I3*/I4*/I5* I6
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6* I7
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9* I10
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10* I11
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13* I14
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13*/I14* I15
```

```
/Q2 := /I0*/I1*/I2*/I3* I4
      + /I0*/I1*/I2*/I3*/I4* I5
      + /I0*/I1*/I2*/I3*/I4*/I5* I6
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6* I7
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11* I12
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12* I13
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13* I14
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13*/I14* I15
```

```
/Q3 := /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7* I8
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8* I9
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9* I10
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10* I11
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11* I12
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12* I13
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13* I14
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13*/I14* I15
```

TS00600M

7

## 16 Input Registered Priority Encoder #1

```

;FUNCTION TABLE FOR PALASM 1
;CLK /OC I15 I14 I13 I12 I11 I10 I9 I8 I7 I6 I5 I4 I3 I2 I1 I0 Q3 Q2 Q1 Q0

; CHIP          SIXTEEN INPUTS      OUTPUTS
;CONTROL        111111              QQQQ
;CLK /OC        5432109876543210    3210      COMMENTS
;-----
; C  L  XXXXXXXXXXXXXXXX  HHHH      I0  INTERRUPT (HIGHEST PRIORITY INPUT)
; C  L  XXXXXXXXXXXXXXXX  HHHL      I1  INTERRUPT
; C  L  XXXXXXXXXXXXXXXX  HHLH      I2  INTERRUPT
; C  L  XXXXXXXXXXXXXXXX  HLLH      I3  INTERRUPT
; C  L  XXXXXXXXXXXXXXXX  HLHH      I4  INTERRUPT
; C  L  XXXXXXXXXXXXXXXX  HLHL      I5  INTERRUPT
; C  L  XXXXXXXXXXXXXXXX  HLLH      I6  INTERRUPT
; C  L  XXXXXXXXXXXXXXXX  HLLL      I7  INTERRUPT
; C  L  XXXXXXXXHLLLLLLLL  LHHH      I8  INTERRUPT
; C  L  XXXXXXXHLLLLLLLLL  LHHL      I9  INTERRUPT
; C  L  XXXXXHLLLLLLLLLLL  LHLH      I10 INTERRUPT
; C  L  XXXXHLLLLLLLLLLL  LHLL      I11 INTERRUPT
; C  L  XXXHLLLLLLLLLLLLL  LLHH      I12 INTERRUPT
; C  L  XXHLLLLLLLLLLLLLL  LLHL      I13 INTERRUPT
; C  L  XHLLLLLLLLLLLLLLL  LLLH      I14 INTERRUPT
; C  L  HLLLLLLLLLLLLLLLL  LLLL      I15 INTERRUPT (LOWEST PRIORITY INPUT)
; X  H  XXXXXXXXXXXXXXXX  ZZZZ      TEST HI-Z
;-----

```

**;DESCRIPTION**

;THE 16 INPUT REGISTERED PRIORITY ENCODER ACCEPTS SIXTEEN ACTIVE-LOW INPUTS (I0-I15) TO LOAD THE BINARY WEIGHTED CODE OF THE PRIORITY ORDER INTO THE OUTPUT REGISTER (Q3-Q0) ON THE RISING EDGE OF THE CLOCK (CLK). A PRIORITY IS ASSIGNED TO EACH INPUT SO THAT WHEN TWO INPUTS ARE SIMULTANEOUSLY ACTIVE, THE INPUT WITH THE HIGHEST PRIORITY IS LOADED INTO THE OUTPUT REGISTER. THEREFORE THE HIGHEST PRIORITY INPUT (I0=H) PRODUCES HHHH IN THE OUTPUT REGISTER AND THE LOWEST PRIORITY INPUT (I15=H) PRODUCES LLLL IN THE OUTPUT REGISTER.

**;OPERATIONS TABLE**

|  | /OC | CLK | I15-I0 | Q3-Q0 | OPERATION                             |
|--|-----|-----|--------|-------|---------------------------------------|
|  | H   | X   | X      | Z     | HI-Z                                  |
|  | L   | C   | I0 =H  | 15    | I0 INTERRUPT (HIGHEST PRIORITY INPUT) |
|  | L   | C   | I1 =H  | 14    | I1 INTERRUPT                          |
|  | L   | C   | I1 =H  | 13    | I2 INTERRUPT                          |
|  | L   | C   | I1 =H  | 12    | I3 INTERRUPT                          |
|  | L   | C   | I1 =H  | 11    | I4 INTERRUPT                          |
|  | L   | C   | I1 =H  | 10    | I5 INTERRUPT                          |
|  | L   | C   | I1 =H  | 9     | I6 INTERRUPT                          |
|  | L   | C   | I1 =H  | 8     | I7 INTERRUPT                          |
|  | L   | C   | I1 =H  | 7     | I8 INTERRUPT                          |
|  | L   | C   | I1 =H  | 6     | I9 INTERRUPT                          |
|  | L   | C   | I1 =H  | 5     | I10 INTERRUPT                         |
|  | L   | C   | I1 =H  | 4     | I11 INTERRUPT                         |
|  | L   | C   | I1 =H  | 3     | I12 INTERRUPT                         |
|  | L   | C   | I1 =H  | 2     | I13 INTERRUPT                         |
|  | L   | C   | I1 =H  | 1     | I14 INTERRUPT                         |
|  | L   | C   | I1 =H  | 0     | I15 INTERRUPT (LOWEST PRIORITY INPUT) |

T800870M

## 16 Input Priority Encoder Interrupt Flag #2

Title 16 INPUT PRIORITY ENCODER INTERRUPT FLAG (CHIP No. 2)  
 Pattern P7091  
 Revision A  
 Author VINCENT COLI  
 Company MMI SUNNYVALE, CALIFORNIA  
 Date 11/13/82

CHIP 16\_INPUT\_PRIORITY\_ENCODER\_INTERRUPT\_FLAG\_(CHIP\_No.\_2) PAL16C1

I0 I1 I2 I3 I4 I5 I6 I7 I8 GND  
 I9 I10 I11 I12 POS\_INT NEG\_INT I13 I14 I15 VCC

EQUATIONS

NEG\_INT = /I0\*/I1\*/I2\*/I3\*/I4\*/I5\*/I6\*/I7\*/I8\*/I9\*/I10\*/I11\*/I12\*/I13\*/I14\*/I15

;FUNCTION TABLE FOR PALASM 1

;I15 I14 I13 I12 I11 I10 I9 I8 I7 I6 I5 I4 I3 I2 I1 I0 NEG\_INT POS\_INT

| SIXTEEN INPUTS                | INTERRUPT FLAG |     | COMMENTS                              |
|-------------------------------|----------------|-----|---------------------------------------|
| ;111111                       | NEG            | POS |                                       |
| ;5432109876543210             |                |     |                                       |
| -----                         |                |     |                                       |
| ;XXXXXXXXXXXXXXXXX            | L              | H   | I0 INTERRUPT (HIGHEST PRIORITY INPUT) |
| ;XXXXXXXXXXXXXXXXHL           | L              | H   | I1 INTERRUPT                          |
| ;XXXXXXXXXXXXXXXXHLL          | L              | H   | I2 INTERRUPT                          |
| ;XXXXXXXXXXXXXXXXHLLL         | L              | H   | I3 INTERRUPT                          |
| ;XXXXXXXXXXXXXXXXHLLLL        | L              | H   | I4 INTERRUPT                          |
| ;XXXXXXXXXXXXXXXXHLLLLL       | L              | H   | I5 INTERRUPT                          |
| ;XXXXXXXXXXXXXXXXHLLLLLL      | L              | H   | I6 INTERRUPT                          |
| ;XXXXXXXXXXXXXXXXHLLLLLLL     | L              | H   | I7 INTERRUPT                          |
| ;XXXXXXXXXXXXXXXXHLLLLLLLL    | L              | H   | I8 INTERRUPT                          |
| ;XXXXXXXXXXXXXXXXHLLLLLLLLL   | L              | H   | I9 INTERRUPT                          |
| ;XXXXXXXXXXXXXXXXHLLLLLLLLLL  | L              | H   | I10 INTERRUPT                         |
| ;XXXXXXXXXXXXXXXXHLLLLLLLLLLL | L              | H   | I11 INTERRUPT                         |
| ;XXXXXXXXXXXXXXXXHLLLLLLLLLLL | L              | H   | I12 INTERRUPT                         |
| ;XXXXXXXXXXXXXXXXHLLLLLLLLLLL | L              | H   | I13 INTERRUPT                         |
| ;XXXXXXXXXXXXXXXXHLLLLLLLLLLL | L              | H   | I14 INTERRUPT                         |
| ;XXXXXXXXXXXXXXXXHLLLLLLLLLLL | L              | H   | I15 INTERRUPT (LOWEST PRIORITY INPUT) |
| ;LLLLLLLLLLLLLLLLLLL          | H              | L   | NO INTERRUPT INPUT                    |
| -----                         |                |     |                                       |

;DESCRIPTION  
 ;THE 16 INPUT PRIORITY ENCODER INTERRUPT FLAG ACCEPTS SIXTEEN ACTIVE-LOW INPUTS  
 ;(I0-I15) IN ORDER TO GENERATE AN ACTIVE LOW (NEG\_INT) AND ACTIVE HIGH (POS\_INT)  
 ;INTERRUPT FLAG.

;UP TO FOUR INTERRUPT ENABLE PINS OF ANY POLARITY CAN BE ADDED IF A PAL20C1 IS  
 ;SUBSTITUTED.

T80080M



## 15 Input Registered Priority Encoder

Title 15 INPUT REGISTERED PRIORITY ENCODER  
Pattern P7092 COLI/VOLPIGNO 10/13/82  
Revision A  
Author COLI/VOLPIGNO  
Company MMI SUNNYVALE, CALIFORNIA  
Date 10/13/82

CHIP 15\_INPUT\_REGISTERED\_PRIORITY\_ENCODER PAL20R4

CLK I0 I1 I2 I3 I4 I5 I6 I7 I8 I9 GND  
/OC I10 I11 FLAG Q3 Q2 Q1 Q0 I12 I13 I14 VCC

EQUATIONS

```
/Q0 := /I0* I1
      + /I0*/I1*/I2* I3
      + /I0*/I1*/I2*/I3*/I4* I5
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6* I7
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8* I9
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10* I11
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12* I13
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13*/I14
```

```
/Q1 := /I0*/I1* I2
      + /I0*/I1*/I2* I3
      + /I0*/I1*/I2*/I3*/I4*/I5* I6
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6* I7
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9* I10
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10* I11
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13* I14
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13*/I14
```

```
/Q2 := /I0*/I1*/I2*/I3* I4
      + /I0*/I1*/I2*/I3*/I4* I5
      + /I0*/I1*/I2*/I3*/I4*/I5* I6
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6* I7
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11* I12
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12* I13
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13* I14
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13*/I14
```

```
/Q3 := /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7* I8
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8* I9
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9* I10
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10* I11
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11* I12
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12* I13
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13* I14
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13*/I14
```

```
/FLAG = /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7*/I8*/I9*/I10*/I11*/I12*/I13*/I14
```

180080M



## 15 Input Registered Priority Encoder

```

;FUNCTION TABLE FOR PALASM 1
;CLK /OC I14 I13 I12 I11 I10 I9 I8 I7 I6 I5 I4 I3 I2 I1 I0 Q3 Q2 Q1 Q0 FLAG
; CHIP      FIFTEEN  INPUTS  --OUTPUTS--
;CONTROL    11111      QQQQ
;CLK /OC    432109876543210  3210  FLAG  COMMENTS
;-----
; C  L  XXXXXXXXXXXXXXXX  HHHH  H  I0  INTERRUPT (HIGHEST PRIORITY INPUT)
; C  L  XXXXXXXXXXXXXXXH  HHHL  H  I1  INTERRUPT
; C  L  XXXXXXXXXXXXXXXL  HHLH  H  I2  INTERRUPT
; C  L  XXXXXXXXXXXXXHLL  HLLL  H  I3  INTERRUPT
; C  L  XXXXXXXXXXXXHLLL  HLHH  H  I4  INTERRUPT
; C  L  XXXXXXXXXXXHLLLL  HLHL  H  I5  INTERRUPT;
; C  L  XXXXXXXXHLLLLLL  HLLH  H  I6  INTERRUPT
; C  L  XXXXXXXXHLLLLLL  HLLL  H  I7  INTERRUPT
; C  L  XXXXXHLLLLLLLLL  LHHL  H  I8  INTERRUPT
; C  L  XXXXHLLLLLLLLLL  LHLL  H  I9  INTERRUPT
; C  L  XXHLLLLLLLLLLLLL  LLHH  H  I10 INTERRUPT
; C  L  XHLLLLLLLLLLLLLL  LLHL  H  I11 INTERRUPT
; C  L  HLLLLLLLLLLLLLLL  LLLH  H  I12 INTERRUPT
; C  L  LLLLLLLLLLLLLLLL  LLLL  L  NO  INTERRUPT (LOWEST PRIORITY INPUT)
; X  H  XXXXXXXXXXXXXXXX  ZZZZ  X  TEST HI-Z
;-----

```

**;DESCRIPTION**

THE 15 INPUT REGISTERED PRIORITY ENCODER ACCEPTS FIFTEEN ACTIVE-LOW INPUTS (I0-I14) TO LOAD THE BINARY WEIGHTED CODE OF THE PRIORITY ORDER INTO THE OUTPUT REGISTER (Q3-Q0) ON THE RISING EDGE OF THE CLOCK (CLK). A PRIORITY IS ASSIGNED TO EACH INPUT SO THAT WHEN TWO INPUTS ARE SIMULTANEOUSLY ACTIVE, THE INPUT WITH THE HIGHEST PRIORITY IS LOADED INTO THE OUTPUT REGISTER. THEREFORE THE HIGHEST PRIORITY INPUT (I0=H) PRODUCES HHHH IN THE OUTPUT REGISTER AND THE LOWEST PRIORITY INPUT (I14=H) PRODUCES LLLH IN THE OUTPUT REGISTER. THE NON-REGISTERED INTERRUPT FLAG (FLAG) GOES HIGH WHEN AN INTERRUPT IS PRESENT AND REMAINS LOW WHEN THERE IS NO INTERRUPT PRESENT.

**;OPERATIONS TABLE**

|  | /OC | CLK | I14-I0 | Q3-Q0 | FLAG | OPERATION                             |
|--|-----|-----|--------|-------|------|---------------------------------------|
|  | H   | X   | X      | Z     | X    | HI-Z                                  |
|  | L   | C   | L      | 0     | L    | NO INTERRUPT                          |
|  | L   | C   | I0 =H  | 15    | H    | I0 INTERRUPT (HIGHEST PRIORITY INPUT) |
|  | L   | C   | I1 =H  | 14    | H    | I1 INTERRUPT                          |
|  | L   | C   | I2 =H  | 13    | H    | I2 INTERRUPT                          |
|  | L   | C   | I3 =H  | 12    | H    | I3 INTERRUPT                          |
|  | L   | C   | I4 =H  | 11    | H    | I4 INTERRUPT                          |
|  | L   | C   | I5 =H  | 10    | H    | I5 INTERRUPT                          |
|  | L   | C   | I6 =H  | 9     | H    | I6 INTERRUPT                          |
|  | L   | C   | I7 =H  | 8     | H    | I7 INTERRUPT                          |
|  | L   | C   | I8 =H  | 7     | H    | I8 INTERRUPT                          |
|  | L   | C   | I9 =H  | 6     | H    | I9 INTERRUPT                          |
|  | L   | C   | I10=H  | 5     | H    | I10 INTERRUPT                         |
|  | L   | C   | I11=H  | 4     | H    | I11 INTERRUPT                         |
|  | L   | C   | I12=H  | 3     | H    | I12 INTERRUPT                         |
|  | L   | C   | I13=H  | 2     | H    | I13 INTERRUPT                         |
|  | L   | C   | I14=H  | 1     | H    | I14 INTERRUPT (LOWEST PRIORITY INPUT) |

180900M



## 8 Input Registered Priority Encoder

Title 8 INPUT REGISTERED PRIORITY ENCODER WITH INTERRUPT FLAG  
Pattern P7093  
Revision A  
Author VINCENT COLI  
Company MMI SUNNYVALE, CALIFORNIA  
Date 06/21/82

CHIP 8\_INPUT\_REGISTERED\_PRIORITY\_ENCODER\_WITH\_INTERRUPT\_FLAG PAL16R4

CLK I0 I1 I2 I3 I4 I5 I6 I7 GND  
/OC /E4 /E3 Q3 Q2 Q1 Q0 E2 E1 VCC

### EQUATIONS

```
/Q0 := /I0* I1 ;DECODE I0=L AND I1=H
      + /I0*/I1*/I2* I3 ;DECODE I0-2=L AND I3=H
      + /I0*/I1*/I2*/I3*/I4* I5 ;DECODE I0-4=L AND I5=H
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6* I7 ;DECODE I0-6=L AND I7=H

/Q1 := /I0*/I1* I2 ;DECODE I0-1=L AND I2=H
      + /I0*/I1*/I2* I3 ;DECODE I0-2=L AND I3=H
      + /I0*/I1*/I2*/I3*/I4*/I5* I6 ;DECODE I0-5=L AND I6=H
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6* I7 ;DECODE I0-6=L AND I7=H

/Q2 := /I0*/I1*/I2*/I3* I4 ;DECODE I0-3=L AND I4=H
      + /I0*/I1*/I2*/I3*/I4* I5 ;DECODE I0-4=L AND I5=H
      + /I0*/I1*/I2*/I3*/I4*/I5* I6 ;DECODE I0-5=L AND I6=H
      + /I0*/I1*/I2*/I3*/I4*/I5*/I6* I7 ;DECODE I0-6=L AND I7=H

/Q3 := E1* E2* E3* E4* I0 ;INTERRUPT FLAG (I0)
      + E1* E2* E3* E4* I1 ;INTERRUPT FLAG (I1)
      + E1* E2* E3* E4* I2 ;INTERRUPT FLAG (I2)
      + E1* E2* E3* E4* I3 ;INTERRUPT FLAG (I3)
      + E1* E2* E3* E4* I4 ;INTERRUPT FLAG (I4)
      + E1* E2* E3* E4* I5 ;INTERRUPT FLAG (I5)
      + E1* E2* E3* E4* I6 ;INTERRUPT FLAG (I6)
      + E1* E2* E3* E4* I7 ;INTERRUPT FLAG (I7)
```

1800910M

## 8 Input Registered Priority Encoder

;FUNCTION TABLE FOR PALASM 1

;CLK /OC E1 E2 /E3 /E4 I7 I6 I5 I4 I3 I2 I1 I0 Q3 Q2 Q1 Q0

| ; CHIP    |   | ----FOUR----  |    |     |     | 8 INPUTS  | OUTPUTS |          |              |          |           |         |  |  |  |
|-----------|---|---------------|----|-----|-----|-----------|---------|----------|--------------|----------|-----------|---------|--|--|--|
| ; CONTROL |   | INPUT ENABLES |    |     |     | IIIIIIII  | Q QQQ   |          |              |          |           |         |  |  |  |
| ; CLK /OC |   | E1            | E2 | /E3 | /E4 | 76543210  | 3 210   | COMMENTS |              |          |           |         |  |  |  |
| -----     |   |               |    |     |     |           |         |          |              |          |           |         |  |  |  |
| ; C       | L | L             | H  | L   | L   | XXXXXXXXH | H HHH   | I0       | INTERRUPT    | NOT      | ENABLED   | (E1=L)  |  |  |  |
| ; C       | L | H             | L  | L   | L   | XXXXXXXXH | H HHH   | I0       | INTERRUPT    | NOT      | ENABLED   | (E2=L)  |  |  |  |
| ; C       | L | H             | H  | H   | L   | XXXXXXXXH | H HHH   | I0       | INTERRUPT    | NOT      | ENABLED   | (/E3=H) |  |  |  |
| ; C       | L | H             | H  | L   | H   | XXXXXXXXH | H HHH   | I0       | INTERRUPT    | NOT      | ENABLED   | (/E4=H) |  |  |  |
| ; C       | L | H             | H  | L   | L   | XXXXXXXXH | L HHH   | I0       | INTERRUPT    | (HIGHEST | PRIORITY) |         |  |  |  |
| ; C       | L | L             | H  | L   | L   | XXXXXXHL  | H HHL   | I1       | INTERRUPT    | NOT      | ENABLED   | (E1=L)  |  |  |  |
| ; C       | L | H             | L  | L   | L   | XXXXXXHL  | H HHL   | I1       | INTERRUPT    | NOT      | ENABLED   | (E2=L)  |  |  |  |
| ; C       | L | H             | H  | H   | L   | XXXXXXHL  | H HHL   | I1       | INTERRUPT    | NOT      | ENABLED   | (/E3=H) |  |  |  |
| ; C       | L | H             | H  | L   | H   | XXXXXXHL  | H HHL   | I1       | INTERRUPT    | NOT      | ENABLED   | (/E4=H) |  |  |  |
| ; C       | L | H             | H  | L   | L   | XXXXXXHL  | L HHL   | I1       | INTERRUPT    |          |           |         |  |  |  |
| ; C       | L | L             | H  | L   | L   | XXXXXXHL  | H HLH   | I2       | INTERRUPT    | NOT      | ENABLED   | (E1=L)  |  |  |  |
| ; C       | L | H             | L  | L   | L   | XXXXXXHL  | H HLH   | I2       | INTERRUPT    | NOT      | ENABLED   | (E2=L)  |  |  |  |
| ; C       | L | H             | H  | H   | L   | XXXXXXHL  | H HLH   | I2       | INTERRUPT    | NOT      | ENABLED   | (/E3=H) |  |  |  |
| ; C       | L | H             | H  | L   | H   | XXXXXXHL  | H HLH   | I2       | INTERRUPT    | NOT      | ENABLED   | (/E4=H) |  |  |  |
| ; C       | L | H             | H  | L   | L   | XXXXXXHL  | L HLH   | I2       | INTERRUPT    |          |           |         |  |  |  |
| ; C       | L | L             | H  | L   | L   | XXXXHLLL  | H HLL   | I3       | INTERRUPT    | NOT      | ENABLED   | (E1=L)  |  |  |  |
| ; C       | L | H             | L  | L   | L   | XXXXHLLL  | H HLL   | I3       | INTERRUPT    | NOT      | ENABLED   | (E2=L)  |  |  |  |
| ; C       | L | H             | H  | H   | L   | XXXXHLLL  | H HLL   | I3       | INTERRUPT    | NOT      | ENABLED   | (/E3=H) |  |  |  |
| ; C       | L | H             | H  | L   | H   | XXXXHLLL  | H HLL   | I3       | INTERRUPT    | NOT      | ENABLED   | (/E4=H) |  |  |  |
| ; C       | L | H             | H  | L   | L   | XXXXHLLL  | L HLL   | I3       | INTERRUPT    |          |           |         |  |  |  |
| ; C       | L | L             | H  | L   | L   | XXXHLLLL  | H LHH   | I4       | INTERRUPT    | NOT      | ENABLED   | (E1=L)  |  |  |  |
| ; C       | L | H             | L  | L   | L   | XXXHLLLL  | H LHH   | I4       | INTERRUPT    | NOT      | ENABLED   | (E2=L)  |  |  |  |
| ; C       | L | H             | H  | H   | L   | XXXHLLLL  | H LHH   | I4       | INTERRUPT    | NOT      | ENABLED   | (/E3=H) |  |  |  |
| ; C       | L | H             | H  | L   | H   | XXXHLLLL  | H LHH   | I4       | INTERRUPT    | NOT      | ENABLED   | (/E4=H) |  |  |  |
| ; C       | L | H             | H  | L   | L   | XXXHLLLL  | L LHH   | I4       | INTERRUPT    |          |           |         |  |  |  |
| ; C       | L | L             | H  | L   | L   | XXHLLLLL  | H LHL   | I5       | INTERRUPT    | NOT      | ENABLED   | (E1=L)  |  |  |  |
| ; C       | L | H             | L  | L   | L   | XXHLLLLL  | H LHL   | I5       | INTERRUPT    | NOT      | ENABLED   | (E2=L)  |  |  |  |
| ; C       | L | H             | H  | H   | L   | XXHLLLLL  | H LHL   | I5       | INTERRUPT    | NOT      | ENABLED   | (/E3=H) |  |  |  |
| ; C       | L | H             | H  | L   | H   | XXHLLLLL  | H LHL   | I5       | INTERRUPT    | NOT      | ENABLED   | (/E4=H) |  |  |  |
| ; C       | L | H             | H  | L   | L   | XXHLLLLL  | L LHL   | I5       | INTERRUPT    |          |           |         |  |  |  |
| ; C       | L | L             | H  | L   | L   | XHLLLLLL  | H LLH   | I6       | INTERRUPT    | NOT      | ENABLED   | (E1=L)  |  |  |  |
| ; C       | L | H             | L  | L   | L   | XHLLLLLL  | H LLH   | I6       | INTERRUPT    | NOT      | ENABLED   | (E2=L)  |  |  |  |
| ; C       | L | H             | H  | H   | L   | XHLLLLLL  | H LLH   | I6       | INTERRUPT    | NOT      | ENABLED   | (/E3=H) |  |  |  |
| ; C       | L | H             | H  | L   | H   | XHLLLLLL  | H LLH   | I6       | INTERRUPT    | NOT      | ENABLED   | (/E4=H) |  |  |  |
| ; C       | L | H             | H  | L   | L   | XHLLLLLL  | L LLH   | I6       | INTERRUPT    |          |           |         |  |  |  |
| ; C       | L | L             | H  | L   | L   | HLLLLLLL  | H LLL   | I7       | INTERRUPT    | NOT      | ENABLED   | (E1=L)  |  |  |  |
| ; C       | L | H             | L  | L   | L   | HLLLLLLL  | H LLL   | I7       | INTERRUPT    | NOT      | ENABLED   | (E2=L)  |  |  |  |
| ; C       | L | H             | H  | H   | L   | HLLLLLLL  | H LLL   | I7       | INTERRUPT    | NOT      | ENABLED   | (/E3=H) |  |  |  |
| ; C       | L | H             | H  | L   | H   | HLLLLLLL  | H LLL   | I7       | INTERRUPT    | NOT      | ENABLED   | (/E4=H) |  |  |  |
| ; C       | L | H             | H  | L   | L   | HLLLLLLL  | L LLL   | I7       | INTERRUPT    | (LOWEST  | PRIORITY) |         |  |  |  |
| ; C       | L | H             | H  | L   | L   | LLLLLLLL  | H HHH   |          | NO INTERRUPT | INPUT    | (Q3=H)    |         |  |  |  |
| ; X       | H | X             | X  | X   | X   | XXXXXXXX  | Z ZZZ   |          | TEST         | HI-Z     |           |         |  |  |  |
| -----     |   |               |    |     |     |           |         |          |              |          |           |         |  |  |  |

1800920M

## 8 Input Registered Priority Encoder

**;DESCRIPTION**

;THE 8 INPUT REGISTERED PRIORITY ENCODER ACCEPTS SIXTEEN ACTIVE-LOW INPUTS (I0-I7) TO LOAD THE BINARY WEIGHTED CODE OF THE PRIORITY ORDER INTO THE OUTPUT REGISTER (Q2-Q0) ON THE RISING EDGE OF THE CLOCK (CLK) PROVIDING THE FOUR ENABLE INPUTS ARE TRUE (E1=H,E2=H,/E3=L,/E4=L). A PRIORITY IS ASSIGNED TO EACH INPUT SO THAT WHEN TWO INPUTS ARE SIMULTANEOUSLY ACTIVE, THE INPUT WITH THE HIGHEST PRIORITY IS LOADED INTO THE OUTPUT REGISTER. THEREFORE THE HIGHEST PRIORITY INPUT (I0=H) PRODUCES HHH IN THE OUTPUT REGISTER AND THE LOWEST PRIORITY INPUT (I7=H) PRODUCES LLL IN THE OUTPUT REGISTER.

;THE PRIORITY INTERRUPT ENCODER REGISTERS (Q3-Q0) ARE UPDATED ON THE RISING EDGE OF THE CLOCK (CLK) PROVIDING THE FOUR ENABLE INPUTS ARE TRUE (E1=H,E2=H,/E3=L,/E4=L). THE PREVIOUS DATA IS HELD IN THE PRIORITY ENCODER REGISTERS IF ANY OF THE ENABLE INPUTS ARE FALSE (E1=L,E2=L,/E3=H,/E4=H) REGARDLESS OF CLOCK TRANSITIONS. NOTE THAT THE POLARITY OF THE ENABLES CAN BE CHANGED BY MERELY EDITING THE LOGIC EQUATIONS.

;OUTPUT Q4 SERVES AS THE INTERRUPT FLAG AND IS TRUE (Q4=L) WHEN ANY OF THE 8 INPUTS ARE ACTIVE (I=H) ON THE RISING EDGE OF THE CLOCK (CLK) PROVIDING THE FOUR ENABLE INPUTS ARE TRUE (E1=H,E2=H,/E3=L,/E4=L). THE INTERRUPT FLAG IS FALSE (Q4=H) WHEN ALL INPUTS ARE INACTIVE (I=L) OR WHEN ANY ONE OF THE FOUR ENABLE INPUTS ARE FALSE (E1=L,E2=L,/E3=H,/E4=H).

**;OPERATIONS TABLE**

| ;/OC | CLK | E1 | E2 | /E3 | /E4 | I7-I0 | Q4 | Q3-Q0 | OPERATION                       |
|------|-----|----|----|-----|-----|-------|----|-------|---------------------------------|
| ; H  | X   | X  | X  | X   | X   | X     | Z  | Z     | HI-Z                            |
| ; L  | C   | L  | X  | X   | X   | X     | H  | Q     | NOT ENABLED (E1=L)              |
| ; L  | C   | X  | L  | X   | X   | X     | H  | Q     | NOT ENABLED (E2=L)              |
| ; L  | C   | X  | X  | H   | X   | X     | H  | Q     | NOT ENABLED (/E3=H)             |
| ; L  | C   | X  | X  | X   | H   | X     | H  | Q     | NOT ENABLED (/E4=H)             |
| ; L  | C   | H  | H  | L   | L   | L     | H  | X     | NO INTERRUPT FLAG               |
| ; L  | C   | H  | H  | L   | L   | I0=H  | L  | 7     | I0 INTERRUPT (HIGHEST PRIORITY) |
| ; L  | C   | H  | H  | L   | L   | I1=H  | L  | 6     | I1 INTERRUPT                    |
| ; L  | C   | H  | H  | L   | L   | I1=H  | L  | 5     | I2 INTERRUPT                    |
| ; L  | C   | H  | H  | L   | L   | I1=H  | L  | 4     | I3 INTERRUPT                    |
| ; L  | C   | H  | H  | L   | L   | I1=H  | L  | 3     | I4 INTERRUPT                    |
| ; L  | C   | H  | H  | L   | L   | I1=H  | L  | 2     | I5 INTERRUPT                    |
| ; L  | C   | H  | H  | L   | L   | I1=H  | L  | 1     | I6 INTERRUPT                    |
| ; L  | C   | H  | H  | L   | L   | I1=H  | L  | 0     | I7 INTERRUPT (LOWEST PRIORITY)  |

1800930M

## Dual Stepper Motor Controller

Title DUAL STEPPER MOTOR CONTROLLER  
 Pattern P7094  
 Revision A  
 Author COLI/SACKETTE  
 Company MMI SUNNYVALE, CALIFORNIA  
 Date 12/07/82

CHIP DUAL\_STEPPER\_MOTOR\_CONTROLLER PAL16R8

CLK /ENA SETA ROTA MODEA /ENB SETB ROTB MODEB GND  
 /OC /SW1B /SW2B /SW3B /SW4B /SW4A /SW3A /SW2A /SW1A VCC

### EQUATIONS

```

SW1A := SW1A                */ENA                ;HOLD SW1A (DISABLE)
+      /SW2A                */SW4A* ENA* ROTA* MODEA ;HALF-STEP MOTOR CW
+      SW3A                 * ENA* ROTA*/MODEA      ;FULL-STEP MOTOR CW
+      /SW2A*/SW3A         * ENA*/ROTA* MODEA      ;HALF-STEP MOTOR CCW
+      SW4A* ENA*/ROTA*/MODEA ;FULL-STEP MOTOR CCW
+      ENA                  * SETA                 ;SET A TO STEP 1

SW2A := SW2A                */ENA                ;HOLD SW2A (DISABLE)
+ /SW1A                    */SW3A                * ENA* ROTA* MODEA*/SETA ;HALF-STEP MOTOR CW
+      SW4A* ENA* ROTA*/MODEA*/SETA ;FULL-STEP MOTOR CW
+ /SW1A                    */SW4A* ENA*/ROTA* MODEA*/SETA ;HALF-STEP MOTOR CCW
+      SW3A                 * ENA*/ROTA*/MODEA*/SETA ;FULL-STEP MOTOR CCW

SW3A := SW3A                */ENA                ;HOLD SW3A (DISABLE)
+ /SW1A                    */SW4A* ENA* ROTA* MODEA ;HALF-STEP MOTOR CW
+      SW2A                 * ENA* ROTA*/MODEA      ;HALF-STEP MOTOR CW
+ /SW2A                    */SW4A* ENA*/ROTA* MODEA ;HALF-STEP MOTOR CCW
+      SW1A                 * ENA*/ROTA*/MODEA      ;FULL-STEP MOTOR CCW
+      ENA                  * SETA                 ;SET A TO STEP 1

SW4A := SW4A                */ENA                ;HOLD SW4A (DISABLE)
+ /SW2A*/SW3A             * ENA* ROTA* MODEA*/SETA ;HALF-STEP MOTOR CW
+      SW1A                 * ENA* ROTA*/MODEA*/SETA ;FULL-STEP MOTOR CW
+ /SW1A                    */SW3A                * ENA*/ROTA* MODEA*/SETA ;HALF-STEP MOTOR CCW
+      SW2A                 * ENA*/ROTA*/MODEA*/SETA ;FULL-STEP MOTOR CCW

SW1B := SW1B                */ENB                ;HOLD SW1B (DISABLE)
+      /SW2B                */SW4B* ENB* ROTB* MODEB ;HALF-STEP MOTOR CW
+      SW3B                 * ENB* ROTB*/MODEB      ;FULL-STEP MOTOR CW
+      /SW2B*/SW3B         * ENB*/ROTB* MODEB      ;HALF-STEP MOTOR CCW
+      SW4B* ENB*/ROTB*/MODEB ;FULL-STEP MOTOR CCW
+      ENB                  * SETB                 ;SET B TO STEP 1

SW2B := SW2B                */ENB                ;HOLD SW2B (DISABLE)
+ /SW1B                    */SW3B                * ENB* ROTB* MODEB*/SETB ;HALF-STEP MOTOR CW
+      SW4B* ENB* ROTB*/MODEB*/SETB ;FULL-STEP MOTOR CW
+ /SW1B                    */SW4B* ENB*/ROTB* MODEB*/SETB ;HALF-STEP MOTOR CCW
+      SW3B                 * ENB*/ROTB*/MODEB*/SETB ;FULL-STEP MOTOR CCW

SW3B := SW3B                */ENB                ;HOLD SW3B (DISABLE)
+ /SW1B                    */SW4B* ENB* ROTB* MODEB ;HALF-STEP MOTOR CW
+      SW2B                 * ENB* ROTB*/MODEB      ;FULL-STEP MOTOR CW
+ /SW2B                    */SW4B* ENB*/ROTB* MODEB ;HALF-STEP MOTOR CCW
+      SW1B                 * ENB*/ROTB*/MODEB      ;FULL-STEP MOTOR CCW
+      ENB                  * SETB                 ;SET B TO STEP 1
  
```

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## Dual Stepper Motor Controller

```

SW4B :=                               SW4B*/ENB                               ;HOLD SW4B (DISABLE)
+      /SW2B*/SW3B                     * ENB* ROTB* MODEB*/SETB         ;HALF-STEP MOTOR CW
+      SW1B                             * ENB* ROTB*/MODEB*/SETB        ;FULL-STEP MOTOR CW
+      /SW1B                             * ENB*/ROTB* MODEB*/SETB       ;HALF-STEP MOTOR CCW
+      SW2B                             * ENB*/ROTB*/MODEB*/SETB       ;FULL-STEP MOTOR CCW
    
```

;FUNCTION TABLE FOR PALASM 1

```

;CLK /OC /ENA SETA ROTA MODEA SW1A SW2A SW3A SW4A /ENB SETB ROTB MODEB SW1B
;SW2B SW3B SW4B
    
```

| ; CHIP CONTROL |     | STEPPER MOTOR A |     |      |      | SSSS | STEPPER MOTOR B |     |      |      | SSSS | COMMENTS              |
|----------------|-----|-----------------|-----|------|------|------|-----------------|-----|------|------|------|-----------------------|
| ;CLK /OC       | /EN | SET             | ROT | MODE | 1234 | /EN  | SET             | ROT | MODE | 1234 |      |                       |
| ; C            | L   | L               | H   | X    | X    | HLHL | L               | H   | X    | X    | HLHL | SET A AND B TO STEP 1 |
| ; C            | L   | L               | L   | H    | H    | HLLL | L               | L   | L    | H    | LLHL | FULL STEP A CW, B CCW |
| ; C            | L   | L               | L   | H    | H    | HLLH | L               | L   | L    | H    | LHHL | FULL STEP A CW, B CCW |
| ; C            | L   | H               | L   | H    | H    | HLLH | H               | L   | L    | H    | LHHL | HOLD MOTOR POSITION   |
| ; C            | L   | L               | L   | H    | H    | LLHL | L               | L   | L    | H    | LHLL | FULL STEP A CW, B CCW |
| ; C            | L   | L               | L   | H    | H    | LHLH | L               | L   | L    | H    | LHLH | FULL STEP A CW, B CCW |
| ; C            | L   | L               | L   | H    | H    | LHLL | L               | L   | L    | H    | LLLH | FULL STEP A CW, B CCW |
| ; C            | L   | L               | L   | H    | H    | LHHL | L               | L   | L    | H    | HLHL | FULL STEP A CW, B CCW |
| ; C            | L   | L               | L   | H    | H    | LLHL | L               | L   | L    | H    | HLLL | FULL STEP A CW, B CCW |
| ; C            | L   | L               | L   | H    | H    | HLHL | L               | L   | L    | H    | HLHL | FULL STEP A CW, B CCW |
| ; C            | L   | H               | L   | L    | L    | HLHL | H               | L   | H    | L    | HLHL | HOLD MOTOR POSITION   |
| ; C            | L   | L               | L   | L    | L    | LHHL | L               | L   | H    | L    | HLLH | HALF STEP A CCW, B CW |
| ; C            | L   | L               | L   | L    | L    | LHLH | L               | L   | H    | L    | LHLH | HALF STEP A CCW, B CW |
| ; C            | L   | L               | L   | L    | L    | HLLH | L               | L   | H    | L    | LHHL | HALF STEP A CCW, B CW |
| ; C            | L   | L               | L   | L    | L    | HLHL | L               | L   | H    | L    | HLHL | HALF STEP A CCW, B CW |
| ; X            | H   | X               | X   | X    | X    | ZZZZ | X               | X   | X    | X    | ZZZZ | TEST HI-Z             |

;DESCRIPTION

| ;CLK /OC | /EN | SET | ROT | MODE | SW1-SW4    | COMMENTS                         |
|----------|-----|-----|-----|------|------------|----------------------------------|
| ;X       | H   | X   | X   | X    | Z          | HI-Z                             |
| ;C       | L   | H   | X   | X    | HOLD       | HOLD MOTOR POSITION              |
| ;C       | L   | L   | H   | X    | 1          | SET MOTOR POSITION TO STEP 1     |
| ;C       | L   | L   | L   | H    | SW PLUS 1  | HALF-STEP MOTOR CLOCKWISE        |
| ;C       | L   | L   | L   | H    | SW PLUS 2  | FULL-STEP MOTOR CLOCKWISE        |
| ;C       | L   | L   | L   | L    | SW MINUS 1 | HALF-STEP MOTOR COUNTERCLOCKWISE |
| ;C       | L   | L   | L   | L    | SW MINUS 2 | FULL-STEP MOTOR COUNTERCLOCKWISE |

TR00950M

## Clean Octal Latch

Title CLEAN OCTAL LATCH  
Pattern P7096  
Revision A  
Author VINCENT COLI  
Company MMI SUNNYVALE, CALIFORNIA  
Date 03/10/83

CHIP CLEAN\_OCTAL\_LATCH PAL20L10

G NC D0 D1 D2 D3 D4 D5 D6 D7 NC GND  
/OC NC Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 NC VCC

### EQUATIONS

```
IF(OC) /Q0 = G*/D0 ;LOAD LATCH (Q0)
           + /G*/Q0 ;LATCH OUTPUT
           + /D0*/Q0 ;COVER ALWAYS HIGH HAZARD

IF(OC) /Q1 = G*/D1 ;LOAD LATCH (Q1)
           + /G*/Q1 ;LATCH OUTPUT
           + /D1*/Q1 ;COVER ALWAYS HIGH HAZARD

IF(OC) /Q2 = G*/D2 ;LOAD LATCH (Q2)
           + /G*/Q2 ;LATCH OUTPUT
           + /D2*/Q2 ;COVER ALWAYS HIGH HAZARD

IF(OC) /Q3 = G*/D3 ;LOAD LATCH (Q3)
           + /G*/Q3 ;LATCH OUTPUT
           + /D3*/Q3 ;COVER ALWAYS HIGH HAZARD

IF(OC) /Q4 = G*/D4 ;LOAD LATCH (Q4)
           + /G*/Q4 ;LATCH OUTPUT
           + /D4*/Q4 ;COVER ALWAYS HIGH HAZARD

IF(OC) /Q5 = G*/D5 ;LOAD LATCH (Q5)
           + /G*/Q5 ;LATCH OUTPUT
           + /D5*/Q5 ;COVER ALWAYS HIGH HAZARD

IF(OC) /Q6 = G*/D6 ;LOAD LATCH (Q6)
           + /G*/Q6 ;LATCH OUTPUT
           + /D6*/Q6 ;COVER ALWAYS HIGH HAZARD

IF(OC) /Q7 = G*/D7 ;LOAD LATCH (Q7)
           + /G*/Q7 ;LATCH OUTPUT
           + /D7*/Q7 ;COVER ALWAYS HIGH HAZARD
```

T300960M

7

## Clean Octal Latch

;FUNCTION TABLE FOR PALASM 1

/OC G D7 D6 D5 D4 D3 D2 D1 D0 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0

| ;CONTROL |   | DDDDDDDD | QQQQQQQQ | COMMENTS                |
|----------|---|----------|----------|-------------------------|
| /OC      | G | 76543210 | 76543210 |                         |
| -----    |   |          |          |                         |
| ; L      | H | LLLLLLLL | LLLLLLLL | LOAD ALL ZEROS          |
| ; L      | L | XXXXXXXX | LLLLLLLL | LATCH ALL ZEROS         |
| ; L      | H | HHHHHHHH | HHHHHHHH | LOAD ALL ONES           |
| ; L      | L | XXXXXXXX | HHHHHHHH | LATCH ALL ONES          |
| ; L      | H | HLHLHLHL | HLHLHLHL | LOAD EVEN CHECKERBOARD  |
| ; L      | L | XXXXXXXX | HLHLHLHL | LATCH EVEN CHECKERBOARD |
| ; L      | H | LHLHLHLH | LHLHLHLH | LOAD ODD CHECKERBOARD   |
| ; L      | L | XXXXXXXX | LHLHLHLH | LATCH ODD CHECKERBOARD  |
| ; H      | X | XXXXXXXX | ZZZZZZZZ | TEST HI-Z               |

-----

;DESCRIPTION

;THIS PAL16L8 IMPLEMENTS AN 8-BIT LATCH FUNCTION WITH THREE-STATE OUTPUTS. THE LATCH PASSES EIGHT BITS OF DATA (D7-D0) TO THE EIGHT OUTPUTS (Q7-Q0) WHEN LATCH ENABLE IS TRUE (G=HIGH). THE DATA IS LATCHED WHEN LATCH ENABLE IS FALSE (G=LOW). THE OUTPUTS WILL BE DISABLED (HI-Z) WHEN OUTPUT ENABLE IS TRUE (/OC=TRUE) REGARDLESS OF ANY OTHER INPUTS.

| /OC   | G | D7-D0 | Q7-Q0 | COMMENTS     |
|-------|---|-------|-------|--------------|
| ----- |   |       |       |              |
| ; H   | X | X     | Z     | HI-Z         |
| ; L   | L | X     | Q     | LATCH OUTPUT |
| ; L   | H | D     | D     | LOAD LATCH   |

-----

;THIS DESIGN SHOWS HOW TO IMPLEMENT A "CLEAN" LATCH SINCE THERE ARE NO OUTPUT GLITCHES AS THE DEVICE CHANGES STATE. THE KARNAUGH MAP BELOW FOR Q+ ILLUSTRATES THIS. THE TWO HORIZONTAL CIRCLES REPRESENT THE "LOAD LATCH" AND "LATCH OUTPUT" PRODUCT LINES. THE VERTICAL CIRCLE LINKS TOGETHER THE OTHER CIRCLES IN ORDER TO COVER A POTENTIAL SWITCHING HAZARD WHICH WOULD OCCUR WHEN THE OUTPUTS ARE ALWAYS HIGH.

```

;G !
;  !
;  !- 00 01 11 10
;  !-----!-----!-----!
;  0 ! 0 ! 1 ! 1 ! 0 !
;  !-----!-----!-----!
;  1 ! 0 ! 1 ! 1 ! 1 !
;  !-----!-----!-----!

```

7B00970M



## Shaft Encoder #1

Title SHAFT ENCODER No. 1PAL16R4  
Pattern P7097  
Revision A  
Author WILLY VOLDAN  
Company MMI GMBH MUNICH  
Date 09/09/82

CHIP SHAFT\_ENCODER\_No.\_1 PAL16R4

CLK PH10 PH190 X4 NC NC NC NC /SSET GND  
/OC DOWN NC S4 S3 S2 S1 NC UP VCC

### EQUATIONS

```
/S1 := /PH10 ;CHECK FOR PH10
      + SSET ;INITIALIZE S1=L

/S2 := /S1 ;CHECK FOR S1
      + SSET ;INITIALIZE S2=L

/S3 := /PH190 ;CHECK FOR PH190
      + SSET ;INITIALIZE S3=L

/S4 := /S3 ;CHECK FOR S3
      + SSET ;INITIALIZE S4=L

IF (VCC) /DOWN = S1* S2* S3*/S4* PH10* PH190 ;PH10 LEADS PH190
                + /S1*/S2*/S3* S4*/PH10*/PH190 ;PH10 LEADS PH190
                + S1*/S2*/S3*/S4* PH10*/PH190 ;PH10 LEADS PH190
                + /S1* S2* S3* S4*/PH10* PH190 ;PH10 LEADS PH190

IF (VCC) /UP = /S1*/S2* S3*/S4*/PH10* PH190 ;PH190 LEADS PH10
              + S1* S2*/S3* S4* PH10*/PH190 ;PH190 LEADS PH10
              + S1*/S2* S3* S4* PH10* PH190 ;PH190 LEADS PH10
              + /S1* S2*/S3*/S4*/PH10*/PH190 ;PH190 LEADS PH10

;FUNCTION TABLE FOR PALASM 1

;CLK /OC /SSET PH10 PH190 S4 S3 S2 S1 UP DOWN
```

T800980M

## Shaft Encoder #1

| ---CONTROLS--- |     |       | --INPUTS-- |       | SSSS | OUTPUTS |      | COMMENTS        |
|----------------|-----|-------|------------|-------|------|---------|------|-----------------|
| CLK            | /OC | /SSET | PHI0       | PHI90 | 4321 | UP      | DOWN |                 |
| ; C            | L   | L     | X          | X     | LLLL | H       | H    | CLEAR REGISTERS |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | L          | H     | LHLL | L       | H    | COUNT UP        |
| ; C            | L   | H     | L          | H     | HHLL | H       | H    |                 |
| ; C            | L   | H     | H          | H     | HHLH | L       | H    | COUNT UP        |
| ; C            | L   | H     | H          | H     | HHHH | H       | H    |                 |
| ; C            | L   | H     | H          | L     | HLHH | L       | H    | COUNT UP        |
| ; C            | L   | H     | H          | L     | LLHH | H       | H    |                 |
| ; C            | L   | H     | L          | L     | LLHL | L       | H    | COUNT UP        |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | L          | H     | LHLL | L       | H    | COUNT UP        |
| ; C            | L   | H     | L          | H     | HHLL | H       | H    |                 |
| ; C            | L   | H     | H          | H     | HHLH | L       | H    | COUNT UP        |
| ; C            | L   | H     | H          | H     | HHHH | H       | H    |                 |
| ; C            | L   | H     | H          | L     | HLHH | L       | H    | COUNT UP        |
| ; C            | L   | H     | H          | L     | LLHH | H       | H    |                 |
| ; C            | L   | H     | L          | L     | LLHL | L       | H    | COUNT UP        |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | L          | H     | LHLL | L       | H    | COUNT UP        |
| ; C            | L   | H     | L          | H     | HHLL | H       | H    |                 |
| ; C            | L   | H     | H          | H     | HHLH | L       | H    | COUNT UP        |
| ; C            | L   | H     | H          | H     | HHHH | H       | H    |                 |
| ; C            | L   | H     | H          | L     | HLHH | L       | H    | COUNT UP        |
| ; C            | L   | H     | H          | L     | LLHH | H       | H    |                 |
| ; C            | L   | H     | L          | L     | LLHL | L       | H    | COUNT UP        |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | L          | H     | LHLL | L       | H    | COUNT UP        |
| ; C            | L   | H     | L          | H     | HHLL | H       | H    |                 |
| ; C            | L   | H     | H          | H     | HHLH | L       | H    | COUNT UP        |
| ; C            | L   | H     | H          | H     | HHHH | H       | H    |                 |
| ; C            | L   | H     | H          | L     | HLHH | L       | H    | COUNT UP        |
| ; C            | L   | H     | H          | L     | LLHH | H       | H    |                 |
| ; C            | L   | H     | L          | L     | LLHL | L       | H    | COUNT UP        |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    | CLEAR REGISTERS |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | H          | L     | LLLH | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | H          | L     | LLHH | H       | H    |                 |
| ; C            | L   | H     | H          | H     | LHHH | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | H          | H     | HHHH | H       | H    |                 |
| ; C            | L   | H     | L          | H     | HHHL | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | L          | H     | HHLH | H       | H    |                 |
| ; C            | L   | H     | L          | L     | HLLL | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | H          | L     | LLLH | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | H          | L     | LLHH | H       | H    |                 |
| ; C            | L   | H     | H          | H     | LHHH | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | H          | H     | HHHH | H       | H    |                 |
| ; C            | L   | H     | L          | H     | HHHL | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | L          | H     | HHLH | H       | H    |                 |
| ; C            | L   | H     | L          | L     | HLLL | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; C            | L   | H     | H          | L     | LLLH | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | H          | L     | LLHH | H       | H    |                 |
| ; C            | L   | H     | H          | H     | LHHH | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | H          | H     | HHHH | H       | H    |                 |
| ; C            | L   | H     | L          | H     | HHHL | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | L          | H     | HHLH | H       | H    |                 |
| ; C            | L   | H     | L          | L     | HLLL | H       | L    | COUNT DOWN      |
| ; C            | L   | H     | L          | L     | LLLL | H       | H    |                 |
| ; X            | H   | X     | X          | X     | ZZZZ | X       | X    | TEST HI-Z       |

18009804

## Shaft Encoder #1

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;DESCRIPTION:

;THIS PAL16R4 IMPLEMENTS A TWO CHANNEL SHAFT ENCODER OF THE TYPE USED IN SPEED CONTROLLERS AND OPTICAL DEVICES.

;BOTH THE "UP" AND "DOWN" OUTPUTS OF THE PAL ARE NORMALLY HIGH.

;WHEN THE SIGNAL AT THE "PHI0" INPUT LEADS THE SIGNAL AT THE "PHI90" INPUT, THE "DOWN" OUTPUT ALTERNATES BETWEEN HIGH AND LOW LEVELS AT HALF THE "CLK" FREQUENCY RATE. ALSO, WHEN THE SIGNAL AT THE "PHI0" INPUT LAGS THE SIGNAL AT THE "PHI90" INPUT, THE "UP" OUTPUT ALTERNATES BETWEEN HIGH AND LOW LEVELS AT HALF THE "CLK" FREQUENCY RATE.

;THE SHAFT ENCODER FEATURES THE CONFIGURATION AND OUTPUT POLARITY TO DRIVE AN 74S193 TYPE UP/DOWN COUNTER.

;THIS DESIGN WITH GLITCHFREE OUTPUTS WILL BE EXTREMELY USEFUL IN ELECTRICALLY NOISY ENVIRONMENTS. THE PINNING IS GIVEN AS A FIRST PROPOSAL AND CAN BE CHANGED ACCORDING TO THE PC-BOARD LAYOUT.

T801000M

## Shaft Encoder #2

Title SHAFT ENCODER No. 2  
Pattern P7098  
Revision A  
Author WILLY VOLDAN  
Company MMI GMBH MUNICH  
Date 09/09/82

CHIP SHAFT\_ENCODER\_No.\_2 PAL16R8

CLK PHIO PHI90 X4 NC NC NC NC /SSET GND  
/OC UD NC S4 S3 S2 S1 NC COUNT VCC

### EQUATIONS

```
/S1 := /PHIO ;CHECK FOR PHIO
      + SSET ;INITIALIZE S1=L

/S3 := /PHI90 ;CHECK FOR PHI90
      + SSET ;INITIALIZE S3=L

/S2 := S1 ;CHECK FOR /S1
      + SSET ;INITIALIZE S2=L

/S4 := S3 ;CHECK FOR /S3
      + SSET ;INITIALIZE S4=L

/COUNT := S1* S2*/S3* S4 ;THIS OUTPUT ALTERNATES
          + /S1*/S2* S3*/S4 ;BETWEEN HIGH AND LOW WITH
          + /S1* S2*/S3*/S4* X4 ;HALF OR QUARTER THE
          + S1*/S2* S3* S4* X4 ;CLK FREQUENCY
          + S1* S2* S3*/S4
          + /S1*/S2*/S3* S4
          + /S1* S2* S3* S4* X4
          + S1*/S2*/S3*/S4* X4

/UD := /S1* S2*/S3* S4 ;THIS OUTPUT DETERMINES
      + /S1* S2* S3* S4 ;IF SIGNAL PHIO LEADS
      + /S1* S2* S3*/S4 ;OR LAGS SIGNAL PHI90
      + S1* S2* S3*/S4
      + S1*/S2* S3*/S4
      + S1*/S2*/S3* S4
      + /S1*/S2*/S3* S4
```

T801010M

## Shaft Encoder #2

;FUNCTION TABLE FOR PALASM 1

;CLK /OC /SSET PHI0 PHI90 X4 S1 S2 S3 S4 COUNT UD

| ---CONTROLS--- |     |       | --INPUTS-- |       | X | SSSS | -OUTPUTS- |    | COMMENTS        |
|----------------|-----|-------|------------|-------|---|------|-----------|----|-----------------|
| CLK            | /OC | /SSET | PHI0       | PHI90 | 4 | 1234 | COUNT     | UD |                 |
| ; C            | L   | L     | X          | X     | X | LLLL | H         | H  | CLEAR REGISTERS |
| ; C            | L   | H     | L          | L     | L | LHLH | H         | H  | COUNT UP X4=L   |
| ; C            | L   | H     | H          | L     | L | HHLH | H         | L  |                 |
| ; C            | L   | H     | H          | L     | L | HLLH | L         | H  |                 |
| ; C            | L   | H     | H          | H     | L | HLHH | H         | L  |                 |
| ; C            | L   | H     | H          | H     | L | HLHL | H         | H  |                 |
| ; C            | L   | H     | L          | H     | L | LLHL | H         | L  |                 |
| ; C            | L   | H     | L          | H     | L | LHHL | L         | H  |                 |
| ; C            | L   | H     | L          | L     | L | LHLL | H         | L  |                 |
| ; C            | L   | H     | L          | L     | L | LHLH | H         | H  |                 |
| ; C            | L   | H     | H          | L     | L | HHLH | H         | L  |                 |
| ; C            | L   | H     | H          | L     | L | HLLH | L         | H  |                 |
| ; C            | L   | H     | H          | H     | L | HLHH | H         | L  |                 |
| ; C            | L   | H     | H          | H     | L | HLHL | H         | H  |                 |
| ; C            | L   | H     | L          | H     | L | LLHL | H         | L  |                 |
| ; C            | L   | H     | L          | H     | L | LHHL | L         | H  |                 |
| ; C            | L   | H     | L          | L     | H | LHLL | H         | L  | COUNT UP X4=L   |
| ; C            | L   | H     | L          | L     | H | LHLH | L         | H  |                 |
| ; C            | L   | H     | H          | L     | H | HHLH | H         | L  |                 |
| ; C            | L   | H     | H          | L     | H | HLLH | L         | H  |                 |
| ; C            | L   | H     | H          | H     | H | HLHH | H         | L  |                 |
| ; C            | L   | H     | H          | H     | H | HLHL | L         | H  |                 |
| ; C            | L   | H     | L          | H     | H | LLHL | H         | L  |                 |
| ; C            | L   | H     | L          | H     | H | LHHL | L         | H  |                 |
| ; C            | L   | H     | L          | L     | H | LHLL | H         | L  |                 |
| ; C            | L   | H     | L          | L     | H | LHLH | L         | H  |                 |
| ; C            | L   | H     | H          | L     | H | HHLH | H         | L  |                 |
| ; C            | L   | H     | H          | L     | H | HLLH | L         | H  |                 |
| ; C            | L   | H     | H          | H     | H | HLHH | H         | L  |                 |
| ; C            | L   | H     | H          | H     | H | HLHL | L         | H  |                 |
| ; C            | L   | L     | X          | X     | X | LLLL | H         | L  | CLEAR REGISTERS |
| ; C            | L   | H     | L          | L     | L | LHLH | H         | H  | COUNT DOWN X4=L |
| ; C            | L   | H     | L          | H     | L | LHHH | H         | L  |                 |
| ; C            | L   | H     | L          | H     | L | LHHL | H         | L  |                 |
| ; C            | L   | H     | H          | H     | L | HHHL | H         | L  |                 |
| ; C            | L   | H     | H          | H     | L | HLHL | L         | L  |                 |
| ; C            | L   | H     | H          | L     | L | HLLL | H         | L  |                 |
| ; C            | L   | H     | H          | L     | L | HLLH | H         | L  |                 |
| ; C            | L   | H     | L          | L     | L | LLLH | H         | L  |                 |
| ; C            | L   | H     | L          | L     | L | LHLH | L         | L  |                 |
| ; C            | L   | H     | L          | H     | L | LHHH | H         | L  |                 |
| ; C            | L   | H     | L          | H     | L | LHHL | H         | L  |                 |
| ; C            | L   | H     | L          | H     | L | LHLL | H         | L  |                 |
| ; C            | L   | H     | L          | L     | H | LLLH | H         | L  | COUNT DOWN X4=H |
| ; C            | L   | H     | L          | L     | H | LHLH | L         | L  |                 |
| ; C            | L   | H     | L          | H     | H | LHHH | H         | L  |                 |
| ; C            | L   | H     | L          | H     | H | LHHL | L         | L  |                 |
| ; C            | L   | H     | H          | H     | H | HHHL | H         | L  |                 |
| ; C            | L   | H     | H          | H     | H | HLHL | L         | L  |                 |

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T801020M

## Shaft Encoder #2

```
; C   L   H   H   L   H   HLLL   H   L
; C   L   H   H   L   H   HLLH   L   L
; C   L   H   L   L   H   LLLH   H   L
; C   L   H   L   L   H   LHLH   L   L
; C   L   H   L   H   H   LHHH   H   L
; C   L   H   L   H   H   LHHL   L   L
; C   L   H   H   H   H   HHHL   H   L
; C   L   H   H   H   H   HLHL   L   L
; X   H   X   X   X   X   ZZZZ   Z   Z      TEST HI-Z
```

---

### ;DESCRIPTION

;THIS PAL16R8 IMPLEMENTS A TWO CHANNEL SHAFT ENCODER OF THE TYPE USED IN SPEED CONTROLLERS AND OPTICAL DEVICES.

;THE "COUNT" OUTPUT OF THE PAL IS NORMALLY HIGH. DURING SHAFT ENCODING THIS OUTPUT ALTERNATES BETWEEN HIGH AND LOW.

;INPUT "X4" SELECTS BETWEEN HALF (X4=H) OR QUARTER (X4=L) CLK FREQUENCY OF THE "COUNTER" OUTPUT.

;OUTPUT "UD" DETERMINES WHETHER SIGNAL PHI0 LEADS (UD=H) OR LAGS (UD=L) SIGNAL PHI90.

;THE SHAFT ENCODER FEATURES THE CONFIGURATION AND OUTPUT POLARITY TO DRIVE AN 74S697 TYPE UP/DOWN COUNTER.

;THIS DESIGN WITH GLITCHFREE OUTPUTS WILL BE EXTREMELY USEFUL IN ELECTRICALLY NOISY ENVIRONMENTS. THE PINNING IS GIVEN AS A FIRST PROPOSAL AND CAN BE CHANGED ACCORDING TO THE PC-BOARD LAYOUT.

TB01030M

### Shaft Encoder #3

Title SHAFT ENCODER No. 3 (WITH INTERNAL 4-BIT UP/DOWN COUNTER)  
Pattern P7099  
Revision A  
Author WILLY VOLDAN  
Company MMI GMBH MUNICH  
Date 09/09/82

CHIP SHAFT\_ENCODER\_No.\_3\_(WITH\_INTERNAL\_4-BIT\_UP/DOWN\_COUNTER) PAL20X10

#### EQUATIONS

CLK PHI0 PHI90 X4 /LD NC D3 D2 D1 D0 /SSET GND  
/OC DOWN S4 S3 S2 S1 Q3 Q2 Q1 Q0 UP VCC

```
/S1 := /PHI0 ;CHECK FOR PHI0
+ SSET ;INITIALIZE S1=L

/S2 := /S1 ;CHECK FOR S1
+ SSET ;INITIALIZE S2=L

/S3 := /PHI90 ;CHECK FOR PHI90
+ SSET ;INITIALIZE S3=L

/S4 := /S3 ;CHECK FOR S3
+ SSET ;INITIALIZE S4=L

/DOWN := S1* S2* S3*/S4* PHI0* PHI90* X4 ;PHI0 LEADS PHI90 - COUNT=FREQ/2
+ /S1*/S2*/S3* S4*/PHI0*/PHI90* X4 ;PHI0 LEADS PHI90 - COUNT=FREQ/2
+: S1*/S2*/S3*/S4* PHI0*/PHI90 ;PHI0 LEADS PHI90 - COUNT=FREQ/4
+ /S1* S2* S3* S4*/PHI0* PHI90 ;PHI0 LEADS PHI90 - COUNT=FREQ/4

/UP := /S1*/S2* S3*/S4*/PHI0* PHI90 ;PHI90 LEADS PHI0 - COUNT=FREQ/4
+ S1* S2*/S3* S4* PHI0*/PHI90 ;PHI90 LEADS PHI0 - COUNT=FREQ/4
+: S1*/S2* S3* S4* PHI0* PHI90* X4 ;PHI90 LEADS PHI0 - COUNT=FREQ/2
+ /S1* S2*/S3*/S4*/PHI0*/PHI90* X4 ;PHI90 LEADS PHI0 - COUNT=FREQ/2

/Q0 := /SSET* LD*/D0 ;LOAD D0 (LSB)
+ /SSET*/LD*/Q0 ;HOLD Q0
+: /SSET*/LD* UP*/DOWN ;DECREMENT
+ /SSET*/LD*/UP* DOWN ;INCREMENT

/Q1 := /SSET* LD*/D1 ;LOAD D1
+ /SSET*/LD*/Q1 ;HOLD Q1
+: /SSET*/LD* UP*/DOWN*/Q0 ;DECREMENT
+ /SSET*/LD*/UP* DOWN* Q0 ;INCREMENT

/Q2 := /SSET* LD*/D2 ;LOAD D2
+ /SSET*/LD*/Q2 ;HOLD Q2
+: /SSET*/LD* UP*/DOWN*/Q0*/Q1 ;DECREMENT
+ /SSET*/LD*/UP* DOWN* Q0* Q1 ;INCREMENT

/Q3 := /SSET* LD*/D3 ;LOAD D3 (MSB)
+ /SSET*/LD*/Q3 ;HOLD Q3
+: /SSET*/LD* UP*/DOWN*/Q0*/Q1*/Q2 ;DECREMENT
+ /SSET*/LD*/UP* DOWN* Q0* Q1* Q2 ;INCREMENT
```

T801040M

## Shaft Encoder #3

;FUNCTION TABLE FOR PALASM 1

;CLK /OC /SSET /LD X4 PHIO PHI90 S1 S2 S3 S4 UP DOWN D3 D2 D1 D0 Q3 Q2 Q1 Q0

| ;---CONTROLS--- |     |    |      |    |     |      |      |      |      | INPUT |      |            |               |                  |  |  |  | COMMENTS |  |
|-----------------|-----|----|------|----|-----|------|------|------|------|-------|------|------------|---------------|------------------|--|--|--|----------|--|
| ;               | /   | /  | /    | /  | PHI | SSSS |      | DDDD | QQQQ |       |      |            |               | COMMENTS         |  |  |  |          |  |
| ;               | CLK | OC | SSET | LD | X4  | 0    | 90   | 1234 | UP   | DOWN  | 3210 | 3210       | (Q HEX VALUE) |                  |  |  |  |          |  |
| ; C             | L   | L  | X    | X  | X   | X    | LLLL | H    | H    | XXXX  | HHHL | INITIALIZE | REGISTERS     | (F)              |  |  |  |          |  |
| ; C             | L   | H  | L    | X  | X   | X    | XXXX | X    | X    | HLHL  | HLHL | LOAD       | (A)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | L    | LLLL | H    | H    | XXXX  | HLHL | HOLD       | (A)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | L    | HLLL | H    | H    | XXXX  | HLHL | HOLD       | (A)           | PHIO LEADS PHI90 |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | L    | HLLL | H    | L    | XXXX  | HLHL | HOLD       | (A)           | X4=H - FREQ/4    |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | H    | HHHL | H    | H    | XXXX  | HLLH | DECREMENT  | (9)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | H    | HHHH | H    | H    | XXXX  | HLLH | HOLD       | (9)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | H    | LHHH | H    | H    | XXXX  | HLLH | HOLD       | (9)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | H    | LLHH | H    | L    | XXXX  | HLLH | HOLD       | (9)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | L    | LLLH | H    | H    | XXXX  | HLLL | DECREMENT  | (8)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | L    | LLLL | H    | H    | XXXX  | HLLL | HOLD       | (8)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | L    | HLLL | H    | H    | XXXX  | HLLL | HOLD       | (8)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | L    | HHLL | H    | L    | XXXX  | HLLL | HOLD       | (8)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | H    | HHHL | H    | H    | XXXX  | LHHH | DECREMENT  | (7)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | H    | HHHH | H    | H    | XXXX  | LHHH | HOLD       | (7)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | H    | LHHH | H    | H    | XXXX  | LHHH | HOLD       | (7)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | H    | LLHH | H    | L    | XXXX  | LHHH | HOLD       | (7)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | L    | LLLH | H    | H    | XXXX  | LHHL | DECREMENT  | (6)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | L    | LLLL | H    | L    | XXXX  | LHHL | HOLD       | (6)           | X4=H - FREQ/2    |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | H   | L    | HLLL | H    | H    | XXXX  | LHHL | DECREMENT  | (5)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | H   | L    | HHLL | H    | L    | XXXX  | LHLH | HOLD       | (5)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | H   | H    | HHHL | H    | H    | XXXX  | LHLL | DECREMENT  | (4)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | H   | H    | HHHH | H    | L    | XXXX  | LHLL | HOLD       | (4)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | H    | LHHH | H    | H    | XXXX  | LLHH | DECREMENT  | (3)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | H    | LLHH | H    | L    | XXXX  | LLHH | HOLD       | (3)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | L    | LLLH | H    | H    | XXXX  | LLHL | DECREMENT  | (2)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | L    | LLLL | H    | L    | XXXX  | LLHL | HOLD       | (2)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | H   | L    | HLLL | H    | H    | XXXX  | LLLH | DECREMENT  | (1)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | H   | L    | HHLL | H    | L    | XXXX  | LLLH | HOLD       | (1)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | H   | H    | HHHL | H    | H    | XXXX  | LLLL | DECREMENT  | (0)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | H   | H    | HHHH | H    | L    | XXXX  | LLLL | HOLD       | (0)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | H    | LHHH | H    | H    | XXXX  | HHHH | DECREMENT  | (F)           | (ROLL UNDER)     |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | H    | LLHH | H    | L    | XXXX  | HHHH | HOLD       | (F)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | L    | LLLH | H    | H    | XXXX  | HHHL | DECREMENT  | (E)           |                  |  |  |  |          |  |
| ; C             | L   | H  | L    | X  | X   | X    | XXXX | X    | X    | LHLH  | LHLH | LOAD       | (5)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | L    | LLLL | H    | H    | XXXX  | LHLH | HOLD       | (5)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | H    | LLHL | H    | H    | XXXX  | LHLH | HOLD       | (5)           | PHI90 LEADS PHIO |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | H    | LLHH | L    | H    | XXXX  | LHLH | HOLD       | (5)           | X4=L - FREQ/4    |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | H    | HLHH | H    | H    | XXXX  | LHHL | INCREMENT  | (6)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | H    | HHHH | H    | H    | XXXX  | LHHL | HOLD       | (6)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | L    | HHLH | H    | H    | XXXX  | LHHL | HOLD       | (6)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | L    | LHLL | H    | H    | XXXX  | LHHH | INCREMENT  | (7)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | L    | LLLH | H    | H    | XXXX  | LHHH | HOLD       | (7)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | H    | LLHL | H    | H    | XXXX  | LHHH | HOLD       | (7)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | L   | H    | LLHH | L    | H    | XXXX  | LHHH | HOLD       | (7)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | H    | HLHH | H    | H    | XXXX  | HLLL | INCREMENT  | (8)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | H    | HHHH | H    | H    | XXXX  | HLLL | HOLD       | (8)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | L    | HHLH | H    | H    | XXXX  | HLLL | HOLD       | (8)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | L  | H   | L    | HLLL | L    | H    | XXXX  | HLLL | HOLD       | (8)           |                  |  |  |  |          |  |
| ; C             | L   | H  | H    | H  | L   | L    | LHLL | H    | H    | XXXX  | HLLH | INCREMENT  | (9)           |                  |  |  |  |          |  |

T801050M



### Shaft Encoder #3

```

; C  L  H  H  H  L  L  LLLL  L  H  XXXX  HLLH  HOLD (9)  X4=H -  FREQ/2
; C  L  H  H  H  L  H  LLHL  H  H  XXXX  HLHL  INCREMENT (A)
; C  L  H  H  H  L  H  LLHH  L  H  XXXX  HLHL  HOLD (A)
; C  L  H  H  H  H  H  HLHH  H  H  XXXX  HLHH  INCREMENT (B)
; C  L  H  H  H  H  H  HHHH  L  H  XXXX  HLHH  HOLD (B)
; C  L  H  H  H  H  L  HHLH  H  H  XXXX  HLLL  INCREMENT (C)
; C  L  H  H  H  H  L  HHLH  L  H  XXXX  HLLL  HOLD (C)
; C  L  H  H  H  L  L  LLLL  H  H  XXXX  HHLH  INCREMENT (D)
; C  L  H  H  H  L  L  LLLL  L  H  XXXX  HHLH  HOLD (D)
; C  L  H  H  H  L  H  LLHL  H  H  XXXX  HHLH  INCREMENT (E)
; C  L  H  H  H  L  H  LLHH  L  H  XXXX  HHLH  HOLD (E)
; C  L  H  H  H  H  H  HLHH  H  H  XXXX  HHHH  INCREMENT (F)
; C  L  H  H  H  H  H  HHHH  L  H  XXXX  HHHH  HOLD (F)
; C  L  H  H  H  H  H  HHLH  H  H  XXXX  LLLL  INCREMENT (0) (ROLL OVER)
; C  L  H  H  H  H  L  HHLH  L  H  XXXX  LLLL  HOLD (0)
; C  L  H  H  H  L  L  LHLL  H  H  XXXX  LLLH  INCREMENT (1)
; C  L  H  L  X  X  X  XXXX  X  X  LLLH  LLLH  LOAD (1)
; C  L  H  L  X  X  X  XXXX  X  X  LLHH  LLHH  LOAD (3)
; C  L  H  L  X  X  X  XXXX  X  X  LHLH  LHLH  LOAD (5)
; C  L  H  L  X  X  X  XXXX  X  X  LHHH  LHHH  LOAD (7)
; C  L  H  L  X  X  X  XXXX  X  X  HLLH  HLLH  LOAD (9)
; C  L  H  L  X  X  X  XXXX  X  X  HLHH  HLHH  LOAD (B)
; C  L  H  L  X  X  X  XXXX  X  X  HHLH  HHLH  LOAD (D)
; C  L  H  L  X  X  X  XXXX  X  X  HHHH  HHHH  LOAD (F)
; X  H  X  X  X  X  X  ZZZZ  Z  Z  XXXX  ZZZZ  TEST HI-Z
;-----

```

**;DESCRIPTION**

;THIS PAL20X10 IMPLEMENTS A TWO CHANNEL SHAFT ENCODER WITH AN INTERNAL 4-BIT UP/DOWN COUNTER.

;BOTH THE "UP" AND "DOWN" OUTPUTS OF THE PAL ARE NORMALLY AT HIGH.

;WHEN THE SIGNAL AT THE "PHI0" INPUT LEADS THE SIGNAL AT THE "PHI90" INPUT, THE "DOWN" OUTPUT ALTERNATES BETWEEN HIGH AND LOW LEVELS AND THE COUNTER WILL COUNT DOWN. WHEN THE SIGNAL AT THE "PHI0" INPUT LEADS THE SIGNAL AT THE "PHI90" INPUT, THE "UP" OUTPUT ALTERNATES BETWEEN HIGH AND LOW LEVELS AND THE COUNTER WILL COUNT UP.

;INPUT "X4" SELECTS BETWEEN HALF (X4=H) OR QUARTER (X4=L) CLK FREQUENCY OF THE COUNTER OUTPUTS.

;THE INTERNAL 4-BIT SYNCHRONOUS COUNTER HAS COUNT UP, COUNT DOWN CAPABILITIES. ALSO, THE COUNTER CAN PARALLEL LOAD AND HOLD DATA INDEPENDENTLY OF THE SHAFT ENCODER SECTION. THE REGISTERS ARE SYNCHRONOUSLY INITIALIZED WHEN /SSET IS HEL LOW.

;THE CONTROL INPUTS PROVIDE THESE OPERATIONS WHICH OCCUR SYNCHRONOUSLY AT THE RISING EDGE OF THE CLOCK.

1901000M

7

# Four-to-Sixteen Decoder

## PAL Device Design Specification

Title 4to16 Decoder  
 Pattern 4-16DEC.PDS  
 Revision A  
 Author Mehrnaz Hada  
 Company Monolithic Memories, Santa Clara, CA  
 Date 1/9/85

CHIP Decoder PAL6L16

Q0 Q1 Q2 A B C D EN1 EN2 Q3 Q4 GND Q5  
 Q6 Q7 Q8 Q9 Q10 Q11 Q12 Q13 Q14 Q15 VCC

### EQUATIONS

```

/Q0 = /D*/C*/B*/A* EN1* EN2 ;Decode 0000
/Q1 = /D*/C*/B* A* EN1* EN2 ;Decode 0001
/Q2 = /D*/C* B*/A* EN1* EN2 ;Decode 0010
/Q3 = /D*/C* B* A* EN1* EN2 ;Decode 0011
/Q4 = /D* C*/B*/A* EN1* EN2 ;Decode 0100
/Q5 = /D* C*/B* A* EN1* EN2 ;Decode 0101
/Q6 = /D* C* B*/A* EN1* EN2 ;Decode 0110
/Q7 = /D* C* B* A* EN1* EN2 ;Decode 0111
/Q8 = D*/C*/B*/A* EN1* EN2 ;Decode 1000
/Q9 = D*/C*/B* A* EN1* EN2 ;Decode 1001
/Q10 = D*/C* B*/A* EN1* EN2 ;Decode 1010
/Q11 = D*/C* B* A* EN1* EN2 ;Decode 1011
/Q12 = D* C*/B*/A* EN1* EN2 ;Decode 1100
/Q13 = D* C*/B* A* EN1* EN2 ;Decode 1101
/Q14 = D* C* B*/A* EN1* EN2 ;Decode 1110
/Q15 = D* C* B* A* EN1* EN2 ;Decode 1111
    
```

### SIMULATION

TRACE\_ON D B C A Q0 Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9 Q10  
 Q11 Q12 Q13 Q14 Q15

```

SETF /D /C /B /A EN1 EN2
SETF A
SETF B
SETF C
SETF D
SETF /D
SETF /C
SETF /B
SETF /A
SETF /EN1
SETF EN1 /EN2
SETF /EN1
    
```

;The 4 to 16 decoder, decodes four binary decoded inputs  
 ;into one of 16 mutually exclusive outputs, whenever the  
 ;two enable lines EN1 and EN2 are high. When one or both  
 ;of the enable lines are low the outputs are all set to  
 ;high values.

## Simulation Results

Page : 1  
 9999999999 99  
 D LLLLLLLLLL LL  
 B LLLLLLLLLL LL  
 C LLLLLLLLLL LL  
 A LLLLLLLLLL LL  
 Q0 LLLLLLLLLL HH  
 Q1 LLLLLLLLLL HH  
 Q2 HHHHHHHHHH HH  
 Q3 HHHHHHHHHH HH  
 Q4 HHHHHHHHHH HH  
 Q5 HHHHHHHHHH HH  
 Q6 HHHHHHHHHH HH  
 Q7 HHHHHHHHHH HH  
 Q8 HHHHHHHHHH HH  
 Q9 HHHHHHHHHH HH  
 Q10 HHHHHHHHHH HH  
 Q11 HHHHHHHHHH HH  
 Q12 HHHHHHHHHH HH  
 Q13 HHHHHHHHHH HH  
 Q14 HHHHHHHHHH HH  
 Q15 HHHHHHHHHH HH

## XPLOT Output

Title : 4to16 Decoder Author : Mehrnaz Hada  
 Pattern : 4-16DEC.PDS Company : Monolithic Memories,  
 Revision : A Date : 1/9/85

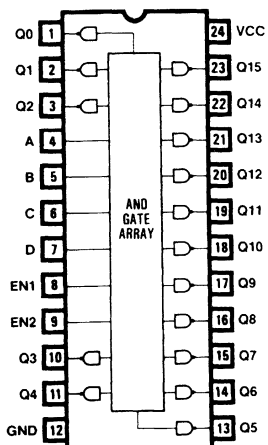
PAL6L16  
 DECODER

```

11
0123 4567 8901
0 -X-X -X-X X-X-
1 X-X- X-X- X-X-
2 X-X- -X-X X-X-
3 -XX- -X-X X-X-
4 -XX- X-X- X-X-
5 X-X- X-X- X-X-
6 -X-X X-X- X-X-
7 X-X- -XX- X-X-
8 -XX- -XX- X-X-
9 X-X- -XX- X-X-
10 -X-X -XX- X-X-
11 X-X- -X-X X-X-
12 X-X- X-X- X-X-
13 -XX- X-X- X-X-
14 -X-X X-X- X-X-
15 X-X- X-X- X-X-
    
```

TOTAL FUSES BLOWN: 96

## Logic Symbol



T801660M

# PC I/O Mapper

## PAL Device Design Specification

```

Title      PC I/O Mapper
Pattern    MemIO.pds
Revision   A
Author     A G Gilbert
Company    Monolithic Memories Inc., Santa Clara, CA
Date       1/8/85

:Personal computers which are hardware compatible with the
:ubiquitous IBM PC share this I/O map.

CHIP PC_IO PAL8L14

NC NC A9 A8 A7 A6 A5 A4 A3 AEN /CSMONOCHRMAD GND
/CSGAMEIOAD /CSCOLORAD /CSPRINTERAD /CSSFLOPPYAD /CSRS232AD /CSNMIMKRG
/CSDMAPGRG /CSPPICHIP /CSTIMERCHIP /CSINTCCHIP /CSDMACCHIP VCC

Equations

CSDMACCHIP = /A9*/A8*/A7*/A6*/A5      :DMA controller
            * /A4*/AEN                 :Chip select
            :HEX address 000-00F

CSINTCCHIP = /A9*/A8*/A7*/A6*A5      :Interrupt controller
            * /A4*/A3*/AEN            :Chip select
            :HEX address 020-021

CSTIMERCHIP = /A9*/A8*/A7*A6*/A5     :Timer
            * /A4*/A3*/AEN            :Chip select
            :HEX address 040-043

CSPPICHIP = /A9*/A8*/A7*A6*A5        :Parallel peripheral interface
            * /A4*/A3*/AEN            :Chip select
            :HEX address 060-063

CSDMAPGRG = /A9*/A8*A7*/A6*/A5       :DMA page register
            * /A4*/A3*/AEN            :Chip select
            :HEX address 080-083

CSNMIMKRG = /A9*/A8*A7*/A6*A5        :NMI mask register
            * /A4*/AEN                 :Chip select
            :HEX address 0A0

CSRS232AD = A9*A8*A7*A6*A5           :RS 232 module
            * A4*A3*/AEN              :Device select
            :HEX address 1F8-1FF

CSSFLOPPYAD = A9*A8*A7*A6*A5         :5.25 floppy disk module
            * A4*/A3*/AEN              :Device select
            :HEX address 3F0-3F7

CSPRINTERAD = A9*/A8*/A7*/A6*A5      :Parallel printer module
            * A4*/A3*/AEN              :Device select
            :HEX address 378-37F

CSCOLORAD = A9*A8*A7*A6*/A5          :Color graphics video module
            * A4*/AEN                  :Device select
            :HEX address 3D0-3DF

CSGAMEIOAD = A9*/A8*/A7*/A6*/A5      :Game I/O module
            * /A4*/AEN                 :Device select
            :HEX address 200-20F

CSMONOCHRMAD = A9*A8*A7*/A6*A5       :Monochrome video module
            * A4*/AEN                  :Device select
            :HEX address 380-3BF
    
```

### SIMULATION

```

TRACE_ON A9 A8 A7 A6 A5 A4 A3 AEN /CSMONOCHRMAD
         /CSGAMEIOAD /CSCOLORAD /CSPRINTERAD /CSSFLOPPYAD
         /CSRS232AD /CSNMIMKRG /CSDMAPGRG /CSPPICHIP
         /CSTIMERCHIP /CSINTCCHIP /CSDMACCHIP

SETF AEN
SETF /A9 /A8 /A7 /A6 /A5 /A4 /A3 /AEN
SETF A5
SETF A6
SETF /A5 A7
SETF A5
SETF A4 /A6
SETF A9 A8 A7 A6 A5 A4 A3
SETF /A3
SETF /A5
SETF /A4 /A6 /A7 /A8
SETF A9 A8 A7 /A6 A5 A4
    
```

## Simulation Results

```

Page : 1
A9      9999999999 99
A8      XLLLLLHMH MH
A7      XLLLLLHMH LH
A6      XLLHHLHMH LL
A5      XLHHLHMH LH
A4      XLLLLLHMH LH
A3      XLLLLLHMH LL
AEN     HLLLLLHMH LL
        /CSMONOCHRMAD HHHHHHHHMH HL
        /CSGAMEIOAD  HHHHHHHHMH LH
        /CSCOLORAD  HHHHHHHHMH MH
        /CSPRINTERAD HHHHHHHHMH MH
        /CSSFLOPPYAD HHHHHHHHMH MH
        /CSRS232AD   HHHHHHHHMH MH
        /CSNMIMKRG   HHHHHHHHMH MH
        /CSDMAPGRG   HHHHHHHHMH MH
        /CSPPICHIP   HHHHHHHHMH MH
        /CSTIMERCHIP HHHHHHHHMH MH
        /CSINTCCHIP  HHLHHHHHMH MH
        /CSDMACCHIP  HLHHHHHHMH MH
    
```

## XPLOT Output

```

Title      : PC I/O Mapper
Pattern    : MemIO.pds
Revision    : A
Author      : A G Gilbert
Company     : Monolithic Memories Inc
Date        : 1/8/85

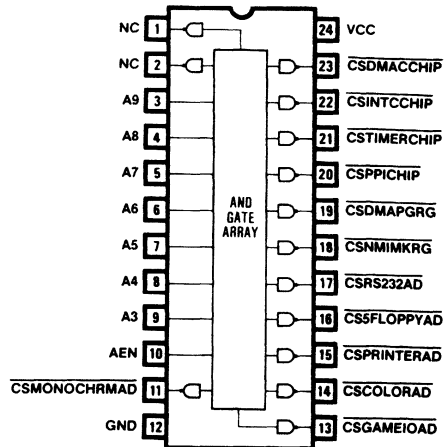
PAL8L14
PC_IO

                                11 1111
                                0123 4567 8901 2345

0 XXXX XXXX XXXX XXXX
1 -X-X -X-X -X-X ---X
2 XXXX XXXX XXXX XXXX
3 -X-X -X-X X-X -X-X
4 -X-X -XX- X-X -X-X
5 -X-X -XX- X-X -X-X
6 -X-X X--X -X-X -X-X
7 -X-X X--X X-X --X
8 X-X- X-X- X-X- X-X-
9 X-X- X-X- X-X- X-X-
10 X--X -XX- X-X- X--X
11 X-X- X-X- --XX- --X
12 X-X- X-X- X-X- ---X
13 X--X -X-X -X-X --X
    
```

TOTAL FUSES BLOWN: 101

## Logic Symbol



T801700M

# Octal Comparator

## PAL Device Design Specification

Title Octal Comparator  
 Pattern OctComp.pds  
 Revision A  
 Author Mehrnaz Hada  
 Company Monolithic Memories Inc., Santa Clara, CA  
 Date 1/29/85

;The octal comparator establishes when two 8-bit data strings (A7-A0) and (B7-B0) are equivalent (EQ=H) or ;equivalent (NE=H).

CHIP OctalComparato PAL16C1

A7 A0 B0 A1 B1 A2 B2 A3 B3 GND  
 A4 B4 A5 B5 EQ NE A6 B6 B7 VCC

### EQUATIONS

```

NE = A0*/B0 + /A0* B0 ;A0 :+: B0
    + A1*/B1 + /A1* B1 ;A1 :+: B1
    + A2*/B2 + /A2* B2 ;A2 :+: B2
    + A3*/B3 + /A3* B3 ;A3 :+: B3
    + A4*/B4 + /A4* B4 ;A4 :+: B4
    + A5*/B5 + /A5* B5 ;A5 :+: B5
    + A6*/B6 + /A6* B6 ;A6 :+: B6
    + A7*/B7 + /A7* B7 ;A7 :+: B7
    
```

### SIMULATION

TRACE\_ON A7 A6 A5 A4 A3 A2 A1 A0 NE  
 B7 B6 B5 B4 B3 B2 B1 B0

```

SETF A7 /A6 /A5 /A4 /A3 /A2 /A1 /A0 ;A7=H, B7=L
    /B7 /B6 /B5 /B4 /B3 /B2 /B1 /B0
SETF /A7 A6 ;A6=H, B6=L
SETF /A6 A5 ;A5=H, B5=L
SETF /A5 A4 ;A4=H, B4=L
SETF /A4 A3 ;A3=H, B3=L
SETF /A3 A2 ;A2=H, B2=L
SETF /A2 A1 ;A1=H, B1=L
SETF /A1 A0 ;A0=H, B0=L
SETF /A7 /A6 /A5 /A4 /A3 /A2 /A1 /A0 ;A7=L, B7=H
    B7
SETF /B7 B6 ;A6=L, B6=H
SETF /B6 B5 ;A5=L, B5=L
SETF /B5 B4 ;A4=L, B4=H
SETF /B4 B3 ;A3=L, B3=H
SETF /B3 B2 ;A2=L, B2=H
SETF /B2 B1 ;A1=L, B1=H
SETF /B1 B0 ;A0=L, B0=H
SETF /B0 ;Test all L's
SETF A7 A6 A5 A4 A3 A2 A1 A0 ;Test all H's
    B7 B6 B5 B4 B3 B2 B1 B0
SETF /A7 A6 /A5 A4 /A3 A2 /A1 A0 ;Test even ones
    /B7 B6 /B5 B4 /B3 B2 /B1 B0
SETF A7 /A6 A5 /A4 A3 /A2 A1 /A0 ;Test odd ones
    B7 /B6 B5 /B4 B3 /B2 B1 /B0
    
```

;Function Table for PALASMI

;A7 A6 A5 A4 A3 A2 A1 A0 B7 B6 B5 B4 B3 B2 B1 B0 NE EQ

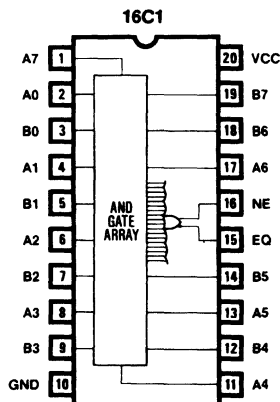
| ; Input A  | Input B  | Outputs | Comments               |
|------------|----------|---------|------------------------|
| ; 76543210 | 76543210 | NE EQ   |                        |
| ; HLLLLLLL | LLLLLLLL | H L     | A7=H, B7=L             |
| ; LHLLLLLL | LLLLLLLL | H L     | A6=H, B6=L             |
| ; LLHLLLLL | LLLLLLLL | H L     | A5=H, B5=L             |
| ; LLLHLLLL | LLLLLLLL | H L     | A4=H, B4=L             |
| ; LLLLHLLL | LLLLLLLL | H L     | A3=H, B3=L             |
| ; LLLLLHLL | LLLLLLLL | H L     | A2=H, B2=L             |
| ; LLLLLLHL | LLLLLLLL | H L     | A1=H, B1=L             |
| ; LLLLLLLH | LLLLLLLL | H L     | A0=H, B0=L             |
| ; LLLLLLLL | HLLLLLLL | H L     | A7=L, B7=H             |
| ; LLLLLLLL | LHLLLLLL | H L     | A6=L, B6=H             |
| ; LLLLLLLL | LLHLLLLL | H L     | A5=L, B5=H             |
| ; LLLLLLLL | LLLHLLLL | H L     | A4=L, B4=H             |
| ; LLLLLLLL | LLLLHLLL | H L     | A3=L, B3=H             |
| ; LLLLLLLL | LLLLLHLL | H L     | A2=L, B2=H             |
| ; LLLLLLLL | LLLLLLHL | H L     | A1=L, B1=H             |
| ; LLLLLLLL | LLLLLLLH | H L     | A0=L, B0=H             |
| ; LLLLLLLL | LLLLLLLL | L H     | Test all L's           |
| ; HHHHHHHH | HHHHHHHH | L H     | Test all H's           |
| ; HLHLHLHL | HLHLHLHL | L H     | Test even checkerboard |
| ; LHHLHLHL | LHHLHLHL | L H     | Test odd checkerboard  |

## Simulation Results

```

Page : 1
ggggggggggg ggggggggggg
A7 HLLLLLLLLL LLLLLLHLH
A6 LHLLLLLLLL LLLLLLHLH
A5 LLHLLLLLLL LLLLLLHLH
A4 LLLHLLLLLL LLLLLLHLH
A3 LLLLHLLLLL LLLLLLHLH
A2 LLLLLHLLL  LLLLLLHLH
A1 LLLLLLHLL LLLLLLHLH
A0 LLLLLLLHL LLLLLLHLH
NE HHHHHHHHHH HHHHHHLHL
B7 LLLLLLHL  LLLLLLHLH
B6 LLLLLLHLL LLLLLLHLH
B5 LLLLLLLLLL LLLLLLHLH
B4 LLLLLLLLLL LLLLLLHLH
B3 LLLLLLLLLL LLLLLLHLH
B2 LLLLLLLLLL LLLLLLHLH
B1 LLLLLLLLLL LLLLLLHLH
B0 LLLLLLLLLL LLLLLLHLH
    
```

## Logic Symbol



T801710M

## Three-to-Eight Demultiplexer

### PAL Device Design Specification

Title 3to8 Dmux  
 Pattern 3to8Dmux.pds  
 Revision A  
 Author Mehrnaz Hada  
 Company Monolithic Memories Inc., Santa Clara, CA  
 Date 1/29/85

;The 3-to-8 demultiplexer with control storage provides a  
 ;conventional 8-bit demux function combined with control  
 ;storage functions: load true, load complement, hold, toggle,  
 ;polarity, clear and preset. Five inputs(/LD,/CLR,/PR,POL,  
 ;TOG) select one of six operations. The six operations are  
 ;summarized in the following operations table:

| Control | Functions    | Polarity | Inputs  | Outputs |              |
|---------|--------------|----------|---------|---------|--------------|
| /OC CLK | /CLR /PR /LD | POL      | TOG ABC | Q7-Q0   | Operation    |
| H       | X X X X X    | X        | X X X   | Z       | HI-Z         |
| L       | C L X X X    | X        | X X X   | L       | Clear        |
| L       | C H L X X    | X        | X X X   | H       | PRESET       |
| L       | C H H L H    | X        | X I     | MUX     | Load true    |
| L       | C H H L L    | X        | X I     | /MUX    | Load comp    |
| L       | C H H H X    | X        | L X     | Q       | Hold         |
| L       | C H H H X    | X        | H X     | /Q      | Tog polarity |

CHIP 3to8Dmux PAL16R8

CLK /CLR /PR A B C /LD POL TOG GND  
 /OC Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

#### EQUATIONS

```

/Q0 := CLR ;Clear Q0
+ /PR* LD*/POL*/C*/B*/A ;Decode 000
+ /PR* LD* POL* B A ;Load true
+ /PR* LD* POL* C ;Load true
+ /PR*/LD*/TOG*/Q0 ;Hold
+ /PR*/LD* TOG* Q0 ;Toggle polarity

/Q1 := CLR ;Clear Q1
+ /PR* LD*/POL*/C*/B*/A ;Decode 001
+ /PR* LD* POL* B /A ;Load true
+ /PR* LD* POL* C ;Load true
+ /PR*/LD*/TOG*/Q1 ;Hold
+ /PR*/LD* TOG* Q1 ;Toggle polarity

/Q2 := CLR ;Clear Q2
+ /PR* LD*/POL*/C* B*/A ;Decode 010
+ /PR* LD* POL* B A ;Load true
+ /PR* LD* POL* /B ;Load true
+ /PR* LD* POL* C ;Load true
+ /PR*/LD*/TOG*/Q2 ;Hold
+ /PR*/LD* TOG* Q2 ;Toggle polarity

/Q3 := CLR ;Clear Q3
+ /PR* LD*/POL*/C* B* A ;Decode 011
+ /PR* LD* POL* B /A ;Load true
+ /PR* LD* POL* C /B ;Load true
+ /PR* LD* POL* C ;Load true
+ /PR*/LD*/TOG*/Q3 ;Hold
+ /PR*/LD* TOG* Q3 ;Toggle polarity

/Q4 := CLR ;Clear Q4
+ /PR* LD*/POL* C*/B*/A ;Decode 100
+ /PR* LD* POL* B A ;Load true
+ /PR* LD* POL* C ;Load true
+ /PR* LD* POL*/C ;Load true
+ /PR*/LD*/TOG*/Q4 ;Hold
+ /PR*/LD* TOG* Q4 ;Toggle polarity

/Q5 := CLR ;Clear Q5
+ /PR* LD*/POL* C*/B* A ;Decode 101
+ /PR* LD* POL* B /A ;Load true
+ /PR* LD* POL* C ;Load true
+ /PR* LD* POL*/C ;Load true
+ /PR*/LD*/TOG*/Q5 ;Hold
+ /PR*/LD* TOG* Q5 ;Toggle polarity

/Q6 := CLR ;Clear Q6
+ /PR* LD*/POL* C* B*/A ;Decode 110
+ /PR* LD* POL* B A ;Load true
+ /PR* LD* POL* C /B ;Load true
+ /PR* LD* POL*/C ;Load true
+ /PR*/LD*/TOG*/Q6 ;Hold
+ /PR*/LD* TOG* Q6 ;Toggle polarity

/Q7 := CLR ;Clear Q7
+ /PR* LD*/POL* C* B* A ;Decode 111
+ /PR* LD* POL* C /B /A ;Load true
+ /PR* LD* POL*/C ;Load true
+ /PR*/LD*/TOG*/Q7 ;Hold
+ /PR*/LD* TOG* Q7 ;Toggle polarity
    
```

SIMULATION

TRACE\_ON /OC /CLR /PR /LD POL TOG C B A  
 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0

```

SETF OC CLR PR LD POL /TOG ;Clear
CLOCKF CLK ;Preset
SETF /CLR ;Load 0
CLOCKF CLK ;Load 1
SETF A ;Load 2
CLOCKF CLK ;Load 3
SETF B /A ;Hold
CLOCKF CLK ;Toggle polarity
SETF /LD ;Toggle polarity
CLOCKF CLK ;Load 0 complement
SETF TOG ;Load 1 complement
CLOCKF CLK ;Test HI-Z
SETF /OC
CLOCKF CLK
    
```

#### Function Table for PALAS1

/OC CLK /CLR /PR /LD POL TOG C B A Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0

| Control | Functions    | Polarity | Input | Output   | Comments  |
|---------|--------------|----------|-------|----------|-----------|
| /OC CLK | /CLR /PR /LD | POL TOG  | CBA   | Q7---Q0  |           |
| L       | C L L L H    | L H L    | XXX   | LLLLLLLL | Clear     |
| L       | C H L L H    | L H L    | XXX   | HHHHHHHH | PRESET    |
| L       | C H H L H    | H X X    | LLL   | LLLLLLLL | Load 0    |
| L       | C H H L H    | H X X    | LLH   | LLLLLHL  | Load 1    |
| L       | C H H L H    | H X X    | LHL   | LLLHLHL  | Load 2    |
| L       | C H H L H    | H X X    | LHH   | LLLHLLL  | Load 3    |
| L       | C H H L H    | H X X    | HLL   | LLHLLL   | Load 4    |
| L       | C H H L H    | H X X    | HLL   | LLHLLL   | Load 5    |
| L       | C H H L H    | H X X    | HLL   | LLHLLL   | Load 6    |
| L       | C H H L H    | H X X    | HHH   | HLHLLL   | Load 7    |
| L       | C H H H X    | L X L    | XXX   | HLHLLL   | Hold 7    |
| L       | C H H H X    | H X H    | XXX   | LHHHHHHH | Hold      |
| L       | C H H H X    | H X H    | XXX   | HLHLLL   | Hold      |
| L       | C H H L L    | L X L    | LLL   | HHHHHHH  | Load 0    |
| L       | C H H L L    | L X L    | LH    | HHHHHL   | Load 1    |
| L       | C H H L L    | L X L    | LH    | HHHHLH   | Load 2    |
| L       | C H H L L    | L X L    | LH    | HHHHLH   | Load 3    |
| L       | C H H L L    | L X L    | HLL   | HHHHLH   | Load 4    |
| L       | C H H L L    | L X L    | HLL   | HHHHLH   | Load 5    |
| L       | C H H L L    | L X L    | HHL   | HHHHLH   | Load 6    |
| L       | C H H L L    | L X L    | HHH   | LHHHHHHH | Load 7    |
| L       | C H H H X    | L X L    | XXX   | LHHHHHHH | Hold 7    |
| L       | C H H H X    | H X H    | XXX   | HLHLLL   | Hold      |
| L       | C H H H X    | H X H    | XXX   | LHHHHHHH | Hold      |
| H       | X X X X X    | X X X    | XXX   | ZZZZZZZZ | Test HI-Z |



### Simulation Results

```

Page : 1
g cgccgc gcgcgc cgc gcg c
/OC LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
/CLR LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
/PR LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
/LD LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
POL HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH
TOG LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
C XXXXXXXLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
B XXXXXXXLLL HHHHHHHHLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
A XXXXXLLHLL HHHHHHHHLL HHHHHHHH HHHHHHHH HHHHHHHH HHHHHHHH HHHHHHHH HHHHHHHH
Q7 XXXLHLLHLL LLLLLLHLLH HHH2ZZZ
Q6 XXXLHLLHLL LLLLLLHLLH HHH2ZZZ
Q5 XXXLHLLHLL LLLLLLHLLH HHH2ZZZ
Q4 XXXLHLLHLL LLLLLLHLLH HHH2ZZZ
Q3 XXXLHLLHLL LLLLLLHLLH HHH2ZZZ
Q2 XXXLHLLHLL LLLLLLHLLH HHH2ZZZ
Q1 XXXLHLLHLL LLLLLLHLLH HLL2ZZZ
Q0 XXXLHLLHLL LLLLLLHLLH LHH2ZZZ
    
```

T801720M

# Basic Flip Flops

## PAL Device Design Specification

Title Basic Flip Flops  
 Pattern FlipFlop.pds  
 Revision A  
 Author Vincent Coli  
 Company Monolithic Memories Inc., Santa Clara, CA  
 Date 2/28/85

CHIP FlipFlop PAL16RP8

CLK J K T PR CLR D S R GND  
 /OC /SRC /SRT /DC /DT /TC /TT /JKC /JKT VCC

### EQUATIONS

```
JKT := J*/JKT*/CLR           ;JK Flip-Flop
      + /K* JKT*/PR         ;(JK = /Q)
      + PR                   ;Preset Q

JKC := /J* K */PR           ;JK Flip-Flop
      + /J*/JKT*/PR         ;(JK = /Q)
      + K* JKT*/PR          ;Clear /Q
      + CLR                   ;Clear /Q

TT := T*/TT*/CLR           ;T Flip-Flop
      + /T* TT*/CLR         ;(TT = Q)
      + PR                   ;Preset Q

TC := /T*/TT*/CLR           ;T Flip-Flop
      + T* TT*/PR           ;(TC = /Q)
      + CLR                   ;Clear /Q

DT := D*/CLR                ;D Flip-Flop
      + PR                   ;Preset Q

DC := /D*/PR                ;D Flip-Flop
      + CLR                   ;Clear /Q

SRT := S* */CLR            ;Set-Reset Flip-Flop
      + /R* SRT*/CLR        ;(SRT = Q)
      + PR                   ;Preset Q

SRC := /S* R */PR           ;Set-Reset Flip-Flop
      + /S*/SRT*/PR         ;(SRC = /Q)
      + CLR                   ;Clear /Q
```

### SIMULATION

TRACE\_ON /OC PR CLR J K JKT T TT D DT S R SRT

```
SETF OC /PR CLR           ; Clear
CLOCKF
SETF /CLR /J /K          ; Toggle
CLOCKF
SETF J                    ; Toggle
CLOCKF
SETF /K                   ; Toggle
CLOCKF
SETF /J                   ; Toggle
CLOCKF
SETF K                    ; Toggle
CLOCKF
SETF PR                   ; Preset
CLOCKF
SETF /PR J K             ; Toggle
CLOCKF
SETF /K                   ; Toggle
CLOCKF
SETF CLR                 ; Clear
CLOCKF
SETF /CLR /T            ; Toggle
CLOCKF
SETF T                   ; Toggle
CLOCKF
SETF /T                  ; Toggle
CLOCKF

SETF CLR                 ; Clear
CLOCKF
SETF /D                  ; Toggle
CLOCKF
SETF D                   ; Toggle
CLOCKF
SETF /D                  ; Toggle
CLOCKF
```

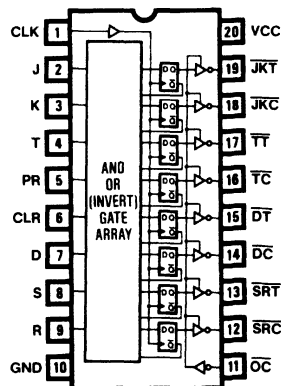
```
SETF CLR                 ; Clear
CLOCKF
SETF /CLR /S /R         ; Set
CLOCKF
SETF S                   ; Set
CLOCKF
SETF /S R               ; Reset
CLOCKF
SETF /S R               ; Hold
CLOCKF
SETF /OC                 ; HI-Z
CLOCKF
```

## Simulation Results

```
g cg cg c g cg cg cg cg cg cg cg cg c
/OC LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
PR LLLLLLLLLL LLLLLLLLLL LHHHHLLLLL LLLLLLLLLL
CLR HHHHHLLLLL LLLLLLLLLL LLLLLLLLLL LHHHHLLLLL
J XXXXLLLLLL HHHHHLLLLL LLLLLHHHHH HHHHHHHHHH
K XXXXLLLLHH HHHLLLLLLL HHHHHHHLLL LLLLLLLLLL
JKT XXXXLLLLLL LHHHHHHHHH HLLHHHLLL HHHLLLLHHH
T XXXXXXXXXXX XXXXXXXXXXX XXXXXXXXXXX XXXXLLHHH
TT XXXXLLXXX XXXXXXXXXXX XXXXXXXXXXX XXXXLLHHH
D XXXXXXXXXXX XXXXXXXXXXX XXXXXXXXXXX XXXXXXXXXXX
DT XXXXLLXXX XXXXXXXXXXX XXXXXXXXXXX XXXXLLXXX
S XXXXXXXXXXX XXXXXXXXXXX XXXXXXXXXXX XXXXXXXXXXX
R XXXXXXXXXXX XXXXXXXXXXX XXXXXXXXXXX XXXXXXXXXXX
SRT XXXXLLXXX XXXXXXXXXXX XXXXHHHXXX XXXXLLXXX
```

```
Page : 2
g cg cg cg cg cg cg cg cg cg cg cg cg cg cg
/OC LLLLLL LLL LLLLLLLLL LLLLLLLLLL LHH
PR LLLLLL LLL LLLLLLLLL LLLLLLLLLL LLL
CLR LLLHHHHHH HHHHHHHLLL LLLLLLLLLL
J HHHHHHHHH HHHHHHHHH HHHHHHHHH
K LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
JKT HHHHHLLLLL LLLLLLLLLL HHHHHHHHH
T LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
TT HHHHHLLLLL LLLLLLLLLL LLLLLLLLLL
D XXXXLLXXX HHHLLLLLLL LLLLLLLLLL
DT XXXXLLXXX LLLLLLLLLL LLLLLLLLLL
S XXXXXXXXXXX XXXXLLXXX HHHLLLLLLL
R XXXXXXXXXXX XXXXLLXXX LLLHHHHHH
SRT XXXXLLLLL LLLLLLLLLL LHHHHLLLLL
```

## Logic Symbol



TB01730M

## 9-Bit Register

### PAL Device Design Specification

Title 9BitRegister  
 Pattern 9BitReg.pds  
 Revision A  
 Author Vincent Coli/Mehrnaz Hada  
 Company Monolithic Memories Inc., Santa Clara, CA  
 Date 1/30/85

This is a design of a 9-bit register with parallel load and hold capabilities. The operations of this register are summarized in the following operations table:

|  | /OC | CLK | /LD | D8-D0 | Q8-Q0 | Operation |
|--|-----|-----|-----|-------|-------|-----------|
|  | H   | X   | X   | X     | Z     | HI-Z      |
|  | L   | 1   | H   | X     | Q     | Hold      |
|  | L   | 1   | L   | D     | D     | Load      |

CHIP 9BitRegister PAL20X10

CLK D0 D1 D2 D3 D4 D5 D6 D7 D8 /LD GND  
 /OC NC Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

#### EQUATIONS

```

/Q0 := /D0* LD ;Load D0
      + /Q0*/LD ;Hold Q0

/Q1 := /D1* LD ;Load D1
      + /Q1*/LD ;Hold Q1

/Q2 := /D2* LD ;Load D2
      + /Q2*/LD ;Hold Q2

/Q3 := /D3* LD ;Load D3
      + /Q3*/LD ;Hold Q3

/Q4 := /D4* LD ;Load D4
      + /Q4*/LD ;Hold Q4

/Q5 := /D5* LD ;Load D5
      + /Q5*/LD ;Hold Q5

/Q6 := /D6* LD ;Load D6
      + /Q6*/LD ;Hold Q6

/Q7 := /D7* LD ;Load D7
      + /Q7*/LD ;Hold Q7

/Q8 := /D8* LD ;Load D8
      + /Q8*/LD ;Hold Q8
    
```

#### SIMULATION

```

TRACE_ON /OC CLK /LD D8 D7 D6 D5 D4 D3 D2 D1 D0
          Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0

SETF OC LD /D8 /D7 /D6 /D5 /D4 /D3 ;Load zeros
      /D2 /D1 /D0
CLOCKF CLK

SETF /LD ;Hold zeros
CLOCKF CLK

SETF LD D8 D7 D6 D5 D4 D3 D2 D1 D0 ;Load ones
CLOCKF CLK

SETF /LD ;Hold ones
CLOCKF CLK

SETF LD /D8 D7 /D6 D5 /D4 D3 /D2 D1 /D0 ;Hold even ones
CLOCKF CLK

SETF /LD ;Hold odd ones
CLOCKF CLK

SETF OC ;Test HI-Z
CLOCKF CLK
    
```

;Function Table for PALASM1

```

;/OC CLK D9 D8 D7 D6 D5 D4 D3 D2 D1 D0
;Q9 Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0
    
```

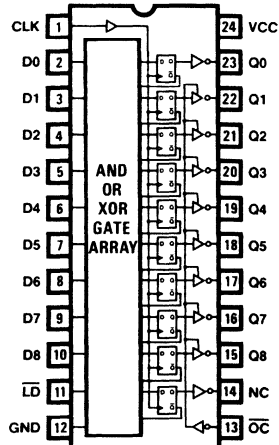
### Simulation Results

|          |            | Data In    | Data Out               |  |
|----------|------------|------------|------------------------|--|
| ;Control | DDDDDDDDDD | QQQQQQQQQQ |                        |  |
| ;/OC CLK | 9876543210 | 9876543210 | Comment                |  |
| ; L C    | LLLLLLLLLL | LLLLLLLLLL | Load all zeros         |  |
| ; L L    | XXXXXXXXXX | LLLLLLLLLL | Hold all zeros         |  |
| ; L C    | HHHHHHHHHH | HHHHHHHHHH | Load all ones          |  |
| ; L L    | XXXXXXXXXX | HHHHHHHHHH | Hold all ones          |  |
| ; L C    | HLHLHLHLHL | HLHLHLHLHL | Load even checkerboard |  |
| ; L L    | XXXXXXXXXX | HLHLHLHLHL | Hold even checkerboard |  |
| ; L C    | LHLHLHLHL  | LHLHLHLHL  | Load odd checkerboard  |  |
| ; L L    | XXXXXXXXXX | LHLHLHLHL  | Hold odd checkerboard  |  |
| ; H X    | XXXXXXXXXX | ZZZZZZZZZZ | Test HI-Z              |  |

Page : 1

```

g cgcgcgc cgcgcgcg c
/OC LLLLLLLLLL LLLLLLLLH MHM
CLK XXHLHLHLHL HLHLHLHL HL
/LD LLLLLHLHLH LHLHLHLH MHM
D8 LLLLLLHHH LLLLHHHHH MHM
D7 LLLLLLHHH HHHHLHLHL LLL
D6 LLLLLLHHH LLLLHHHHH MHM
D5 LLLLLLHHH HHHHLHLHL LLL
D4 LLLLLLHHH LLLLHHHHH MHM
D3 LLLLLLHHH HHHHLHLHL LLL
D2 LLLLLLHHH LLLLHHHHH MHM
D1 LLLLLLHHH HHHHLHLHL LLL
D0 LLLLLLHHH LLLLHHHHH MHM
Q8 XXXLLLLLHH HLLLHHHHZ ZZZ
Q7 XXXLLLLLHH HHHHLHLHL ZZZ
Q6 XXXLLLLLHH HLLLHHHHZ ZZZ
Q5 XXXLLLLLHH HHHHLHLHL ZZZ
Q4 XXXLLLLLHH HLLLHHHHZ ZZZ
Q3 XXXLLLLLHH HHHHLHLHL ZZZ
Q2 XXXLLLLLHH HLLLHHHHZ ZZZ
Q1 XXXLLLLLHH HHHHLHLHL ZZZ
Q0 XXXLLLLLHH HLLLHHHHZ ZZZ
    
```



T801740M

# 10-Bit Register

## PAL Device Design Specification

Title 10BitRegister  
 Pattern 10BitReg.pds  
 Revision A  
 Author Vincent Coli/Mehrnaz Hada  
 Company Monolithic Memories Inc., Santa Clara, CA  
 Date 1/28/85

;The 10-bit register loads the data (D9-D0) on the rising edge of the clock(CLK) into the register(Q9-Q0). The data is held in the register until the next positive edge of the clock.

| ;/OC | CLK | D9-D0 | Q9-Q0 | Operation |
|------|-----|-------|-------|-----------|
| H    | X   | X     | Z     | HI-Z      |
| L    | C   | D     | D     | Load      |
| L    | L   | X     | Q     | Hold      |

CHIP 10BitReg PAL20X10

CLK D0 D1 D2 D3 D4 D5 D6 D7 D8 D9 GND  
 /OC Q9 Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

### EQUATIONS

```

/Q0 := /D0 ;Load D0
/Q1 := /D1 ;Load D1
/Q2 := /D2 ;Load D2
/Q3 := /D3 ;Load D3
/Q4 := /D4 ;Load D4
/Q5 := /D5 ;Load D5
/Q6 := /D6 ;Load D6
/Q7 := /D7 ;Load D7
/Q8 := /D8 ;Load D8
/Q9 := /D9 ;Load D9
    
```

### SIMULATION

TRACE\_ON /OC CLK Q9 Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0  
 D9 D8 D7 D6 D5 D4 D3 D2 D1 D0

SETF OC /D9 /D8 /D7 /D6 /D5 /D4 /D3 /D2 /D1 /D0  
 CLOCKF CLK ;Load all zeros

SETF D9 D8 D7 D6 D5 D4 D3 D2 D1 D0  
 CLOCKF CLK ;Load all ones

SETF D9 /D8 D7 /D6 D5 /D4 D3 /D2 D1 /D0  
 CLOCKF CLK

SETF /D9 D8 /D7 D6 /D5 D4 /D3 D2 /D1 D0  
 CLOCKF CLK

SETF /OC  
 CLOCKF CLK ;Test HI-Z

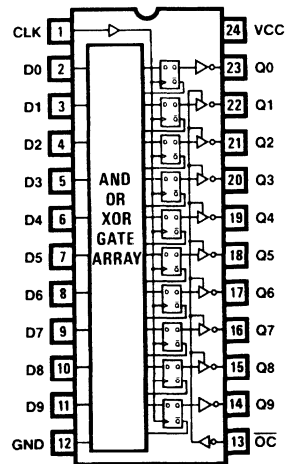
;Function Table for PALASM1

;/OC CLK D9 D8 D7 D6 D5 D4 D3 D2 D1 D0  
 ;Q9 Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0

| ;        |   | Data In    | Data Out   | Comment                         |
|----------|---|------------|------------|---------------------------------|
| ;/OC CLK |   | 9876543210 | 9876543210 |                                 |
| ;        | L | C          | LLLLLLLLLL | LLLLLLLLLL Load all zeros       |
| ;        | L | L          | XXXXXXXXXX | LLLLLLLLLL Hold all zeros       |
| ;        | L | C          | HHHHHHHHH  | HHHHHHHHH Load all ones         |
| ;        | L | L          | XXXXXXXXXX | HHHHHHHHH Hold all ones         |
| ;        | L | C          | HLHLHLHL   | HLHLHLHL Load even checkerboard |
| ;        | L | L          | XXXXXXXXXX | HLHLHLHL Hold even checkerboard |
| ;        | L | C          | LHLHLHLH   | LHLHLHLH Load odd checkerboard  |
| ;        | L | L          | XXXXXXXXXX | LHLHLHLH Hold odd checkerboard  |
| ;        | H | X          | ZZZZZZZZ   | ZZZZZZZZ Test HI-Z              |

## Simulation Results

Page : 1  
 g cg cg cg cg c  
 /OC LLLLLLLLLL LLLLLHHHH  
 CLK XXHLLLLLH LLLLLLHHL  
 Q9 XXXLLLLLH HHHLLZZZZ  
 Q8 XXXLLLLLH LLLHHZZZZ  
 Q7 XXXLLLLLH HHHLLZZZZ  
 Q6 XXXLLLLLH LLLHHZZZZ  
 Q5 XXXLLLLLH HHHLLZZZZ  
 Q4 XXXLLLLLH LLLHHZZZZ  
 Q3 XXXLLLLLH HHHLLZZZZ  
 Q2 XXXLLLLLH LLLHHZZZZ  
 Q1 XXXLLLLLH HHHLLZZZZ  
 Q0 XXXLLLLLH LLLHHZZZZ  
 D9 LLLLLHHHH HLLLLLLLL  
 D8 LLLLLHHHL LHHHHHHH  
 D7 LLLLLHHHH HLLLLLLLL  
 D6 LLLLLHHLL LHHHHHHH  
 D5 LLLLLHHHH HLLLLLLLL  
 D4 LLLLLHHLL LHHHHHHH  
 D3 LLLLLHHHH HLLLLLLLL  
 D2 LLLLLHHLL LHHHHHHH  
 D1 LLLLLHHHH HLLLLLLLL  
 D0 LLLLLHHLL LHHHHHHH



T801750M



# 16-Bit Barrel Shifter

## PAL Device Design Specification

```

Title      Barrel Shifter
Pattern    Barrel.pds
Revision   A
Author     Mehrnaz Hada
Company    Monolithic Memories Inc. Santa Clara, CA
Date       1/15/85

;The 16-bit barrel shifter will shift 16 bits of data
;(D15-D0) a number of locations into the output pins, as
;specified by the binary encoded input. A compacted
;equation can be used to specify this design. It can be
;specified as following:
;
;Q[J=0..15] :=
;    OR[K=0..15][D[(J+K)-((J+K)/16)*16]*BIN[K,I=3..0]S(I)]
;
;Inputs are shown by D. S1 are shift amount inputs and
;Q1 are outputs. 16 product terms in each output pair
;are directed to one output; thus only 16 out of 32
;output pins are used.

CHIP BarrelShift PAL64R32

D7 D6 D5 D4 D3 D2 D1 D0 /PL1 /PS1 GND CLK1
/OC1 Q0 NC Q1 NC Q2 NC Q3 NC Q4 NC Q5 NC Q6
NC Q7 NC /OC2 CLK2 VCC /PS2 /PL2 NC NC NC
NC NC S0 S1 S2 S3 NC NC NC NC NC NC NC
/PL3 /PS3 GND CLK3 /OC3 NC Q8 NC Q9 NC Q10
NC Q11 NC Q12 NC Q13 NC Q14 NC Q15 /OC4
CLK4 VCC /PS4 /PL4 D15 D14 D13 D12 D11 D10
D9 D8

EQUATIONS

Q0 := /S3 * /S2 * /S1 * /S0 * D0      ; No shift
+ /S3 * /S2 * /S1 * S0 * D1          ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D2          ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D3           ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D4          ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D5           ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D6           ; Shift 6 spaces
+ /S3 * S2 * S1 * S0 * D7           ; Shift 7 spaces
+ S3 * /S2 * /S1 * /S0 * D8          ; Shift 8 spaces
+ S3 * /S2 * /S1 * S0 * D9           ; Shift 9 spaces
+ S3 * /S2 * S1 * /S0 * D10          ; Shift 10 spaces
+ S3 * /S2 * S1 * S0 * D11           ; Shift 11 spaces
+ S3 * S2 * /S1 * /S0 * D12          ; Shift 12 spaces
+ S3 * S2 * /S1 * S0 * D13           ; Shift 13 spaces
+ S3 * S2 * S1 * /S0 * D14          ; Shift 14 spaces
+ S3 * S2 * S1 * S0 * D15           ; Shift 15 spaces

Q1 := /S3 * /S2 * /S1 * /S0 * D1      ; No shift
+ /S3 * /S2 * /S1 * S0 * D2          ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D3          ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D4           ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D5           ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D6           ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D7           ; Shift 6 spaces
+ /S3 * S2 * S1 * S0 * D8           ; Shift 7 spaces
+ S3 * /S2 * /S1 * /S0 * D9          ; Shift 8 spaces
+ S3 * /S2 * /S1 * S0 * D10          ; Shift 9 spaces
+ S3 * /S2 * S1 * /S0 * D11          ; Shift 10 spaces
+ S3 * /S2 * S1 * S0 * D12           ; Shift 11 spaces
+ S3 * S2 * /S1 * /S0 * D13          ; Shift 12 spaces
+ S3 * S2 * /S1 * S0 * D14           ; Shift 13 spaces
+ S3 * S2 * S1 * /S0 * D15          ; Shift 14 spaces
+ S3 * S2 * S1 * S0 * D0            ; Shift 15 spaces

Q2 := /S3 * /S2 * /S1 * /S0 * D2      ; No shift
+ /S3 * /S2 * /S1 * S0 * D3          ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D4          ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D5           ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D6           ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D7           ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D8           ; Shift 6 spaces
+ /S3 * S2 * S1 * S0 * D9           ; Shift 7 spaces
+ S3 * /S2 * /S1 * /S0 * D10          ; Shift 8 spaces
+ S3 * /S2 * /S1 * S0 * D11          ; Shift 9 spaces
+ S3 * /S2 * S1 * /S0 * D12          ; Shift 10 spaces
+ S3 * /S2 * S1 * S0 * D13           ; Shift 11 spaces
+ S3 * S2 * /S1 * /S0 * D14          ; Shift 12 spaces
+ S3 * S2 * /S1 * S0 * D15          ; Shift 13 spaces
+ S3 * S2 * S1 * /S0 * D0            ; Shift 14 spaces
+ S3 * S2 * S1 * S0 * D1            ; Shift 15 spaces

Q3 := /S3 * /S2 * /S1 * /S0 * D3      ; No shift
+ /S3 * /S2 * /S1 * S0 * D4          ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D5          ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D6           ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D7           ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D8           ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D9           ; Shift 6 spaces
+ /S3 * S2 * S1 * S0 * D10          ; Shift 7 spaces
+ S3 * /S2 * /S1 * /S0 * D11          ; Shift 8 spaces
+ S3 * /S2 * /S1 * S0 * D12          ; Shift 9 spaces
+ S3 * /S2 * S1 * /S0 * D13          ; Shift 10 spaces
+ S3 * /S2 * S1 * S0 * D14           ; Shift 11 spaces

Q4 := /S3 * /S2 * /S1 * /S0 * D4      ; No shift
+ /S3 * /S2 * /S1 * S0 * D5          ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D6          ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D7           ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D8           ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D9           ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D10          ; Shift 6 spaces
+ /S3 * S2 * S1 * S0 * D11          ; Shift 7 spaces
+ S3 * /S2 * /S1 * /S0 * D12          ; Shift 8 spaces
+ S3 * /S2 * /S1 * S0 * D13          ; Shift 9 spaces
+ S3 * /S2 * S1 * /S0 * D14          ; Shift 10 spaces
+ S3 * /S2 * S1 * S0 * D15          ; Shift 11 spaces
+ S3 * S2 * /S1 * /S0 * D0            ; Shift 12 spaces
+ S3 * S2 * /S1 * S0 * D1            ; Shift 13 spaces
+ S3 * S2 * S1 * /S0 * D2            ; Shift 14 spaces
+ S3 * S2 * S1 * S0 * D3            ; Shift 15 spaces

Q5 := /S3 * /S2 * /S1 * /S0 * D5      ; No shift
+ /S3 * /S2 * /S1 * S0 * D6          ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D7          ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D8           ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D9           ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D10          ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D11          ; Shift 6 spaces
+ /S3 * S2 * S1 * S0 * D12           ; Shift 7 spaces
+ S3 * /S2 * /S1 * /S0 * D13          ; Shift 8 spaces
+ S3 * /S2 * /S1 * S0 * D14          ; Shift 9 spaces
+ S3 * /S2 * S1 * /S0 * D15          ; Shift 10 spaces
+ S3 * S2 * /S1 * /S0 * D0            ; Shift 11 spaces
+ S3 * S2 * /S1 * S0 * D1            ; Shift 12 spaces
+ S3 * S2 * S1 * /S0 * D2            ; Shift 13 spaces
+ S3 * S2 * S1 * S0 * D3            ; Shift 14 spaces
+ S3 * S2 * S1 * S0 * D4            ; Shift 15 spaces

Q6 := /S3 * /S2 * /S1 * /S0 * D6      ; No shift
+ /S3 * /S2 * /S1 * S0 * D7          ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D8          ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D9           ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D10          ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D11          ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D12          ; Shift 6 spaces
+ /S3 * S2 * S1 * S0 * D13           ; Shift 7 spaces
+ S3 * /S2 * /S1 * /S0 * D14          ; Shift 8 spaces
+ S3 * /S2 * /S1 * S0 * D15          ; Shift 9 spaces
+ S3 * /S2 * S1 * /S0 * D0            ; Shift 10 spaces
+ S3 * /S2 * S1 * S0 * D1            ; Shift 11 spaces
+ S3 * S2 * /S1 * /S0 * D2            ; Shift 12 spaces
+ S3 * S2 * /S1 * S0 * D3            ; Shift 13 spaces
+ S3 * S2 * S1 * /S0 * D4            ; Shift 14 spaces
+ S3 * S2 * S1 * S0 * D5            ; Shift 15 spaces

Q7 := /S3 * /S2 * /S1 * /S0 * D7      ; No shift
+ /S3 * /S2 * /S1 * S0 * D8          ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D9          ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D10          ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D11          ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D12          ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D13          ; Shift 6 spaces
+ /S3 * S2 * S1 * S0 * D14           ; Shift 7 spaces
+ S3 * /S2 * /S1 * /S0 * D15          ; Shift 8 spaces
+ S3 * /S2 * /S1 * S0 * D0            ; Shift 9 spaces
+ S3 * /S2 * S1 * /S0 * D1            ; Shift 10 spaces
+ S3 * /S2 * S1 * S0 * D2            ; Shift 11 spaces
+ S3 * S2 * /S1 * /S0 * D3            ; Shift 12 spaces
+ S3 * S2 * /S1 * S0 * D4            ; Shift 13 spaces
+ S3 * S2 * S1 * /S0 * D5            ; Shift 14 spaces
+ S3 * S2 * S1 * S0 * D6            ; Shift 15 spaces

Q8 := /S3 * /S2 * /S1 * /S0 * D8      ; No shift
+ /S3 * /S2 * /S1 * S0 * D9          ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D10         ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D11          ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D12          ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D13          ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D14          ; Shift 6 spaces
+ /S3 * S2 * S1 * S0 * D15           ; Shift 7 spaces
+ S3 * /S2 * /S1 * /S0 * D0            ; Shift 8 spaces
+ S3 * /S2 * /S1 * S0 * D1            ; Shift 9 spaces
+ S3 * /S2 * S1 * /S0 * D2            ; Shift 10 spaces
+ S3 * /S2 * S1 * S0 * D3            ; Shift 11 spaces
+ S3 * S2 * /S1 * /S0 * D4            ; Shift 12 spaces
+ S3 * S2 * /S1 * S0 * D5            ; Shift 13 spaces
+ S3 * S2 * S1 * /S0 * D6            ; Shift 14 spaces
+ S3 * S2 * S1 * S0 * D7            ; Shift 15 spaces

Q9 := /S3 * /S2 * /S1 * /S0 * D9      ; No shift
+ /S3 * /S2 * /S1 * S0 * D10         ; Shift 1 space
+ /S3 * /S2 * S1 * /S0 * D11         ; Shift 2 spaces
+ /S3 * /S2 * S1 * S0 * D12          ; Shift 3 spaces
+ /S3 * S2 * /S1 * /S0 * D13          ; Shift 4 spaces
+ /S3 * S2 * /S1 * S0 * D14          ; Shift 5 spaces
+ /S3 * S2 * S1 * /S0 * D15          ; Shift 6 spaces
+ S3 * /S2 * /S1 * /S0 * D0            ; Shift 7 spaces
+ S3 * /S2 * /S1 * S0 * D1            ; Shift 8 spaces
+ S3 * /S2 * S1 * /S0 * D2            ; Shift 9 spaces
+ S3 * /S2 * S1 * S0 * D3            ; Shift 10 spaces
+ S3 * S2 * /S1 * /S0 * D4            ; Shift 11 spaces
+ S3 * S2 * /S1 * S0 * D5            ; Shift 12 spaces
+ S3 * S2 * S1 * /S0 * D6            ; Shift 13 spaces
+ S3 * S2 * S1 * S0 * D7            ; Shift 14 spaces
+ S3 * S2 * S1 * S0 * D8            ; Shift 15 spaces

```

TR017604



# 16-Bit Addressable Register

## PAL Device Design Specification

**TITLE** 16-BIT ADDRESSABLE REGISTER  
**PATTERN** ADREG16.PDS  
**REVISION** 1  
**AUTHOR** John Birkner  
**COMPANY** Monolithic Memories Inc. Santa Clara, CA  
**DATE** 2/11/85  
 ; The 16-bit addressable register loads one of 16 registers selected by ADDR(0..3) with data input, DATA.

**CHIP** ADREG16 PAL32R16  
 Q0 Q1 Q2 Q3 /E1 NC NC A0 A1 VCC A2 A3 DATA NC /PRLD2 CLK2  
 Q4 Q5 Q6 Q7 Q8 Q9 Q10 Q11 /E2 NC NC NC NC GND NC NC NC NC /PRLD1 CLK1  
 Q12 Q13 Q14 Q15

**EQUATIONS**

```

Q0 := A0          *Q0      ;hold
    + A1          *Q0      ;hold
    + A2          *Q0      ;hold
    + A3*Q0       ;hold
    + /A0*/A1*/A2*/A3*DATA ;load

Q1 := /A0         *Q1      ;hold
    + A1          *Q1      ;hold
    + A2          *Q1      ;hold
    + A3*Q1       ;hold
    + A0*/A1*/A2*/A3*DATA ;load

Q2 := A0          *Q2      ;hold
    + /A1         *Q2      ;hold
    + A2          *Q2      ;hold
    + A3*Q2       ;hold
    + /A0* A1*/A2*/A3*DATA ;load

Q3 := /A0         *Q3      ;hold
    + /A1         *Q3      ;hold
    + A2          *Q3      ;hold
    + A3*Q3       ;hold
    + A0* A1*/A2*/A3*DATA ;load

Q4 := A0          *Q4      ;hold
    + A1          *Q4      ;hold
    + /A2         *Q4      ;hold
    + A3*Q4       ;hold
    + /A0*/A1* A2*/A3*DATA ;load

Q5 := /A0         *Q5      ;hold
    + A1          *Q5      ;hold
    + /A2         *Q5      ;hold
    + A3*Q5       ;hold
    + A0*/A1* A2*/A3*DATA ;load

Q6 := A0          *Q6      ;hold
    + /A1         *Q6      ;hold
    + /A2         *Q6      ;hold
    + A3*Q6       ;hold
    + /A0* A1* A2*/A3*DATA ;load

Q7 := /A0         *Q7      ;hold
    + /A1         *Q7      ;hold
    + /A2         *Q7      ;hold
    + A3*Q7       ;hold
    + A0* A1* A2*/A3*DATA ;load

Q8 := A0          *Q8      ;hold
    + A1          *Q8      ;hold
    + A2          *Q8      ;hold
    + /A3*Q8       ;hold
    + /A0*/A1*/A2* A3*DATA ;load

Q9 := /A0         *Q9      ;hold
    + A1          *Q9      ;hold
    + A2          *Q9      ;hold
    + /A3*Q9       ;hold
    + A0*/A1*/A2* A3*DATA ;load

Q10 := A0         *Q10     ;hold
    + /A1         *Q10     ;hold
    + A2          *Q10     ;hold
    + /A3*Q10      ;hold
    + /A0* A1*/A2* A3*DATA ;load

Q11 := /A0        *Q11     ;hold
    + /A1         *Q11     ;hold
    + A2          *Q11     ;hold
    + /A3*Q11      ;hold
    + A0* A1*/A2* A3*DATA ;load

Q12 := A0         *Q12     ;hold
    + A1          *Q12     ;hold
    + /A2         *Q12     ;hold
    + /A3*Q12      ;hold
    + /A0*/A1* A2* A3*DATA ;load

Q13 := /A0        *Q13     ;hold
    + A1          *Q13     ;hold
    + /A2         *Q13     ;hold
    + /A3*Q13      ;hold
    + A0*/A1* A2* A3*DATA ;load

Q14 := A0         *Q14     ;hold
    + /A1         *Q14     ;hold
    + /A2         *Q14     ;hold
    + /A3*Q14      ;hold
  
```

```

+ /A3*Q14      ;hold
+ /A0* A1* A2* A3*DATA ;load

Q15 := /A0      *Q15      ;hold
    + /A1       *Q15      ;hold
    + /A2       *Q15      ;hold
    + /A3*Q15   ;hold
    + A0* A1* A2* A3*DATA ;load
  
```

**SIMULATION**

```

TRACE_ON Q0 Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9 Q10 Q11 Q12 Q13 Q14 Q15
A0 A1 A2 A3 DATA
SETF E1 E2 /DATA /PRLD1 /PRLD2
  
```

```

SETF /A0 /A1 /A2 /A3
CLOCKF CLK1 CLK2

SETF A0 /A1 /A2 /A3
CLOCKF CLK1 CLK2

SETF /A0 A1 /A2 /A3
CLOCKF CLK1 CLK2

SETF A0 A1 /A2 /A3
CLOCKF CLK1 CLK2

SETF /A0 /A1 A2 /A3
CLOCKF CLK1 CLK2

SETF A0 /A1 A2 /A3
CLOCKF CLK1 CLK2

SETF /A0 A1 /A2 A3
CLOCKF CLK1 CLK2

SETF A0 A1 /A2 A3
CLOCKF CLK1 CLK2

SETF /A0 /A1 A2 A3
CLOCKF CLK1 CLK2

SETF A0 /A1 A2 A3
CLOCKF CLK1 CLK2

SETF /A0 A1 A2 A3
CLOCKF CLK1 CLK2

SETF DATA

SETF /A0 /A1 /A2 /A3
CLOCKF CLK1 CLK2
  
```



## Simulation Results

```

Page : 1
g 5 cgcgcgc cgcgcgcgcgc cgcgcgcgcgc cgcgcgcgc
Q0 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q1 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q2 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q3 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q4 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q5 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q6 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q7 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q8 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q9 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q10 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q11 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q12 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q13 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q14 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Q15 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
A0 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
A1 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
A2 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
A3 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
DATA XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  
```

T801780M

# 16-Bit Addressable Register

## XPLOT Output

PALASH XPLOT, V2.06 - BETA RELEASE  
(C) - COPYRIGHT MONOLITHIC MEMORIES INC., 1984

Title : 16-Bit Addressable Register  
Pattern : ADREG16.PDS  
Revision : A  
Author : John Birkner  
Company : Monolithic Memories Inc  
Date : 2/11/85

PAL32R16  
ADREG16

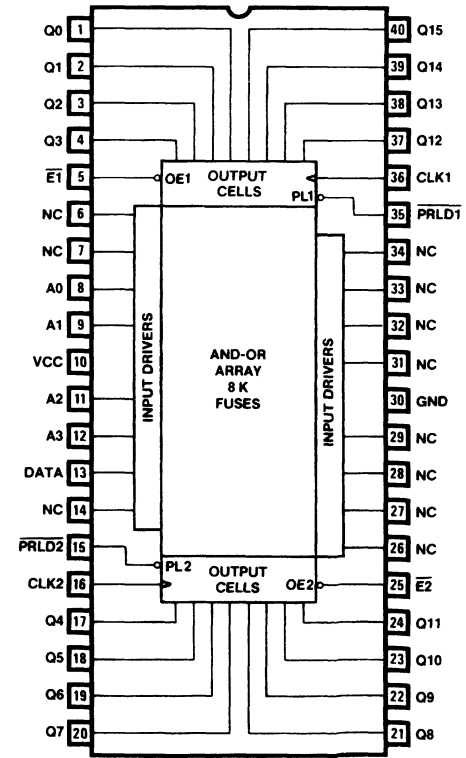
|          |          |          |          |          |          |          |        |
|----------|----------|----------|----------|----------|----------|----------|--------|
| 0        | 111111   | 11112222 | 22223333 | 33333333 | 44444444 | 44555555 | 555555 |
| 01234567 | 89012345 | 67890123 | 45678901 | 23-56789 | 01234567 | 89012345 | 67890  |
| 1        |          |          |          |          |          |          |        |
| 2        |          |          |          |          |          |          |        |
| 3        |          |          |          |          |          |          |        |
| 4        |          |          |          |          |          |          |        |
| 5        |          |          |          |          |          |          |        |
| 6        |          |          |          |          |          |          |        |
| 7        |          |          |          |          |          |          |        |
| 8        |          |          |          |          |          |          |        |
| 9        |          |          |          |          |          |          |        |
| 10       |          |          |          |          |          |          |        |
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| 85       |          |          |          |          |          |          |        |
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| 90       |          |          |          |          |          |          |        |
| 91       |          |          |          |          |          |          |        |
| 92       |          |          |          |          |          |          |        |
| 93       |          |          |          |          |          |          |        |
| 94       |          |          |          |          |          |          |        |
| 95       |          |          |          |          |          |          |        |

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| 123 |  |  |  |  |  |  |  |
| 124 |  |  |  |  |  |  |  |
| 125 |  |  |  |  |  |  |  |
| 126 |  |  |  |  |  |  |  |
| 127 |  |  |  |  |  |  |  |

OUTPUT PINS: 11122223334  
POLARITY FUSE: 1234789012347890

OUTPUT BANK: 4-40 17-24  
FLUSH FUSE: X X

TOTAL FUSES BLOWN: 5008



## Traffic Signal Controller

### State Machine Design Example

Figure 1 illustrates a simple traffic intersection consisting of two one-way streets, direction 1 and direction 2. Each direction has a signal consisting of red, yellow, and green lamps which are activated with appropriately named active high signals. Also each direction has a sensor which provides an active high signal indicating the presence of an oncoming vehicle. Our controller is to manage this intersection with the sensors as inputs and the lamps as outputs, as shown in Figure 2.

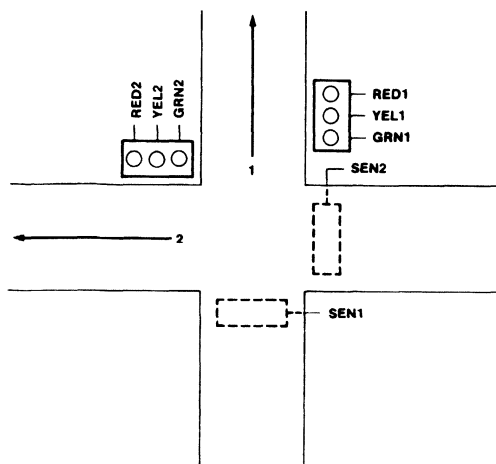


Figure 1. Traffic Intersection

Figure 2 also includes the system clock and an initialize (or reset) signal, which drives the controller to a predefined initial state. This raises two important issues in designing sequential logic with PAL devices. First, all circuit implementations of sequential logic with PAL devices are totally synchronous. This implies that all state variables (flip-flops) change at the same time, precisely after the rising edge of the clock. Second, PAL sequential logic designs should include a means for initialization to implement test programs and ensure reliable circuit operation. The specifics of the controller operations are detailed with a state diagram shown in Figure 3.

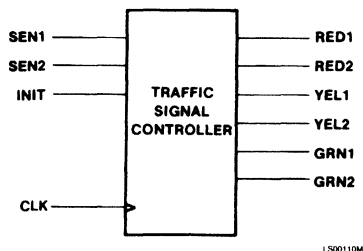


Figure 2

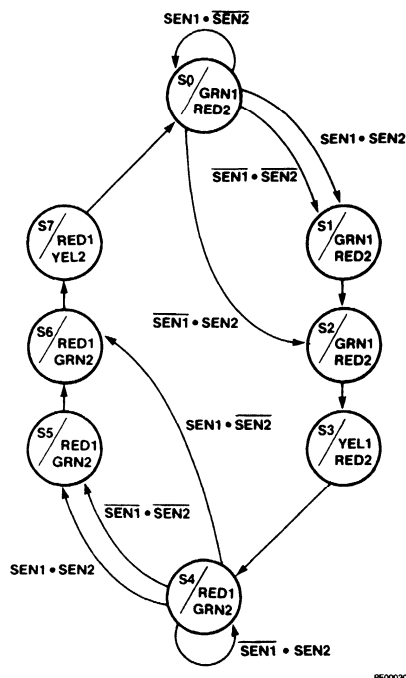


Figure 3. State Diagram — Traffic Signal Controller

Each circle in Figure 3 represents a stable state, i.e. an output configuration lasting at least one clock cycle. Inside the circles is the name of the state (S0 – S7) and the outputs associated with that state. For the sake of simplicity in the state diagram, the transitions involving INIT are omitted; INIT simply drives the circuit to S0 from any state, regardless of other inputs. Since RED1 =  $\overline{\text{RED2}}$ , RED1 is implemented with one flip-flop and RED2 with an external inverter.

# Traffic Signal Controller

## PAL Device Design Specification

```

TITLE          TRAFFIC SIGNAL CONTROLLER
PATTERN        TRAFFIC1.PDS
REVISION       A
AUTHOR         KELVIN CHOW
COMPANY        MONOLITHIC MEMORIES INC., SANTA CLARA
DATE           2/28/85
    
```

CHIP TRAFFIC PAL16RP8

```

CLK SEN1 SEN2 INIT NC NC NC NC NC GND
/OE Q2 Q1 Q0 R1 Y1 G1 Y2 G2 VCC
    
```

```

STRING I1 ' /SEN1*/SEN2*/INIT '
STRING I2 ' /SEN1*SEN2*/INIT '
STRING I3 ' SEN1*/SEN2*/INIT '
STRING I4 ' SEN1*SEN2*/INIT '
STRING I5 ' INIT '
    
```

STATE

```

S0 = BIN[4](R1,Y1,G1,Y2,G2)
S1 = BIN[4](R1,Y1,G1,Y2,G2)
S2 = BIN[4](R1,Y1,G1,Y2,G2)
S3 = BIN[8](R1,Y1,G1,Y2,G2)
S4 = BIN[17](R1,Y1,G1,Y2,G2)
S5 = BIN[17](R1,Y1,G1,Y2,G2)
S6 = BIN[17](R1,Y1,G1,Y2,G2)
S7 = BIN[18](R1,Y1,G1,Y2,G2)
    
```

EQUATIONS

```

S0 = I1*S1 + I2*S2 + I3*S0 + I4*S1 + I5*S0
S1 = I1*S2 + I2*S2 + I3*S2 + I4*S2 + I5*S0
S2 = I1*S3 + I2*S3 + I3*S3 + I4*S3 + I5*S0
S3 = I1*S4 + I2*S4 + I3*S4 + I4*S4 + I5*S0
S4 = I1*S5 + I2*S4 + I3*S6 + I4*S5 + I5*S0
S5 = I1*S6 + I2*S6 + I3*S6 + I4*S6 + I5*S0
S6 = I1*S7 + I2*S7 + I3*S7 + I4*S7 + I5*S0
S7 = I1*S0 + I2*S0 + I3*S0 + I4*S0 + I5*S0
    
```

SIMULATION

```
TRACE_ON CLK INIT SEN1 SEN2 R1 Y1 G1 Y2 G2
```

```

SETF OE INIT
CLOCKF
CLOCKF
CHECK /R1 /Y1 G1 /Y2 /G2
    
```

```

SETF /INIT /SEN1 /SEN2
CLOCKF
    
```

```

SETF SEN1 /SEN2
CLOCKF
CHECK /R1 /Y1 G1 /Y2 /G2
    
```

```

SETF /SEN1 SEN2
CLOCKF
CHECK /R1 /Y1 G1 /Y2 /G2
    
```

```

SETF SEN1 SEN2
CLOCKF
CHECK /R1 Y1 /G1 /Y2 /G2
    
```

```

SETF /SEN1 /SEN2
CLOCKF
CHECK R1 /Y1 /G1 /Y2 G2
    
```

```

SETF /SEN1 SEN2
CLOCKF
CHECK R1 G2
    
```

```

CLOCKF
CHECK R1 G2
    
```

```

CLOCKF
CHECK R1 /Y1 /G1 Y2 /G2
    
```

```

CLOCKF
CHECK /R1 /Y1 G1 /Y2 /G2
    
```

```

CLOCKF
CLOCKF
CLOCKF
CLOCKF
    
```

```

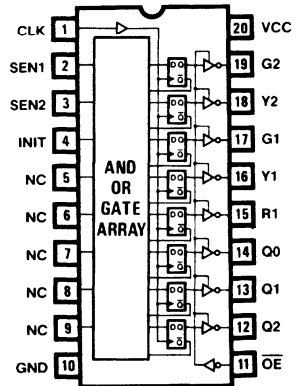
; This simulation was done using the alpha release version
; of Palasm2 software.
    
```

## Simulation Results

```

g c cg c g cg cg cg cg c c c c c c c c
CLK XXHLHLLHLL LHLHLLHLL HLLHLLHLL LHHLHHL
INIT HHHHHHLLL LLLLLLLL LLLLLLLL LLLLLLL
SEN1 XXXXXXXLLL HHLLHHLHLL LLLLLLLL LLLLLLL
SEN2 XXXXXXXLLL LLLHHHHHLL LHHHHHHHH HHHHHHH
R1 XXXXLLHLLL LLLLLLLL LHHHHHHHH LLLLLLH
Y1 XXXXLLHLLL LLLLLLLL HLLLLLLL LLLLLLH
G1 XXXXHHHHH HHHHHHLL LLLLLLLL HHHHLLL
Y2 XXXXLLHLLL LLLLLLLL LLLLLLH LLLLLLL
G2 XXXXLLHLLL LLLLLLLL LHHHHHLL LLLLLLH
    
```

## Logic Symbol



## Memory Handshake Logic

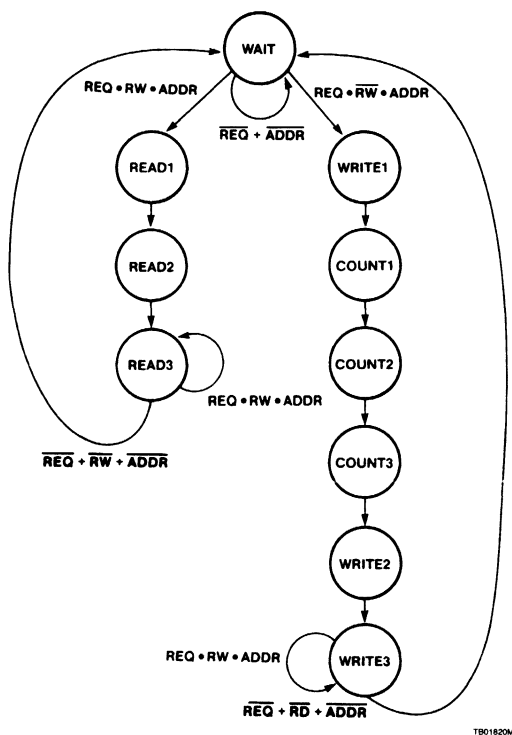
### State Machine Design Example

A typical control logic problem is the memory-to-processor handshake on memory transfer used in many computer architectures. The processor makes a transfer request by activating a request line (REQ) and specifies a read or write operation on a Read/Write line (R/W).

During a read operation, the processor waits for a Data Available signal at which time the data bus is sampled and the request line lowered, thus completing the cycle. During a write operation, the processor places data on the bus and waits for a Write Complete signal after the write cycle is finished. Upon

write complete, the request line is lowered, hence completing the cycle. Table 1 shows the state assignments and the appropriate outputs. The state diagram is shown in Figure 1. Also the handshaking operation is illustrated in the timing diagram of Figure 2.

The memory-board logic to implement this function may be designed with gates and edge-triggered flip-flops as shown in Figure 3. This particular design would require about five SSI/MSI packages, but the same design can be implemented by a single PAL16RP6. The PAL design specification using state equations is shown on the next page.



| STATE  | DOUT | DA | WE | WC | C0 | C1 |
|--------|------|----|----|----|----|----|
| WAIT   | 0    | 0  | 0  | 0  | 0  | 0  |
| READ1  | 1    | 0  | 0  | 0  | 0  | 0  |
| READ2  | 1    | 1  | 0  | 0  | 0  | 0  |
| READ3  | 0    | 0  | 0  | 0  | 0  | 0  |
| COUNT1 | 0    | 0  | 1  | 0  | 1  | 0  |
| COUNT2 | 0    | 0  | 1  | 0  | 0  | 1  |
| COUNT3 | 0    | 0  | 1  | 0  | 1  | 1  |
| WRITE1 | 0    | 0  | 1  | 0  | 0  | 0  |
| WRITE2 | 0    | 0  | 1  | 1  | 0  | 0  |
| WRITE3 | 0    | 0  | 0  | 1  | 0  | 0  |

Figure 1. State Diagram - Memory Handshake Logic

## Memory Handshake Logic

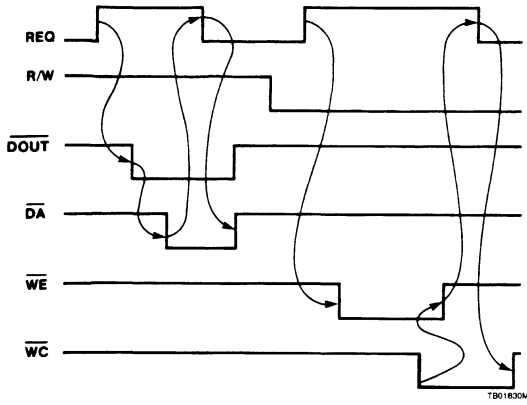


Figure 2. Memory Handshake Timing

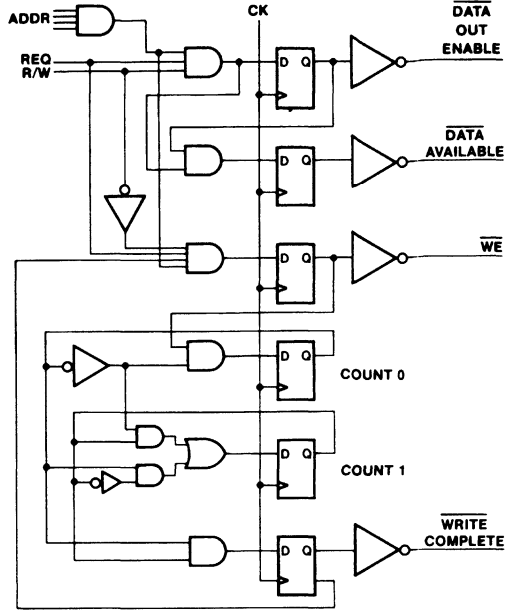


Figure 3. Memory Handshake Logic



## Memory Handshake Logic

### PAL Device Design Specification

```

TITLE          MEMORY HANDSHAKE LOGIC
PATTERN        MEMORY1.PDS
REVISION       A
AUTHOR         KELVIN CHOW
COMPANY        MONOLITHIC MEMORIES INC., SANTA CLARA, CA
DATE           2/28/85
    
```

CHIP MEMORY PAL16RP6

```

CLK ADDR1 ADDR2 ADDR3 ADDR4 REQ RW INIT NC GND
/OE NC /WC C1 CO /WE /DA /DOUT NC VCC
    
```

```

STRING I1 ' REQ*RW*ADDR1*ADDR2*ADDR3*ADDR4*/INIT '
STRING I2 ' REQ*/RW*ADDR1*ADDR2*ADDR3*ADDR4*/INIT'
STRING I3 ' (/REQ+/ADDR1+/ADDR2+/ADDR3+/ADDR4) * /INIT '
STRING I4 ' (/REQ+/RW+/ADDR1+/ADDR2+/ADDR3+/ADDR4) * /INIT '
STRING I5 ' INIT '
    
```

STATE

```

WAIT      = BIN[0] (DOUT, DA, WE, WC, CO, C1)
READ1     = BIN[32] (DOUT, DA, WE, WC, CO, C1)
READ2     = BIN[48] (DOUT, DA, WE, WC, CO, C1)
READ3     = BIN[0] (DOUT, DA, WE, WC, CO, C1)
WRITE1    = BIN[8] (DOUT, DA, WE, WC, CO, C1)
COUNT1   = BIN[10] (DOUT, DA, WE, WC, CO, C1)
COUNT2   = BIN[9] (DOUT, DA, WE, WC, CO, C1)
COUNT3   = BIN[11] (DOUT, DA, WE, WC, CO, C1)
WRITE2    = BIN[12] (DOUT, DA, WE, WC, CO, C1)
WRITE3    = BIN[4] (DOUT, DA, WE, WC, CO, C1)
    
```

EQUATIONS

```

WAIT      := I2*WRITE1 + I1*READ1 + I3*WAIT
           + I5*WAIT
READ1     := I4*READ2 + I3*READ2 + I2*READ2 + I1*READ2
           + I5*WAIT
READ2     := I4*READ3 + I3*READ3 + I2*READ3 + I1*READ3
           + I5*WAIT
READ3     := I1*READ3 + I4*WAIT
           + I5*WAIT
WRITE1    := I4*COUNT1 + I3*COUNT1 + I2*COUNT1 + I1*COUNT1
           + I5*WAIT
COUNT1   := I4*COUNT2 + I3*COUNT2 + I2*COUNT2 + I1*COUNT2
           + I5*WAIT
COUNT2   := I4*COUNT3 + I3*COUNT3 + I2*COUNT3 + I1*COUNT3
           + I5*WAIT
COUNT3   := I4*WRITE2 + I3*WRITE2 + I2*WRITE2 + I1*WRITE2
           + I5*WAIT
WRITE2    := I4*WRITE3 + I3*WRITE3 + I2*WRITE3 + I1*WRITE3
           + I5*WAIT
WRITE3    := I1*WRITE3 + I4*WAIT
           + I5*WAIT
    
```

SIMULATION

```
TRACE_ON REQ RW CLK /DOUT /DA /WE /WC
```

```
SETF INIT /REQ OE RW ADDR1 ADDR2 ADDR3 ADDR4
CLOCKF CLK
CHECK /DOUT
```

```
SETF REQ /INIT
CLOCKF
CLOCKF
CLOCKF
CLOCKF
CHECK DOUT DA
```

```
SETF /REQ
CLOCKF
CHECK /DOUT /DA
```

```
SETF REQ /RW
CLOCKF
CLOCKF
CLOCKF
CLOCKF
CLOCKF
```

```
SETF /REQ
CLOCKF
CLOCKF
CLOCKF
```

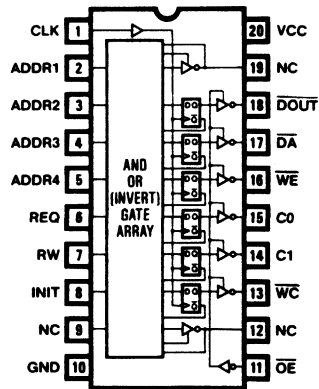
```
; This simulation was done using the alpha release version of
; Palasm2 software.
```

### Simulation Results

```

Page : 1
g  cg c  cc cg cg  ccc c  cg c c
CLK  XXXLLLHHLHH LHHLHLHLL HHHLHLHLH LHLLHLHL
REQ  LLLLHHHHHH HHHLHLHLH HHHLHHHHHH HHHLHLHL
RW   HHHHHHHHHH HHHLHHHHHL LLLLLLLLLL LLLLLLLL
/DOUT XXXHHHLLLL LLLLLLHHH HHHLHHHHHH HHHLHHHH
/DA  XXXHHHLHLH LLLLLLHHH HHHLHHHHHH HHHLHHHH
/WE  XXXHHHHHHH HHHLHHHHHH HLLLLLLLLL LLHHHHHH
/WC  XXXXXXHHHH HHHLHHHHHH HHHLHHHHHH LLHHHHHH
    
```

### Logic Symbol



7

## 4-Bit Counter

### PAL Device Design Specification

```
Title      4Bit_Counter
Pattern    4cnt.pds
Revision    A
Author      Mehrnaz Hada
Company     Monolithic Memories Inc. Santa Clara, CA
Date        1/14/85
```

CHIP 4BitCounter PAL16RP4

```
CLK UP AI BI C1 DI CLR LOAD NC GND
/OC NC NC D C B A NC NC VCC
```

#### EQUATIONS

```
A := /A*/B*/C*/D*/UP*/LOAD*/CLR      ;When CLR=1, A=0.
+ /A* B* C* D* UP*/LOAD*/CLR        ;Else it will count
+ A* B* /D*/UP*/LOAD*/CLR           ;UP or DOWN.
+ A*/B* C* UP*/LOAD*/CLR
+ A* /C* UP*/LOAD*/CLR
+ A* D*/UP*/LOAD*/CLR
+ LOAD*/CLR* AI                      ;New value is loaded
;when LOAD=1, CLR=0.

B := /B*/C*/D*/UP*/LOAD*/CLR      ;When CLR=1, B=0.
+ /B* C* D* UP*/LOAD*/CLR          ;Else it will count.
+ B* C*/D* /LOAD*/CLR
+ B*/C* UP*/LOAD*/CLR
+ B* D*/UP*/LOAD*/CLR
+ LOAD*/CLR* BI                      ;New value is loaded
;when LOAD=1, CLR=0.

C := /C*/D*/UP*/LOAD*/CLR      ;When CLR=1, C=0.
+ /C* D* UP*/LOAD*/CLR          ;Else it will count.
+ C*/D* UP*/LOAD*/CLR
+ C* D*/UP*/LOAD*/CLR
+ LOAD*/CLR* CI                      ;New value is loaded
;when LOAD=1, CLR=0.

D := /D* /LOAD*/CLR            ;Count
+ /D* /LOAD*/CLR* DI            ;New value is loaded
;when LOAD=1, CLR=0.
```

#### SIMULATION

```
TRACE_ON AI BI CI DI LOAD CLR UP A B C D

SETF LOAD /CLR AI BI CI DI OC      ;Load all registers
CLOCKF CLK                          ;to HIGH and count up

SETF CLR                             ;Clear all registers
CLOCKF CLK

SETF /CLR UP /LOAD                   ;Start Counting up

FOR I:= 1 TO 16 DO                   ;Count up 16 clock
  BEGIN                               ;cycles
    CLOCKF CLK
  END

SETF LOAD /CLR /UP AI BI CI DI      ;Load all registers
CLOCKF CLK                          ;to HIGH and count
SETF /LOAD                          ;down
FOR I:= 1 TO 16 DO                  ;Count down 16 clock
  BEGIN                               ;cycles
    CLOCKF CLK
  END

SETF LOAD CLR AI /BI CI /DI         ;Test setting LOAD
CLOCKF CLK                          ;and CLR on at the
;same time.

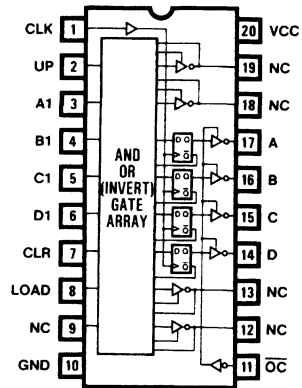
SETF /OC
```

;The 4-bit counter counts up or down and has the clear and load capability. The clear operation overrides count and load. The counter counts up when CLR=low, LOAD=low, and UP=high. It counts down whenever CLR=low, LOAD=low, and

### Simulation Results

```
Page : 1
g cgcgc c c c c c c c c c c c c c c c cgc
AI  HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH
BI  HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH
CI  HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH
DI  HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHHH
LOAD HHHHHHHLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
CLR  LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
UP   XXXXXXHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHHLL
A    XXXHHHLLL LLLLLLLLLL LHHHHHHHHH HHHHHHLLHH
B    XXXHHHLLL LLLLLHHHHH HLLLLLLLLLH HHHHHHLLH
C    XXXHHHLLL HHHHLLHHH HLLLLHHHHL LLLHHHLLH
D    XXXHHHLLL LHHLLHLLH HLLHLLHHL LHHHLLHLL
```

### Logic Symbol



1B01850M

## 8-Bit Counter

### PAL Device Design Specification

Title 8count  
 Pattern 8count.pds  
 Revision A  
 Author Mehrnaz Hada  
 Company Monolithic Memories Inc. Santa Clara, CA  
 Date 1/15/85

;This 8-bit up/down counter has the hold and load  
 ;capabilities. It sets all the outputs high if SET=high.  
 ;It loads new value when SET=low and LOAD=high. Else it  
 ;counts up if UP=high and counts down if UP=low.

CHIP 8BitCounter PAL20X8

CLK UP D0 D1 D2 D3 D4 D5 D6 D7 LD GND  
 /OC SET Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 CIN VCC

#### EQUATIONS

```

/Q0 := /SET* LD*/D0           ;Load D0
      + /SET*/LD*/Q0         ;Hold
      +: /SET*/LD*CIN* UP    ;Increment
      + /SET*/LD*CIN*/UP    ;Decrement

/Q1 := /SET* LD*/D1           ;Load D1
      + /SET*/LD*/Q1         ;Hold
      +: /SET*/LD*CIN* UP* Q0 ;Increment
      + /SET*/LD*CIN*/UP*/Q0 ;Decrement

/Q2 := /SET* LD*/D2           ;Load D2
      + /SET*/LD*/Q2         ;Hold
      +: /SET*/LD*CIN* UP* Q0* Q1 ;Increment
      + /SET*/LD*CIN*/UP*/Q0*/Q1 ;Decrement

/Q3 := /SET* LD*/D3           ;Load D3
      + /SET*/LD*/Q3         ;Hold
      +: /SET*/LD*CIN* UP* Q0* Q1* Q2 ;Increment
      + /SET*/LD*CIN*/UP*/Q0*/Q1*/Q2 ;Decrement

/Q4 := /SET* LD*/D4           ;Load D4
      + /SET*/LD*/Q4         ;Hold
      +: /SET*/LD*CIN* UP* Q0* Q1* Q2* Q3 ;Increment
      + /SET*/LD*CIN*/UP*/Q0*/Q1*/Q2*/Q3 ;Decrement

/Q5 := /SET* LD*/D5           ;Load D5
      + /SET*/LD*/Q5         ;Hold
      +: /SET*/LD*CIN* UP* Q0* Q1* Q2* Q3
      * Q4 ;Increment
      + /SET*/LD*CIN*/UP*/Q0*/Q1*/Q2*/Q3
      */Q4 ;Decrement

/Q6 := /SET* LD*/D6           ;Load D6
      + /SET*/LD*/Q6         ;Hold
      +: /SET*/LD*CIN* UP* Q0* Q1* Q2* Q3
      * Q4* Q5 ;Increment
      + /SET*/LD*CIN*/UP*/Q0*/Q1*/Q2*/Q3
      */Q4*/Q5 ;Decrement

/Q7 := /SET* LD*/D7           ;Load D7
      + /SET*/LD*/Q7         ;Hold
      +: /SET*/LD*CIN* UP* Q0* Q1* Q2* Q3
      * Q4* Q5* Q6 ;Increment
      + /SET*/LD*CIN*/UP*/Q0*/Q1*/Q2*/Q3
      */Q4*/Q5*/Q6 ;Decrement
    
```

#### SIMULATION

TRACE\_ON SET LD CIN UP  
 D0 D1 D2 D3 D4 D5 D6 D7  
 Q0 Q1 Q2 Q3 Q4 Q5 Q6 Q7

SETF OC SET  
 CLOCKF CLK  
 CHECK Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 ;All outputs high  
 SETF /SET UP CIN /LD ;Counting up

FOR I:=1 TO 9 DO  
 BEGIN  
 CLOCKF CLK  
 IF I=8 THEN ;Checking after 8  
 BEGIN ;clock pulses  
 CHECK /Q7 /Q6 /Q5 /Q4 /Q3 Q2 Q1 Q0  
 END  
 END

SETF /CIN ;Holding  
 CLOCKF CLK ;The outputs hold to  
 CLOCKF CLK ;their values

SETF /UP CIN ;Counting down

```

SETF LD /D7 D6 /D5 D4 /D3 D2 /D1 D0 ;Loading some data
CLOCKF CLK
CHECK /Q7 Q6 /Q5 Q4 /Q3 Q2 /Q1 Q0 ;Checking the output
;for the loaded data
SETF /LD UP ;counting up after
FOR I:=1 TO 5 DO ;removing HOLD, count
BEGIN ;up 3 cycles, count
CLOCKF CLK ;down for 2 cycles.
IF I=3 THEN
BEGIN
SETF /UP
END
END
    
```

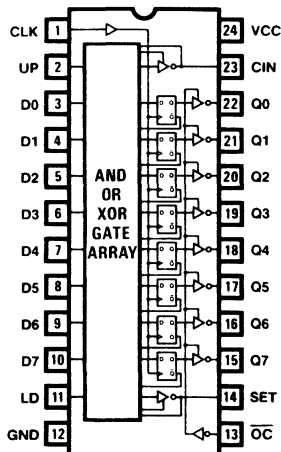
### Simulation Results

Page : 1

```

g cgc c c c c c c c cgc cgcgc c cgc c
SET HHHHLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
LD XXXXLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
CIN XXXXHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHHHH
UP XXXXHHHHHHH HHHHHHHHHH HHHHHHHHHH HHHHHLLL
D0 XXXXXXXXXXX XXXXXXXXXXX XXXXXXXXXXX HHHHHHHH
D1 XXXXXXXXXXX XXXXXXXXXXX XXXXXXXLLL LLLLLLLL
D2 XXXXXXXXXXX XXXXXXXXXXX XXXXXXXHHH HHHHHHHH
D3 XXXXXXXXXXX XXXXXXXXXXX XXXXXXXLLL LLLLLLLL
D4 XXXXXXXXXXX XXXXXXXXXXX XXXXXXXHHH HHHHHHHH
D5 XXXXXXXXXXX XXXXXXXXXXX XXXXXXXLLL LLLLLLLL
D6 XXXXXXXXXXX XXXXXXXXXXX XXXXXXXHHH HHHHHHHH
D7 XXXXXXXXXXX XXXXXXXXXXX XXXXXXXLLL LLLLLLLL
Q0 XXXHLLLLLH LHHLLHLLH LLLLLLLLLL LHHLLHLL
Q1 XXXHLLLLLH HHHLLHLLH LLLLLLLLLL HHHLLHLL
Q2 XXXHLLLLLH LLLHLLHLLH LHHLLHLLH HHHLLHLL
Q3 XXXHLLLLLH LLLLLLLLLL LHHHHHLLH LLLHLLHLL
Q4 XXXHLLLLLH LLLLLLLLLL LLLLLLLLLL HHHHHHHH
Q5 XXXHLLLLLH LLLLLLLLLL LLLLLLLLLL LLLLLLLL
Q6 XXXHLLLLLH LLLLLLLLLL LLLLLLLLLL HHHHHHHH
Q7 XXXHLLLLLH LLLLLLLLLL LLLLLLLLLL LLLLLLLL
    
```

### Logic Symbol



# 9-Bit Counter

## PAL Device Design Specification

Title 9BitCounter  
 Pattern 9BitCnt.pds  
 Revision A  
 Author Mahnaz Hada  
 Company Monolithic Memories Inc., Santa Clara, CA  
 Date 1/28/85

The 9-bit synchronous counter has parallel load, increment, and hold capabilities. The carry out pin (/CO) shows how to implement a carry out using a register by anticipated one count before the terminal count if counting and the terminal count if loading.

### Operations Table

| /OC | CLK | /LD | D8-D0 | Q8-Q0    | Operation |
|-----|-----|-----|-------|----------|-----------|
| H   | X   | X   | X     | Z        | HI-Z      |
| L   | L   | X   | X     | Q        | Hold      |
| L   | C   | L   | D     | D        | Load      |
| L   | C   | H   | X     | Q PLUS 1 | Increment |

CHIP 9BitCounter PAL20X10

CLK D0 D1 D2 D3 D4 D5 D6 D7 D8 /LD GND  
 /OC /CO Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

### EQUATIONS

```

/Q0 := /LD*/Q0          :Hold Q0
      + LD*/D0          :Load D0 (LSB)
      := /LD            :Count

/Q1 := /LD*/Q1
      + LD*/D1          :Load D1
      := /LD* Q0        :Count

/Q2 := /LD*/Q2
      + LD*/D2          :Load D2
      := /LD* Q0* Q1    :Count

/Q3 := /LD*/Q3
      + LD*/D3          :Load D3
      := /LD* Q0* Q1* Q2 :Count

/Q4 := /LD*/Q4
      + LD*/D4          :Load D4
      := /LD* Q0* Q1* Q2* Q3 :Count

/Q5 := /LD*/Q5
      + LD*/D5          :Load D5
      := /LD* Q0* Q1* Q2* Q3* Q4 :Count

/Q6 := /LD*/Q6
      + LD*/D6          :Load D6
      := /LD* Q0* Q1* Q2* Q3* Q4* Q5 :Count

/Q7 := /LD*/Q7
      + LD*/D7          :Load D7
      := /LD* Q0* Q1* Q2* Q3* Q4* Q5* Q6 :Count

/Q8 := /LD*/Q8
      + LD*/D8          :Load D8 (MSB)
      := /LD* Q0* Q1* Q2* Q3* Q4* Q5* Q6* Q7 :Count

CO := /LD*/Q0* Q1* Q2* Q3* Q4* Q5* Q6* Q7* Q8 :Carry out (Anticipate)
      + LD*/D0* D1* D2* D3* D4* D5* D6* D7* D8 :Carry out (Anticipate)
    
```

### SIMULATION

```

TRACE_ON /OC /LD D8 D7 D6 D5 D4 D3 D2 D1 D0
      /CO Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0

SETF OC LD /D8 /D7 /D6 /D5 /D4 /D3 /D2 /D1 /D0 :Load
CLOCKF CLK                                     :Increment

SETF /LD                                       :Increment
CLOCKF CLK

SETF LD /D8 /D7 /D6 /D5 /D4 /D3 /D2 /D1 D0   :Load
CLOCKF CLK

SETF /LD                                       :Increment
CLOCKF CLK

SETF LD /D8 /D7 /D6 /D5 /D4 /D3 D2 D1 D0     :Load
CLOCKF CLK

SETF /LD                                       :Increment
CLOCKF CLK

SETF LD /D8 /D7 /D6 /D5 D4 D3 D2 D1 D0       :Load
CLOCKF CLK

SETF /LD                                       :Increment
CLOCKF CLK

SETF LD /D8 D7 D6 D5 D4 D3 D2 D1 D0         :Load
    
```

```

CLOCKF CLK
SETF /LD :Increment
CLOCKF CLK
    
```

### Function Table

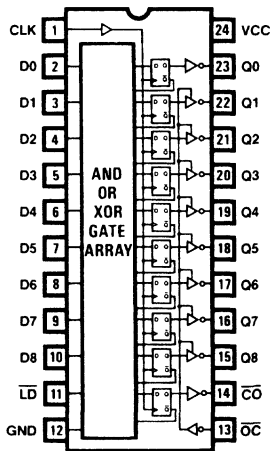
| CLK /OC /LD | D8 D7 D6 D5 D4 D3 D2 D1 D0 /CO | Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0 | Data In Control | Data Out  | Comment |
|-------------|--------------------------------|----------------------------|-----------------|-----------|---------|
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| C L L       | LLLLLLLLL                      | H                          | LLLLLLLLL       | Load      |         |
| C L H       | XXXXXXXXX                      | H                          | LLLLLLLLL       | Increment |         |
| X H X       | XXXXXXXXX                      | Z                          | ZZZZZZZZ        | Test HI-Z |         |

## Simulation Results

```

Page : 1
g cgcgcgc gcgcgcgc gcgcgc c
/OC LLLLLLLLLL LLLLLLLLLL LLLLLL
/LD LLLLLLHLLH LLLLHLLHLL HLLHLL
D8 LLLLLLLLLL LLLLLLLLLL LLLLLL
D7 LLLLLLLLLL LLLLLLLLLL LLLLHLLH
D6 LLLLLLLLLL LLLLLLLLLL LLLLHLLH
D5 LLLLLLLLLL LLLLLLLLLL LLLLHLLH
D4 LLLLLLLLLL LLLLLLLLLL HHHHHHHH
D3 LLLLLLLLLL LLLLLLLLLL HHHHHHHH
D2 LLLLLLLLLL HHHHHHHHHH HHHHHHHH
D1 LLLLLLLLLL HHHHHHHHHH HHHHHHHH
D0 LLLLLLHLLH HHHHHHHHHH HHHHHHHH
/CO XXXHHHHHHH HHHHHHHHHH HHHHHH
Q8 XXXLLLLLLL LLLLLLLLLL LLLLLL
Q7 XXXLLLLLLL LLLLLLLLLL LLLLHLLH
Q6 XXXLLLLLLL LLLLLLLLLL LLLLHLLH
Q5 XXXLLLLLLL LLLLLLLLLL LLLLHLLH
Q4 XXXLLLLLLL LLLLLLHLLH HLLHLL
Q3 XXXLLLLLLL LLLLHLLHLL HLLHLL
Q2 XXXLLLLLLL LLLLHLLHLL HLLHLL
Q1 XXXLLLLLLL HLLHLLHLL HLLHLL
Q0 XXXLLHHLLH LLLLHLLHLL HLLHLL
    
```

## Logic Symbol



T80187CM

# 10-Bit Counter

## PAL Device Design Specification

Title 10Bit\_Counter  
 Pattern 10count.pds  
 Revision A  
 Author Mahrnaz Hada  
 Company Monolithic Memories Inc. Santa Clara, CA  
 Date 1/15/85

The 10-bit counter increments on the rising edge of the clock input (CLK), if CNT input is high. The outputs are HIGH-Z when the enable line (/OE) is high and enabled when the enable line (/OE) is low. The counter is cleared (all lows) if CLR=HIGH.

CHIP 10BitCount PAL20RS10

CLK /SET NC CNT NC /CLR NC NC NC NC NC GND  
 /OE Q5 Q3 Q6 Q2 Q7 Q1 Q8 Q0 Q9 Q4 VCC

### EQUATIONS

```

/Q0 := /SET * CNT * /CLR * Q0      ;Toggle
      + /SET * /CNT * /CLR * /Q0    ;Hold
      + CLR                          ;CLR

/Q1 := /SET * CNT * /CLR * Q0 * Q1 ;Toggle
      + /SET * CNT * /CLR * /Q0 * /Q1 ;Toggle
      + /SET * /CNT * /CLR * /Q1      ;Hold
      + CLR                          ;CLR

/Q2 := /SET * CNT * /CLR * Q0 * Q1 * ;Toggle
      Q2
      + /SET * CNT * /CLR * /Q0 * /Q2 ;Toggle
      + /SET * CNT * /CLR * /Q1 * /Q2 ;Toggle
      + /SET * /CNT * /CLR * /Q2      ;Hold
      + CLR                          ;CLR

/Q3 := /SET * CNT * /CLR * Q0 * Q1 * ;Toggle
      Q2 * Q3
      + /SET * CNT * /CLR * /Q0 * /Q3 ;Toggle
      + /SET * CNT * /CLR * /Q1 * /Q3 ;Toggle
      + /SET * CNT * /CLR * /Q2 * /Q3 ;Toggle
      + /SET * /CNT * /CLR * /Q3      ;Hold
      + CLR                          ;CLR

/Q4 := /SET * CNT * /CLR * Q0 * Q1 * ;Toggle
      Q2 * Q3 * Q4
      + /SET * CNT * /CLR * /Q0 * /Q4 ;Toggle
      + /SET * CNT * /CLR * /Q1 * /Q4 ;Toggle
      + /SET * CNT * /CLR * /Q2 * /Q4 ;Toggle
      + /SET * CNT * /CLR * /Q3 * /Q4 ;Toggle
      + /SET * /CNT * /CLR * /Q4      ;Hold
      - CLR                          ;CLR

/Q5 := /SET * CNT * /CLR * Q0 * Q1 * ;Toggle
      Q2 * Q3 * Q4 * Q5
      + /SET * CNT * /CLR * /Q0 * /Q5 ;Toggle
      + /SET * CNT * /CLR * /Q1 * /Q5 ;Toggle
      + /SET * CNT * /CLR * /Q2 * /Q5 ;Toggle
      + /SET * CNT * /CLR * /Q3 * /Q5 ;Toggle
      + /SET * CNT * /CLR * /Q4 * /Q5 ;Toggle
      + /SET * /CNT * /CLR * /Q5      ;Hold
      + CLR                          ;CLR

/Q6 := /SET * CNT * /CLR * Q0 * Q1 * ;Toggle
      Q2 * Q3 * Q4 * Q5 * Q6
      + /SET * CNT * /CLR * /Q0 * /Q6 ;Toggle
      + /SET * CNT * /CLR * /Q1 * /Q6 ;Toggle
      + /SET * CNT * /CLR * /Q2 * /Q6 ;Toggle
      + /SET * CNT * /CLR * /Q3 * /Q6 ;Toggle
      + /SET * CNT * /CLR * /Q4 * /Q6 ;Toggle
      + /SET * CNT * /CLR * /Q5 * /Q6 ;Toggle
      + /SET * /CNT * /CLR * /Q6      ;Hold
      + CLR                          ;CLR

/Q7 := /SET * CNT * /CLR * Q0 * Q1 * ;Toggle
      Q2 * Q3 * Q4 * Q5 * Q6 * Q7
      + /SET * CNT * /CLR * /Q0 * /Q7 ;Toggle
      + /SET * CNT * /CLR * /Q1 * /Q7 ;Toggle
      + /SET * CNT * /CLR * /Q2 * /Q7 ;Toggle
      + /SET * CNT * /CLR * /Q3 * /Q7 ;Toggle
      + /SET * CNT * /CLR * /Q4 * /Q7 ;Toggle
      + /SET * CNT * /CLR * /Q5 * /Q7 ;Toggle
      + /SET * CNT * /CLR * /Q6 * /Q7 ;Toggle
      + /SET * /CNT * /CLR * /Q7      ;Hold
      + CLR                          ;CLR

/Q8 := /SET * CNT * /CLR * Q0 * Q1 * ;Toggle
      Q2 * Q3 * Q4 * Q5 * Q6 * Q7 * ;Toggle
      Q8
      + /SET * CNT * /CLR * /Q0 * /Q8 ;Toggle
      + /SET * CNT * /CLR * /Q1 * /Q8 ;Toggle
      + /SET * CNT * /CLR * /Q2 * /Q8 ;Toggle
      + /SET * CNT * /CLR * /Q3 * /Q8 ;Toggle
      + /SET * CNT * /CLR * /Q4 * /Q8 ;Toggle
      + /SET * CNT * /CLR * /Q5 * /Q8 ;Toggle
      + /SET * CNT * /CLR * /Q6 * /Q8 ;Toggle
      + /SET * CNT * /CLR * /Q7 * /Q8 ;Toggle
    
```

```

+ /SET * /CNT * /CLR * /Q8      ;Hold
+ CLR                          ;CLR

/Q9 := /SET * CNT * /CLR * Q0 * Q1 * ;Toggle
      Q2 * Q3 * Q4 * Q5 * Q6 * Q7 * ;Toggle
      Q8 * Q9
      + /SET * CNT * /CLR * /Q0 * /Q9 ;Toggle
      + /SET * CNT * /CLR * /Q1 * /Q9 ;Toggle
      + /SET * CNT * /CLR * /Q2 * /Q9 ;Toggle
      + /SET * CNT * /CLR * /Q3 * /Q9 ;Toggle
      + /SET * CNT * /CLR * /Q4 * /Q9 ;Toggle
      + /SET * CNT * /CLR * /Q5 * /Q9 ;Toggle
      + /SET * CNT * /CLR * /Q6 * /Q9 ;Toggle
      + /SET * CNT * /CLR * /Q7 * /Q9 ;Toggle
      + /SET * CNT * /CLR * /Q8 * /Q9 ;Toggle
      + /SET * /CNT * /CLR * /Q9      ;Hold
      + CLR                          ;CLR
    
```

### SIMULATION

```

TRACE_ON OE CLK SET CLR CNT Q0 Q1 Q2 Q3
      Q4 Q5 Q6 Q7 Q8 Q9

SETF OE /CLR SET                ;Set high all the
CLOCKF CLK                      ;registers

SETF CLR                         ;Clear all the
CLOCKF CLK                      ;registers

SETF /SET CNT /CLR              ;Start counting

FOR I:= 1 TO 5 DO                ;Count for five
  BEGIN                          ;cycles. At the count
  CLOCKF CLK                    ;or four check for
  IF I=4 THEN                   ;four on the output.
  BEGIN
  CHECK /Q0 /Q1 Q2
  END
  END

SETF /CNT                        ;Hold
CLOCKF CLK
    
```

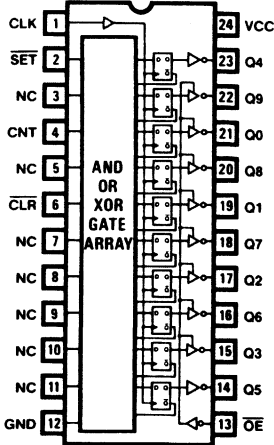
### Simulation Results

```

Page : 1
g cg cg c c c c cg c
OE HHHHHHHHH HHHHHHHHH H
CLK XXHLHLHLHL HLHLHLHL L
SET HHHHHHHLLL LLLLLLLLL L
CLR LLLLLHHLLL LLLLLLLLL L
CNT XXXXXXXXXX HHHHHHHLL L
Q0 XXXHHHLLL HLHLHLHH H
Q1 XXXHHHLLL LHHHLLL L
Q2 XXXHHHLLL LLLLHHHH H
Q3 XXXHHHLLL LLLLLLLLL L
Q4 XXXHHHLLL LLLLLLLLL L
Q5 XXXHHHLLL LLLLLLLLL L
Q6 XXXHHHLLL LLLLLLLLL L
Q7 XXXHHHLLL LLLLLLLLL L
Q8 XXXHHHLLL LLLLLLLLL L
Q9 XXXHHHLLL LLLLLLLLL L
    
```



### Logic Symbol



T80180M

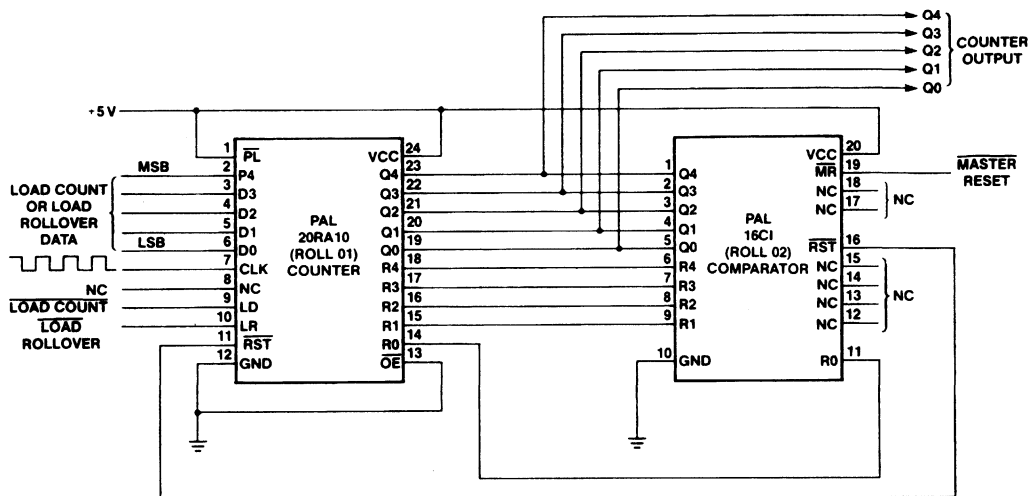
## 5-Bit Up Counter

### Functional Description

Shown below is a schematic of two PAL devices implementing a 5-bit up asynchronous ring counter with programmable rollover, asynchronous load, and reset. Initial count point can be loaded by asserting /LD low. Rollover point is loaded by

asserting /LR low. Q4...Q0 and R4...R0 are compared in the PAL16C1 which is implemented as a comparator. The result of the comparison is fed back from the PAL16C1 to the PAL20RA10 device through the /RST line. Note that a Master Reset must be executed first before an initial count point can be loaded.

### Block Diagram



TC00020M

## 5-Bit Up Counter

### PAL Device Design Specification

Title 5-Bit Up Counter  
 Pattern UpCount.pds  
 Revision A  
 Author Bill Markula  
 Company Monolithic Memories Inc., Santa Clara, CA  
 Date 7/19/84

CHIP UpCounter PAL20RA10

/PL D4 D3 D2 D1 D0 CK NC /LD /LR /RST GND  
 /OE R0 R1 R2 R3 R4 Q0 Q1 Q2 Q3 Q4 VCC

#### EQUATIONS

```

/Q4 := Q4 ;Toggle if lower MSB
Q4.CLKF = /Q3 ;becomes a zero
Q4.RSTF = RST ;Rollover/master RST
Q4.SETF = D4*LD ;Load initial count

/Q3 := Q3 ;Toggle when Q2
Q3.CLKF = /Q2 ;becomes a zero
Q3.RSTF = RST ;Rollover/master RST
Q3.SETF = D3*LD ;Load initial count

/Q2 := Q2 ;Toggle when Q1
Q2.CLKF = /Q1 ;becomes a zero
Q2.RSTF = RST ;Rollover/master RST
Q2.SETF = D2*LD ;Load initial count

/Q1 := Q1 ;Toggle when Q0
Q1.CLKF = /Q0 ;becomes a zero
Q1.RSTF = RST ;Rollover/master RST
Q1.SETF = D3*LD ;Load initial count

/Q0 := Q0 ;Toggle LSB
Q0.CLKF = CK ;External CLKF input
Q0.RSTF = RST ;Rollover/master RST
Q0.SETF = D0*LD ;Load initial count

/R4 := /D4 ;Load rollover point
R4.CLKF = LR ;if /LR is low
/R3 := /D3 ;Load rollover bit 3
R3.CLKF = LR ;if /LR is asserted
/R2 := /D2 ;Load rollover bit 2
R2.CLKF = LR ;if /LR is asserted
/R1 := /D1 ;Load rollover bit 1
R1.CLKF = LR ;if /LR is asserted
/R0 := /D0 ;Load rollover bit 0
R0.CLKF = LR ;if /LR is asserted
    
```

#### SIMULATION

```

TRACE_ON PL OE CK Q0 Q1 Q2 Q3 Q4

SETF RST /LD ;Test SET function
;of registers
CHECK Q0 Q1 Q2 Q3 Q4 ;Check for high
;on reg. outputs
SETF /RST ;Deassert SET funct

SETF D0 D1 D2 D3 D4 LD ;Test RESET function
CHECK /Q0 /Q1 /Q2 /Q3 /Q4

SETF /OE Q4 Q3 Q2 Q1 /Q0 /LD

SETF PL

SETF OE /PL

SETF CK
SETF /CK

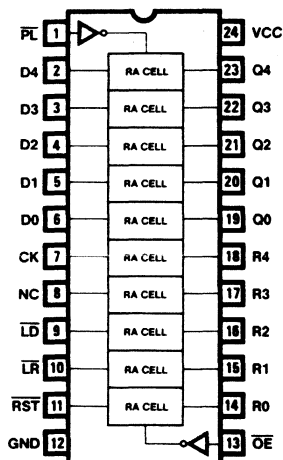
SETF CK
SETF /CK

SETF CK
SETF /CK
    
```

### Simulation Results

```

          9 99 9 999 99 99 99
PL XXXXXXXXHL LLLLLLLLLL LLL
OE XXXXXLLLH HHHHHHHHHH HHH
CK XXXXXXXCKH HHLHLHLHHH LHH
Q0 HHHLLZZHH LLLLLHHLLL LHH
Q1 HHHLLZZHLL LHHHHHHLLL LLL
Q2 HHHLLZZHLL LLLLLLLLLL HHH
Q3 HHHLLZZHLL LLLLLLLLLL LLL
Q4 HHHLLZZHLL LLLLLLLLLL LLL
    
```



TB01900M

# 5-Bit Up Counter

## PAL Device Design Specification

PAL16C1  
 ROLLO2  
 COMPARATOR  
 MONOLITHIC MEMORIES INC., SANTA CLARA, CA  
 Q4 Q3 Q2 Q1 Q0 R4 R3 R2 R1 GND  
 R0 NC NC NC NC /RST NC NC /MR VCC

**EQUATIONS**

```

/RST = Q4*/R4*/MR + /Q4*R4*/MR ;COMPARE Q4 & R4 MSB
      + Q3*/R3*/MR + /Q3*R3*/MR ;COMPARE Q3 & R3
      + Q2*/R2*/MR + /Q2*R2*/MR ;COMPARE Q2 & R2
      + Q1*/R1*/MR + /Q1*R1*/MR ;COMPARE Q1 & R1
      + Q0*/R0*/MR + /Q0*R0*/MR ;COMPARE Q0 & R0 LSB
    
```

**FUNCTION TABLE**

Q4 Q3 Q2 Q1 Q0 R4 R3 R2 R1 R0 /MR /RST

```

; /
; / R
;QQQQQ RRRRR M S
;43210 43210 R T
-----
HLLLL LLLLL H H 1 Q4=H, R4=L
LHLLL LLLLL H H 2 Q3=H, R3=L
LLHLL LLLLL H H 3 Q2=H, R2=L
LLLHL LLLLL H H 4 Q1=H, R1=L
LLLLH LLLLL H H 5 Q0=H, R0=L
LLLLL HLLLL H H 6 Q4=L, R4=H
LHLLL LHLLL H H 7 Q3=L, R3=H
LLLLL LHLLL H H 8 Q2=L, R2=H
LLLLL LLHLH H H 9 Q1=L, R1=H
LLLLL LLLLH H H 10 Q0=L, R0=H
LLLLL LLLLL H L 11 TEST ALL LOWS
HHHHH HHHHH H L 12 TEST ALL HIGHS
LHLHL LHHLH H L 13 TEST EVEN CHECKERBOARD
HLHLH HLHLH H L 14 TEST ODD CHECKERBOARD
LLLLL HHHHH L L 15 TEST MASTER RESET
HHHHH LLLLL L L 16 TEST MASTER RESET
-----
    
```

**DESCRIPTION**

PAL16C1 DESIGN SPECIFICATION  
 5-BIT COMPARATOR WITH MASTER RESET OVERRIDE  
 (SECOND OF THE TWO PALS SOLUTION ON THE 5-BIT COUNTER WITH  
 PROGRAMMABLE ROLLOVER, ASYNCHRONOUS LOAD AND RESET.)  
 MONOLITHIC MEMORIES INC., SANTA CLARA, CA  
 BILL KARKULA 7/19/84

THIS DEVICE COMPARES 5 BITS OF DATA (R4...R0) WITH Q4...Q0  
 AND ASSERTS /RST IF THEY ARE EQUAL. THEREFORE /RST  
 GOES LOW WHEN PROGRAMMED ROLLOVER POINT R4...R0  
 MATCHES COUNT Q4...Q0. /RST ALSO GOES LOW WHEN /MR  
 GOES LOW, INDICATING A MASTER RESET.

NOTE: THIS PAL DESIGN SPEC WAS ASSEMBLED ON PALASH V1.7.

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**PAL Device Design Specification**

**Simulation Results**

Title 7-Bit I/O Port with Handshake Logic  
 Pattern Port.pds  
 Revision A  
 Author Sadahiro Horiko / Kelvin Chow  
 Company Monolithic Memories Inc., Santa Clara, Ca  
 Date 3/1/85

Page : 1  
 g g gg gg g  
 CLR HHHLLLLLLL L  
 Q0 XZZLLLLLLL L  
 Q1 XZZLLHHHH H  
 Q2 XZZLLLLLLL L  
 Q3 XZZLLHHHH H  
 Q4 XZZLLLLLLL L  
 Q5 XZZLLHHHH H  
 Q6 XZZLLLLLLL L  
 DCLK LLLLLHHLL L  
 DRDY XLZZLHHHL L  
 DACK LLLLLLLHH L

CHIP IOPORT PAL20RA10

PL D0 D1 D2 D3 D4 D5 D6 CE DCLK CLR GND  
 OE DACK DRDY NC Q6 Q5 Q4 Q3 Q2 Q1 Q0 VCC

**EQUATIONS**

```

Q0      := D0           ;LSB of 7-bit regs
Q0.CLKF = DCLK         ;External clock
Q0.SETF = CLR          ;Clear register
Q0.TRST = CE           ;Tristate control

Q1      := D1           ;Data 1
Q1.CLKF = DCLK         ;External clock
Q1.SETF = CLR          ;Clear register
Q1.TRST = CE           ;Tristate control

Q2      := D2           ;Data 2
Q2.CLKF = DCLK         ;External clock
Q2.SETF = CLR          ;Clear register
Q2.TRST = CE           ;Tristate control

Q3      := D3           ;Data 3
Q3.CLKF = DCLK         ;External clock
Q3.SETF = CLR          ;Clear register
Q3.TRST = CE           ;Tristate control

Q4      := D4           ;Data 4
Q4.CLKF = DCLK         ;External clock
Q4.SETF = CLR          ;Clear register
Q4.TRST = CE           ;Tristate control

Q5      := D5           ;Data 5
Q5.CLKF = DCLK         ;External clock
Q5.SETF = CLR          ;Clear register
Q5.TRST = CE           ;Tristate control

Q6      := D6           ;Data 6
Q6.CLKF = DCLK         ;External clock
Q6.SETF = CLR          ;Clear register
Q6.TRST = CE           ;Tristate control

DRDY    := GND          ;Handshake logic
DRDY.CLKF = DACK       ;Cleared by DACK
DRDY.RSTF = DCLK       ;Clear
DRDY.SETF = CLR        ;Asserted by DCLK
DRDY.TRST = VCC        ;(External clock)
    
```

**SIMULATION**

```

TRACE_ON CLR Q0 Q1 Q2 Q3 Q4 Q5 Q6 DCLK DRDY DACK

SETF PL /CE /OE /D0 /D1 /D2 D3 /D4 D5 /D6 CLR /DCLK /DACK
;Set input values
;Tristate outputs

SETF CE OE CLR
;Remove the tri-
;states on the
;outputs and clear
;registers

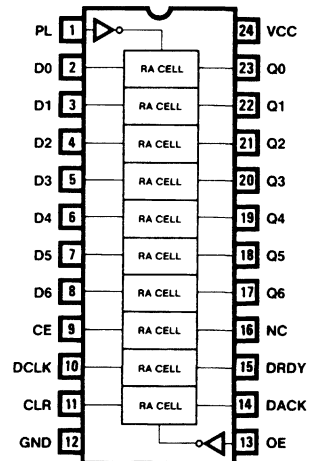
SETF CLR
SETF CLR

SETF /CLR
SETF DCLK
SETF DCLK
;Clock the data &
;set DRDY register

SETF /DCLK
;Remove the clock

SETF DACK
SETF DACK
;Assert DACK

SETF /DACK
SETF /DACK
;Lower DACK
    
```



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## Serial Data Link Controller

### Functional Description

Original application was developed by LTT, Conflans Ste. Honorine, FRANCE. Part of the schematics, reprinted with courtesy of LTT, is used to control a serial data link based upon a specialized LSI chip.

Originally designed with six standard SSI/MSI circuits, this same function can now be implemented, not only into a single PAL20RA10 device, but with even more features and better performance. The function can be divided into three subfunctions:

1. Address Decoding
2. Control Flags
3. Transmission Speed Selection

Up to four address lines are allowed (eight were actually used), plus two extra lines which are special decoding controls (MEM/IO selection, Enable Control...). Two flip-flop load flag conditions, from the address bus (A1 and A2), providing handshake between the 6850 UART and the communication lines. They have a common clock which also serves as Chip Select (CSO) for the UART.

The UART Transmit clock (TXCLK) can be directly connected to the Receive Clock (CK or RXCLK) or represents the Receive Clock value divided by sixteen. This function was performed by four D-type Flip-Flops connected as a 4-stage Asynchronous Divider. Since each basic cell, used in a PAL20RA10 device has four Product Terms available, this function could be implemented either asynchronously or synchronously. In the PAL Design Specification example, a 4-bit synchronous divider was used instead of the asynchronous circuit shown in the schematic.

### Pin Description

- |                    |   |
|--------------------|---|
| 1. TEST .....      | Allows preload function for testing.                |
| 2. SYSRESET .....  | Reset line from microprocessor.                     |
| 3. A2 .....        | Address line from address bus.                      |
| 4. A1 .....        | Address line from address bus.                      |
| 5. HDSHAKE .....   | Handshake line (CTS/RTS).                           |
| 6. CK .....        | External clock.                                     |
| 7. E .....         | Enable line from microprocessor.                    |
| 8. AUXDECOD .....  | Extra decoding line<br>(e.g. board level decoding). |
| 9. A3 .....        | Address line from address bus.                      |
| 10. A4 .....       | Address line from address bus.                      |
| 11. A5 .....       | Address line from address bus.                      |
| 12. GND .....      | Reference power supply ground.                      |
| 13. /OE .....      | Output enable line.                                 |
| 14. A6 .....       | Address line from address bus.                      |
| 15. SPEEDSEL ..... | Speed selection line.                               |
| 16. DIV4 .....     | MSB 4-bit synchronous counter.                      |
| 17. DIV3 .....     | 3rd stage synchronous counter.                      |
| 18. DIV2 .....     | 2nd stage synchronous counter.                      |
| 19. DIV1 .....     | LSB 4-bit synchronous counter.                      |
| 20. CS0 .....      | UART chip select line (CSO).                        |
| 21. BLOCREC .....  | Bloc receive line.                                  |
| 22. DIR DIV .....  | Direct or divided clock.                            |
| 23. /TPH .....     | External use flag.                                  |
| 24. VCC .....      | 5V power supply.                                    |



# Serial Data Link Controller

## PAL Device Design Specification

```

Title      Serial Data Link Controller
Pattern    Link.pds
Revision    A
Author     Jose Juntas / Kelvin Chow
Company    Monolithic Memories Inc., Santa Clara, Ca
Date       3/1/85

CHIP SE_CNTRL PAL20RA10

TEST SYSRESET A2 A1 HDSSHAKE CK E AUXDECOD A3 A4 A5 GND
/OE A6 SPEEDSEL DIV4 DIV3 DIV2 DIV1 CSO BLOCREC DIRDIV
/TPH VCC

EQUATIONS

/TPH          := A2          ;Load A2 as flag
/TPH.CLKF     = CSO         ;CLK W/ ADDR. decode
/TPH.SETF     = SYSRESET    ;global system reset

DIRDIV        := A1          ;Load speed ratio
DIRDIV.CLKF   = CSO         ;CLK W/ ADDR. decode
DIRDIV.SETF   = /HDSSHAKE   ;CLR by CTS/RTS line

/BLOCREC      = /DIRDIV     ;Controlled by speed
                + HDSSHAKE  ;option and CTS/RTS
                :line

CSO           = /A6*A5*A4*A3*AUXDECOD*E
                :UART address valid

/DIV1         := DIV1       ;4-bit synchronous
                :divider LSB

/DIV1.CLKF    = CK          ;CLK by CK(external)
/DIV1.SETF    = /DIRDIV    ;CLR by speed option

/DIV2         := /DIV1*/DIV2 ;2ND stage of
                + DIV1*/DIV2 ;divider
/DIV2.CLKF    = CK          ;CLK by CK(external)
/DIV2.SETF    = /DIRDIV    ;CLR by speed option

/DIV3         := /DIV2*/DIV3 ;3RD stage of
                + /DIV1*/DIV3 ;divider
                + DIV1*DIV2*DIV3
/DIV3.CLKF    = CK          ;CLK by CK(external)
/DIV3.SETF    = /DIRDIV    ;CLR by speed option

/DIV4         := /DIV3*/DIV4 ;4TH stage of
                + /DIV2*/DIV4 ;divider MSB
                + /DIV1*/DIV4
                + DIV1*DIV2*DIV3*DIV4
/DIV4.CLKF    = CK          ;CLK by CK(external)
/DIV4.SETF    = /DIRDIV    ;CLR by speed option

SPEEDSEL      := /A1        ;Load speed choice
SPEEDSEL.CLKF = CSO        ;CLK W/ ADDR. decode
SPEEDSEL.SETF = /HDSSHAKE  ;CLR by CTS/RTS line

SIMULATION

TRACE_ON A1,A2,A3,A4,A5,A6,E, ;Signals to be
        AUXDECOD,SYSRESET,/TPH,HDSSHAKE, ;observed
        CSO,SPEEDSEL,DIRDIV,CK,
        DIV1,DIV2,DIV3,DIV4
SETF SYSRESET,/HDSSHAKE      ;Reset all regs

CHECK /SPEEDSEL,/DIRDIV,TPH
SETF /SYSRESET,A1,A2,A3,A4,A5,/A6,HDSSHAKE, ;Set decode
        E,AUXDECOD           ;condition

CHECK /SPEEDSEL,DIRDIV      ;Check SPEEDSEL and
                            ;DIRDIV regs

FOR I:=1 TO 15 DO
BEGIN
    SETF CK                  ;This portion
                            ;simulates divide
                            ;by four counter
    SETF /CK
END
    
```

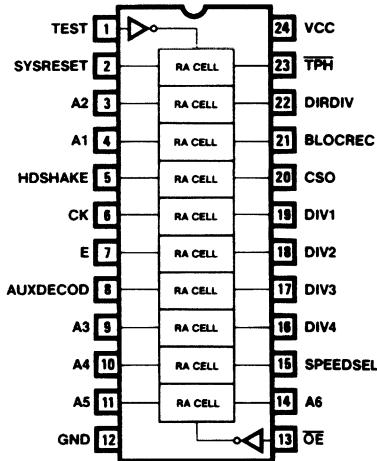
## Simulation Results

```

Page : 1
g g g gg gg gg g g gg gg gg gg gg gg
A1  XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
A2  XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
A3  XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
A4  XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
A5  XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
A6  XXLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
E   XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
AUXDECOD XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
SYSRESET  HLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
/TPH      LLLLLLLLLL XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
HDSSHAKE  LLLLLLLLLL XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
CSO       XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
SPEEDSEL  LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
DIRDIV    LLLLLLLLLL XXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXX
CK        XXXXXXXXXXXX LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
DIV1     XLLLLLLLLL LLLLLLLLLL LLLLLLLLLL LLLLLLLLLL
DIV2     XLLLLLLLLL XXXXXXXXXXXX LLLLLLLLLL LLLLLLLLLL
DIV3     XLLLLLLLLL LLLLLLLLLL XXXXXXXXXXXX LLLLLLLLLL
DIV4     XLLLLLLLLL LLLLLLLLLL LLLLLLLLLL XXXXXXXXXXXX
    
```

```

Page : 2
gg gg gg g
A1  HHHHHHHHHH
A2  HHHHHHHHHH
A3  HHHHHHHHHH
A4  HHHHHHHHHH
A5  HHHHHHHHHH
A6  LLLLLLLLLL
E   HHHHHHHHHH
AUXDECOD HHHHHHHHHH
SYSRESET  LLLLLLLLLL
/TPH      HHHHHHHHHH
HDSSHAKE  HHHHHHHHHH
CSO       HHHHHHHHHH
SPEEDSEL  LLLLLLLLLL
DIRDIV    HHHHHHHHHH
CK        LLLLLLLLLL
DIV1     LLLLLLLLLL
DIV2     LLLLLLLLLL
DIV3     HHHHHHHHHH
DIV4     HHHHHHHHHH
    
```



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## Interrupt Controller

---

### Functional Description

One of the more widely used computer families is the Digital Equipment Corp.'s PDP-11 series. This family of computers uses the DEC unibus to communicate between cards. A specific protocol is required to interface a card to the unibus. This protocol is described in the available DEC literature.

Since the unibus is an asynchronous bus, much of the interface circuitry consists of combinational logic to generate specific signals and flip-flops which are set and reset as flags. This tends to use a lot of SSI and MSI logic packages. Using Monolithic Memories' PAL devices, much of this logic can be condensed into a few packages. Figure 2 is the schematic diagram for an interrupt Controller to be used on the unibus. (p.6 - 30 of the 1976 DEC PDP-11 Peripherals Handbook.)

Many cards communicate over the bus by taking control of the unibus with an interrupt request, and then do whatever they require before releasing control. As can be seen, this interrupt controller takes six special interface ICs, (380 and 8881 bus

drivers and receivers) eight MSI, SSIIC, (7400, 7402 and 7474s) along with some transistors and discrete parts. This parts count can be considerably reduced by using PAL20RA10 and PAL20L10 devices.

Figure 1 shows how the circuit with the PAL devices would look. The two PAL devices allow almost all of the 7400, 7402 and 7474 packages to be removed. (Almost a 4-1 saving in chip count.) In addition the preload pin (PRLD) on the 20RA10 allows the flip-flops to be easily set to a known state on power up, or when re-initializing. So the PAL devices reduce the logic package count from eight chips to three.

This shows that by using PAL devices substantial space and circuit savings can be realized when interfacing to the unibus.

In the schematic shown, there are three VLSI devices, three MSIs and two SSIs. Using a PAL20RA10 logic circuit, it is possible to replace three MSIs and one SSI device, thereby reducing the chip count by a factor of two. The ICs inside the enclosed loop were replaced.

## Interrupt Controller

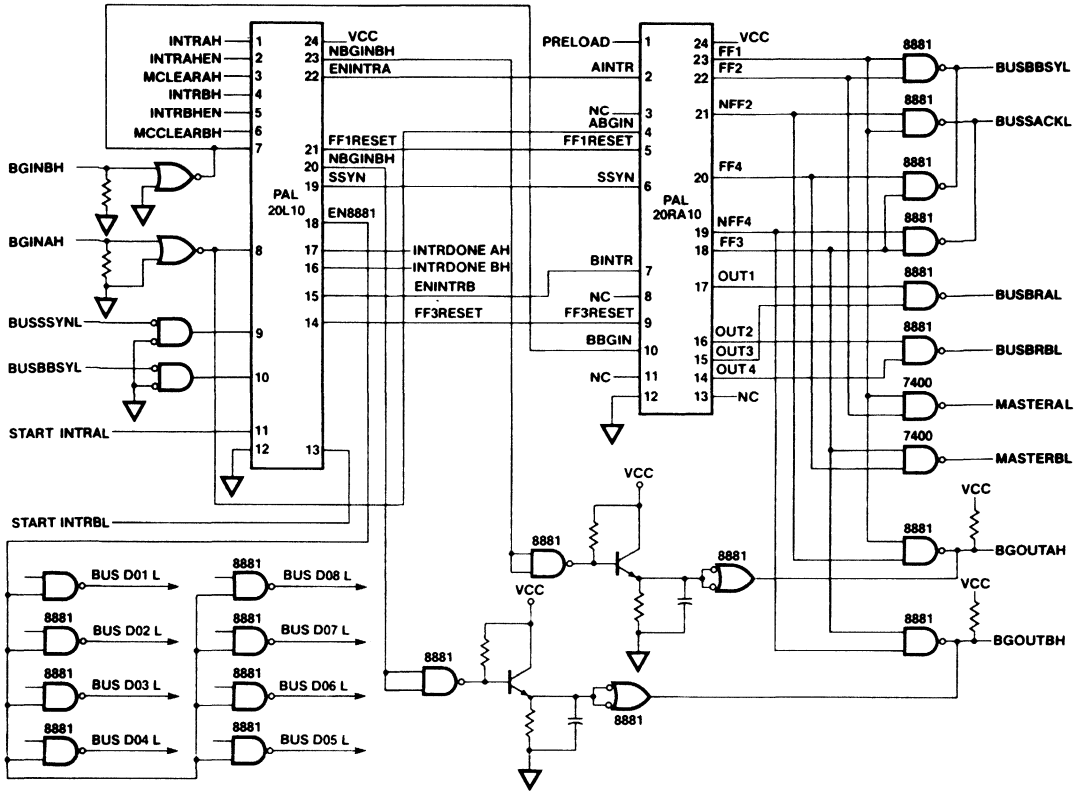


Figure 1.

### PAL Design Specification

PAL20L10  
INTRP01  
INTERRUPT LOGIC  
MONOLITHIC MEMORIES INC., SANTA CLARA, CA  
INTRAH INTRAH MCLARAH INTRBH INTRBHN MCCLEARBH BGINBH  
BGINAH BUSSSYNL BUSBBSYL STARTINTRAL GND  
STARTINTRBL FF3RESET ENINTRB INTRDONEBH INTRDONEAH EN8881  
SSYN NBGINBH FF1RESET ENINTRA NBGINAH VCC

#### DESCRIPTION

COMBINATORIAL LOGIC FOR PAL20RA10 INTERRUPT CONTROLLER  
(1ST PART OF THE TWO PALS SOLUTION: PAL20L10 & PAL20RA10)  
MONOLITHIC MEMORIES INC., SANTA CLARA, CA  
DAN KINSELLA 7/19/84

NOTE: THIS PAL DESIGN SPEC WAS ASSEMBLED ON PALASM V1.7.

#### EQUATIONS

```

/NBGINAH      =  BGINAH          ;FF1 CLK CONTROL
                ; BLOCK A
/FF1RESET     =  MCLARAH+ENINTRA ;SET FF1 CONTROL
                ; BLOCK A
/ENINTRA      =  INTRAH*INTRAH   ;ENABLE INTERRUPT A
/NBGINBH      =  BGINBH          ;FF3 CLOCK CONTROL
                ; BLOCK B
/SSYN         =  BUSSSYNL*BUSBBSYL ;SYNCHRONIZE FF2 &
                ; FF4
/EN8881       =  STARTINTRAL*STARTINTRBL ;INTERRUPT BUS
/INTRDONEAH   =  BUSSSYNL+STARTINTRAL ;SIGNAL INTERRUPT
                ; DONE
/ENINTRB      =  INTRBH*INTRBHN  ;ENABLE INTERRUPT B
/FF3RESET     =  MCLARAH+ENINTRB ;SET FF3 CONTROL
                ; BLOCK B
/INTRDONEBH   =  BUSSSYNL+STARTINTRBL ;SIGNAL INTERRUPT
                ; DONE
    
```

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# Interrupt Controller

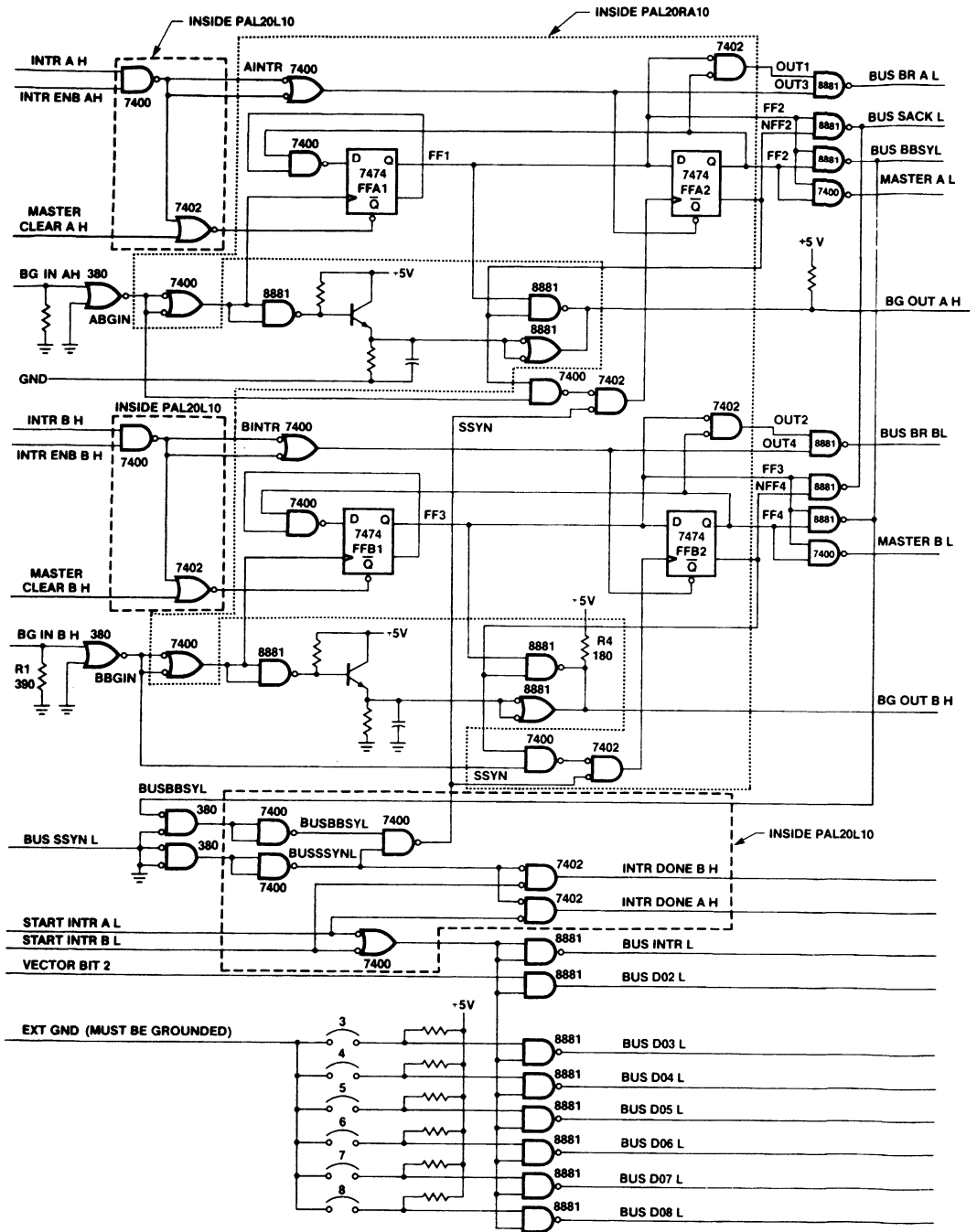


Figure 2.



# Interrupt Controller

## PAL Device Design Specification

Title DEC PDP-11 unibus interrupt controller  
 Pattern Control.pds  
 Revision A  
 Author Dan Kinsella  
 Company Monolithic Memories Inc., Santa Clara, CA  
 Date 3/1/85

CHIP INTR\_CONTROL PAL20RA10

PL AINTR NC ABGIN FF1RESET SSYN BINTR NC FF3RESET BBGIN  
 NC GND  
 NC OUT4 OUT3 OUT2 OUT1 FF3 NFF4 FF4 NFF2 FF2 FF1 VCC

### EQUATIONS

```

/FF1      := /FF1*FF2      ;Master control
FF1.SETF  = /FF1RESET     ;block A
FF1.CLKF  = /ABGIN

FF2      := FF1           ;Bus Busy Signal
FF2.SETF  = /AINTR
FF2.CLKF  = ABGIN*FF2*/SSYN

/NFF2     := FF1           ;Bus sack signal
NFF2.SETF = /AINTR
NFF2.CLKF = ABGIN*NFF2*/SSYN

/FF3      := /FF3*FF4     ;Master control
FF3.SETF  = /FF3RESET     ;block B
FF3.CLKF  = /BBGIN

FF4      := FF4           ;Bus busy signal
FF4.SETF  = /BINTR
FF4.CLKF  = BBGIN*FF4*/SSYN

/NFF4     := FF3           ;Bus sack signal
NFF4.SETF = /BINTR
NFF4.CLKF = BBGIN*NFF4*/SSYN

/OUT1     = FF1+FF2       ;Bus request signal
;block A
/OUT2     = FF4+FF3       ;Bus request signal
;block B
/OUT3     = AINTR         ;Intr. signal for
;bus req. block A
/OUT4     = BINTR         ;Intr. signal for
;bus req. block B
    
```

### SIMULATION

```

TRACE_ON FF1RESET FF3RESET AINTR BINTR SSYN ABGIN BBGIN
FF1 FF3 NFF2 NFF4 OUT1 OUT2 OUT3 OUT4

SETF /FF1RESET /FF3RESET AINTR BINTR ;Reset all regs

SETF FF1RESET FF3RESET /AINTR /BINTR ;Clock FF1 and FF3
ABGIN BBGIN ;regs

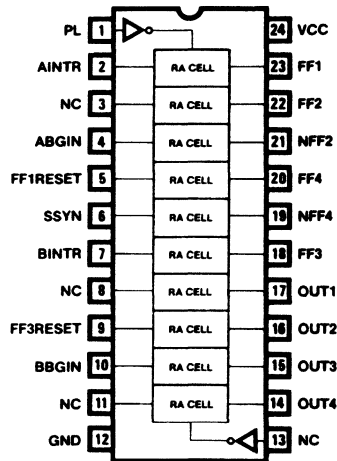
SETF /SSYN ;Clock NFF and NFF3
;regs
    
```

## Simulation Results

Page : 1

```

99 9
FF1RESET LHHH
FF3RESET LHHH
AINTR     HLLL
BINTR     HLLL
SSYN     XXXL
ABGIN     XHHH
BBGIN     XHHH
FF1       LLLL
FF3       LLLL
NFF2     XLLL
NFF4     XLLL
OUT1     XHHH
OUT2     XHHH
OUT3     LHHH
OUT4     LHHH
    
```

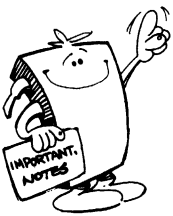


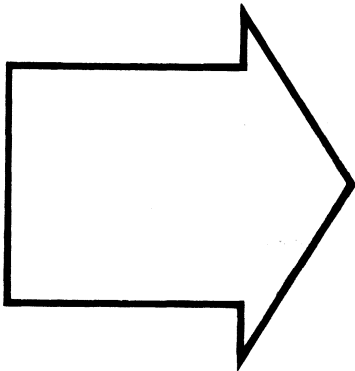
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# Notes

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# Logic Tutorial

## 1. Boolean Algebra

### 1.1 The Language of Logic

Although you may not be aware of it, you are already an expert at forming, simplifying and comprehending Boolean equations and expressions. Boolean algebra, in its most common application, is concerned with the truth or falsity of statements. Any time you describe what circumstances would make something true or false, you have made a Boolean equation.

For example, suppose A is true only if B and C are true. These three letters may represent anything you like — A may be whether or not you may become president, B may be whether or not you are elected, and C may be whether or not you are a citizen of the U.S.A. You may become president only if you are elected and you are a citizen of the United States. If we wrote that statement in equation form, it might look like this:

$$A = B \cdot C$$

where the  $\cdot$  is a shorthand notation for the word 'AND'. A, B and C are all Boolean variables, since they represent some value which may be either true or false. You either are a citizen of the United States, or you are not — there is no in between. Examining the relationship between these three variables, we find that:

- 1) if you are elected and you are citizen then you may become president;
- 2) if you are elected but you are not a citizen then you cannot become president;
- 3) if you are not elected, but you are a citizen, you still can't become president, and;
- 4) if you are neither elected nor a citizen, then you definitely cannot become president.

This same relationship, which may be expressed in terms of an English sentence, may also be represented by a table of all the possibilities, called a truth table. If we let '1' stand for true, and '0' stand for false, we can make the following table:

| B | C | A |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

Figure 1-1. The AND Operator

The table above is a standard way of expressing logical relationships. Our truth table lists the possibilities one-by-one. If B and C are false, then A will be false. If B is true and C is false, then A will still be false. If B is false, and C is true then A will again be false. However, if B and C are both true, then A will be true.

### 1.2 AND, OR and NOT

The fact is that every time you have an equation of the form:

$$A = B \cdot C$$

you will have a truth table in the form of Figure 1-1 because the table and the word 'AND' are just two ways of expressing the same relationship between two Boolean variables.

Now let's look at the operator 'OR'. Suppose A is true if B or C is true. This equation can be written:

$$A = B + C$$

Do not confuse the  $+$  with the addition sign of arithmetic; in Boolean algebra, it is shorthand notation for the word 'OR'. A truth table for this equation would be:

| B | C | A |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

Figure 1-2. The OR Operator

This table expresses a different relationship between the variables than AND does; AND requires that both of its operands be true for the expression to be true. OR only requires that one of its operands be true for the expression to be true. From the table above, we can see that:

- 1) if both B and C are false, then A is false;
- 2) if B is false, and C is true, then A is true;
- 3) if B is true and C is false, then A is true and;
- 4) if both B and C are true, then A is true.

Finally, let's look at the operator 'NOT'. If A equals NOT B, then the value of A is the inverse of B. This equation would be:

$$A = /B$$

Again, the  $/$  should not be mistaken for the division sign of arithmetic. It is a shorthand notation for the Boolean operator, 'NOT'. The truth table for this equation is:

| B | A |
|---|---|
| 0 | 1 |
| 1 | 0 |

Figure 1-3. The NOT Operator.

which is to say that:

- 1) if B is false, then A is true and;
- 2) if B is true then A is false.

The elementary operators are summarized in Figure 1-4.

| OPERATOR | SYMBOL  |
|----------|---------|
| AND      | $\cdot$ |
| OR       | $+$     |
| NOT      | $/$     |

Figure 1-4. Elementary Boolean Operators

## 1.3 Precedence

In arithmetic, the multiplication sign is always evaluated before the addition sign. For example:

$$3 + 4 \times 7$$

is 31, not 49. Similarly, the AND sign is always evaluated before the OR sign. Another way to say this is that AND has a higher precedence than OR.

Of course, in arithmetic, the precedence of operators may be changed with parentheses. If you wish the expression:

$$3 + 4 \times 7$$

to be evaluated as 49, then you should write it as:

$$(3 + 4) \times 7$$

The parentheses enclose a subexpression that should be evaluated before the expression as a whole can be evaluated.

Of the three Boolean operators we have seen so far, NOT has the highest precedence, then AND, then OR.

## 1.4 Associativity and Commutativity

Both the AND and OR operators (and, in fact, all binary Boolean operators) have the property of associativity. The property of associativity says that in an expression with more than one operator of the same kind, it does not matter which you evaluate first. In terms of equations, this would be:

$$B \cdot (C \cdot D) = (B \cdot C) \cdot D$$

or

$$B + (C + D) = (B + C) + D$$

All binary Boolean operators are also commutative. This means that the order in which the operands appear is not important. In equations, that would be

$$B \cdot C = C \cdot B$$

or

$$B + C = C + B$$

## 1.5 Postulates and Theorems

In 1854, the mathematician and philosopher George Boole published his book, 'An Investigation of The Laws of Thought', in which he demonstrated how classical logic could be defined with algebraic terminology and operations. Then, in 1938, C. E. Shannon published his paper "A Symbolic Analysis of Relay and Switching Circuits", which demonstrated a Boolean algebra of two values called "switching algebra", which could be used to represent the properties of bistable electric switching circuits. A minimal set of formal postulates is needed in order to define this Boolean algebra. Here we will define Boolean algebra to be an algebra defined over the set B, where B = {False, True} and over the operators AND (\*), OR (+) and NOT (/), such that:

- 1) All operators are closed (which means that it is impossible to create a Boolean expression that has a value other than True or False),
- 2) Postulates 1 through 4 in Figure 1-5 are true, and
- 3) NOT is an operator which, when applied to a Boolean variable x, creates its complement such that if x = True then /x = False, and if x = False then /x = True.

Given this basic set of rules, it is possible to derive any of the theorems in Figure 1-5. For example:

Theorem 1a:  $x + x = x$

|                                     |                 |
|-------------------------------------|-----------------|
| $x + x = (x + x) \cdot \text{True}$ | by Postulate 1b |
| $= (x + x) \cdot (x + /x)$          | by Postulate 2a |
| $= x + (x \cdot /x)$                | by Postulate 4b |
| $= x + \text{False}$                | by Postulate 2b |
| $= x$                               | by Postulate 1a |

### 1.5.1 Duality

One of the most important properties of Boolean algebra is the *duality principle*. This principle states that any algebraic expression that may be deduced from the postulates of Boolean algebra has a dual which is also true. The dual of an expression is obtained by replacing all Trues with Falses, all Falses with Trues, all ANDs with ORs, and all ORs with ANDs. For example:

Theorem 2a:  $x + \text{True} = \text{True}$

has the dual:  $x \cdot \text{False} = \text{False}$

which is theorem 2b. All postulates and theorems listed in Figure 1-5 are listed as pairs of duals. Of course, any of these theorems could also be derived without using the duality principle. For example:

Theorem 2b:  $x \cdot \text{False} = \text{False}$

|  |                 |
|--|-----------------|
| $x \cdot \text{False} = \text{False} + (x \cdot \text{False})$ | by Postulate 1a |
| $= (x \cdot /x) + (x \cdot \text{False})$                      | by Postulate 2b |
| $= x \cdot (/x + \text{False})$                                | by Postulate 4a |
| $= x \cdot /x$   | by Postulate 1a |
| $= \text{False}$   | by Postulate 2b |

|             |  |
|-------------|--|
| Postulate 1 | (a) $x + \text{False} = x$<br>(b) $x \cdot \text{True} = x$  |
| Postulate 2 | (a) $x + /x = \text{True}$<br>(b) $x \cdot /x = \text{False}$                                      |
| Postulate 3 | (a) $x + y = y + x$<br>(b) $x \cdot y = y \cdot x$   |
| Postulate 4 | (a) $x \cdot (y + z) = (x \cdot y) + (x \cdot z)$<br>(b) $x + (y \cdot z) = (x + y) \cdot (x + z)$ |
| Theorem 1   | (a) $x + x = x$<br>(b) $x \cdot x = x$   |
| Theorem 2   | (a) $x + \text{True} = \text{True}$<br>(b) $x \cdot \text{False} = \text{False}$                   |
| Theorem 3   | $/(/x) = x$  |
| Theorem 4   | (a) $x + (y + z) = (x + y) + z$<br>(b) $x \cdot (y \cdot z) = (x \cdot y) \cdot z$                 |
| Theorem 5   | (a) $/x + y = /x \cdot /y$<br>(b) $/x \cdot y = /x + /y$   |
| Theorem 6   | (a) $x + (x \cdot y) = x$<br>(b) $x \cdot (x + y) = x$   |
| Theorem 7   | (a) $(x \cdot y) + (x \cdot /y) = x$<br>(b) $(x + y) \cdot (x + /y) = x$                           |
| Theorem 8   | (a) $x + (/x \cdot y) = x + y$<br>(b) $x \cdot (/x + y) = x \cdot y$                               |
| Theorem 9   | $(x \cdot y) + (/x \cdot z) + (y \cdot z) = (x \cdot y) + (/x \cdot z)$                            |

Figure 1-5. Postulates and Theorems of Boolean Algebra

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### 1.5.2 Using Truth Tables

Finally, theorems may be demonstrated with truth tables. A theorem always holds true if it holds true for all cases. Since two variables can only have two values each, there are only four possible cases, so it is reasonable to look at a theorem on a case-by-case basis. For example, we can prove Theorem 5a with the following truth table:

| x | y | $\overline{(x + y)}$ | $\overline{(x \cdot y)}$ |
|---|---|----------------------|--------------------------|
| F | F | T                    | T                        |
| F | T | F                    | F                        |
| T | F | F                    | F                        |
| T | T | F                    | F                        |

Figure 1-6

It can be seen from Figure 1-6 that, in every case,  $\overline{(x + y)}$  is equal to  $\overline{(x \cdot y)}$ .

### 1.5.3 Complement of a Boolean Function

A *Boolean expression* is some mixture of Boolean variables and operators that has a value. For example:

$$x + y \cdot z \cdot a$$

is a Boolean expression. A *Boolean function* is a statement in which two expressions are equated. For example:

$$a = b \cdot c$$

$$\overline{(c \cdot d)} = \overline{c} + \overline{d}$$

are Boolean functions. The difference is the presence of an equal sign. It is worth noting that 'equals', or equivalence, is also a Boolean function, since two expressions either are or are not equal. However, in this book we will attempt to present only true equations, so the Boolean value of an equal sign may be ignored in functions.

So far, we have talked about a Boolean expression's value as True or False. More frequently, these values are written as 1 and 0, with 1 standing for True, and 0 standing for False. From here on, we will also adopt this standard.

The complement of an expression may be written easily by placing the NOT operator in front of the enclosed expression:

$$\overline{(x + y \cdot z \cdot a)},$$

but it is also possible to complement a function. The *complement* of a function is obtained by complementing both sides of an equation. For example, given the equation:

$$\overline{a} = b \cdot c + 1$$

the complement would be:

$$\overline{\overline{a}} = \overline{(b \cdot c + 1)}$$

which could be simplified:

|   |                    |
|---|--------------------|
| $a = \overline{(b \cdot c + 1)}$                | by Theorem 3       |
| $a = \overline{(b \cdot c)} \cdot \overline{1}$ | by Theorem 5a      |
| $a = \overline{(b \cdot c)} \cdot 0$            | def. of complement |
| $a = 0$   | by Theorem 2b      |

Note the differences between obtaining the complement of a function, and obtaining the dual of a function. The complement is obtained by complementing the entire expression on both sides of the equation, and manipulating it from there with the given postulates and theorems. The dual of a function is

obtained by replacing all 1's with 0's, all 0's with 1's, all ANDs with ORs, and all ORs with ANDs.

In fact, the easiest way in which to obtain the complement of a function is by taking the dual of the function and complementing each individual variable (called a *literal*). For example, the complement of:

$$F = (x + \overline{y}) \cdot [W \cdot (x + z)]$$

can be found by

1) taking the dual:

$$F^D = (x \cdot \overline{y}) + [W + (x \cdot z)]$$

2) complementing each literal:

$$\overline{F} = \overline{(x \cdot \overline{y})} + \overline{[W + (x \cdot z)]}$$

## 1.6 Algebraic Simplification

A *literal* is a complemented ( $\overline{x}$ ) or uncomplemented ( $x$ ) variable. A *term* is a subexpression, often enclosed in parentheses. The equation:

$$F = (x + \overline{y}) \cdot \overline{x}$$

has three literals and two terms. *Simplifying* a Boolean equation is an attempt to minimize the number of literals or the number of terms in an equation. Unfortunately, in many situations, one can only be minimized at the expense of the other, so it is important to decide from the outset whether you are minimizing literals or terms. Literals can be minimized by repeated applications of the postulates and theorems of Boolean algebra (Table 1-6), but there is no algorithm; it is a trial and error process, and the result may not be unique. For example, the equation:

$$F = (x \cdot \overline{z}) + [(x + y) \cdot \overline{z}]$$

may be simplified through the following steps:

|   |              |
|---|--------------|
| $F = (x \cdot \overline{z}) + [(x + y) \cdot \overline{z}]$ |              |
| $= (\overline{z} \cdot x) + [\overline{z} \cdot (x + y)]$   | Postulate 3b |
| $= \overline{z} \cdot [x + (x + y)]$                        | Postulate 4a |
| $= \overline{z} \cdot [(x + x) + y]$                        | Theorem 4a   |
| $= \overline{z} \cdot (x + y)$                              | Theorem 1a   |

The equation is now simplified because there are no postulates or theorems which, when applied, will serve to reduce the number of items further.

### 1.6.1 Sum-of-Products and Product-of-Sums

When an equation is in the form:

$$F = (a \cdot b) + (c \cdot \overline{a}) + d$$

for example, it is said to be in *sum of products* form. This is because the equation is composed of a number of product terms (AND) that are summed (ORed) together. The subexpression resulting from two operands being ANDed together is referred to as a product because of the resemblance of the AND operator to the multiplication operator of arithmetic; the result of OR is referred to as a sum because of the resemblance of the OR operator to the addition operator of arithmetic.

When an equation is in the form:

$$F = (a + b) \cdot (a + \overline{c})$$

for example, it is said to be in *product of sums* form, because it is composed of a number of sum terms (OR) that are ANDed together. Both sum of products and product of sums forms are called *standard forms*.

## 1.6.2 Canonical Forms

If an equation has three variables that are complemented or uncomplemented, then there are a limited number of ways in which these variables can be ANDed or ORed together. Referring to Figure 1-7, under the column 'Minterms', and the subcolumn 'Term', there are eight different ways in which three variables could be ANDed together. Each combination has been given a name: the letter 'm' and a number. For example, the expression:

$$(\overline{x}y^{\ast}z) \text{ is } m_3$$

while the expression:

$$(x^{\ast}y^{\ast}/z) \text{ is } m_7$$

| Minterms              |       | Maxterms       |       |
|-----------------------|-------|----------------|-------|
| Term                  | Name  | Term           | Name  |
| $x^{\ast}/y^{\ast}/z$ | $m_0$ | $x + y + z$    | $M_0$ |
| $x^{\ast}/y^{\ast}z$  | $m_1$ | $x + y + /z$   | $M_1$ |
| $x^{\ast}y^{\ast}/z$  | $m_2$ | $x + /y + z$   | $M_2$ |
| $x^{\ast}y^{\ast}z$   | $m_3$ | $x + /y + /z$  | $M_3$ |
| $x/y^{\ast}/z$        | $m_4$ | $/x + y + z$   | $M_4$ |
| $x/y^{\ast}z$         | $m_5$ | $/x + y + /z$  | $M_5$ |
| $x^{\ast}/y^{\ast}/z$ | $m_6$ | $x + /y + z$   | $M_6$ |
| $x^{\ast}/y^{\ast}z$  | $m_7$ | $/x + /y + /z$ | $M_7$ |

Figure 1-7

Using these shorthand notations for expressions, we can refer to the equation:

$$F = (\overline{x}y^{\ast}/z) + (x^{\ast}/y^{\ast}z) + (x^{\ast}/y^{\ast}z)$$

as:

$$F = m_2 + m_4 + m_5$$

which is much more compact. When an equation is expressed in terms of these named AND subexpressions, or *minterms* it is said to be in *sum-of-minterms* form.

Similarly, there are eight ways in which three variables may be ORed together. Such an OR subexpression is called a *maxterm*. The equation:

$$F = (x + y + z)(x + /y + /z)(/x + /y + /z)$$

could also be written as:

$$F = M_0 \cdot M_3 \cdot M_7$$

since each OR subexpression has been given a name consisting of an 'M' and a number (see the column 'Maxterms' in Figure 1-7). An equation expressed in this way is said to be written in *product-of-maxterms* form. Both sum of minterms and product of maxterms forms are called *canonical forms*.

In many equations, not every variable is represented in every term, but it is still possible to write them in canonical form. A little algebraic manipulation will produce the missing terms that are needed. For example, the equation:

$$F = (x^{\ast}y^{\ast}z) + (/x^{\ast}y)$$

is missing a 'z' in its second term. In order to write this equation in sum of minterms form, we must first take the following steps:

$$\begin{aligned} F &= (x^{\ast}y^{\ast}z) + (/x^{\ast}y^{\ast}1) && \text{Postulate 1b} \\ &= (x^{\ast}y^{\ast}z) + [/x^{\ast}y^{\ast}(z + /z)] && \text{Postulate 2a} \\ &= (x^{\ast}y^{\ast}z) + (/x^{\ast}y^{\ast}z) + (/x^{\ast}y^{\ast}/z) && \text{Postulate 4a} \\ &= m_2 + m_3 + m_7 \end{aligned}$$

To create a missing variable in a maxterm, use the duals of the postulates used above. To create more than one missing variable, expand the equation as many times as is needed by following the steps above.

## 1.6.3 Conversion Between Canonical Forms

Canonical forms do not only exist because they are more compact. With canonical forms, it is a trivial matter to invert an expression, or to convert between sum-of-product and product-of-sum representations.

Given the equation:

$$\begin{aligned} F &= (/a^{\ast}b^{\ast}/c) + (a^{\ast}/b^{\ast}c) + (a^{\ast} b^{\ast}c) \\ &= m_2 + m_5 + m_7 \end{aligned}$$

we can take its complement by forming an equation from all the minterms that are NOT present in the equation:

$$\begin{aligned} /F &= m_0 + m_1 + m_3 + m_4 + m_6 \\ &= (/a^{\ast}/b^{\ast}/c) + (/a^{\ast}/b^{\ast}c) + (/a^{\ast}b^{\ast}c) + (a^{\ast}/b^{\ast}/c) + \\ &\quad (a^{\ast}b^{\ast}/c) \end{aligned}$$

Finally, using the dual/complement method, we can take the complement again. Of course, by Theorem 3 (Figure 1-5), anything that is complemented twice returns to its original value:

$$\begin{aligned} F &= (a + b + c)(a + b + /c)(a + /b + /c) \\ &\quad \cdot (/a + b + c)(/a + b + /c) \end{aligned}$$

We have now expressed function F, originally a sum of products, in product-of-sums form. Any Boolean equation can be written in either form.

Thus a quick way of doing this conversion is to write a product-of-maxterm equation using the maxterm numbers which did not appear in the original equation. In our example, we used the numbers 2, 5 and 7 for the sum-of-minterms form. In our product-of-maxterms form, we would use the maxterms 0, 1, 3, 4 and 6.

$$\begin{aligned} F &= M_0 \cdot M_1 \cdot M_3 \cdot M_4 \cdot M_6 \\ &= (a + b + c)(a + b + /c)(a + /b + /c) \\ &\quad \cdot (/a + b + c)(/a + /b + c) \end{aligned}$$

This works because each maxterm is the dual of the minterm that has the same number.

Of course, any equation written in the canonical forms can likely be simplified. After converting from standard form to canonical form, then converting from one canonical form to another, you may wish to simplify your equation.

## 1.7 Exclusive-OR (XOR) and Equivalence (XNOR)

There are two other frequently used operators which are really just special combinations of the AND, OR, and NOT operators.

The first is the Exclusive OR operator. Its symbol and truth table is shown in Figure 1-8. Note that the simple OR function is true even when both conditions are true, which is somewhat unlike our conversational use of the word 'OR'. The XOR function is more like our normal use of 'OR': one or the other condition is true, but not both.



## Logic Tutorial

The XOR function

$$X \oplus Y$$

is equivalent to

$$x \oplus y + \overline{x} \oplus y.$$

| A | B | A $\oplus$ B |
|---|---|--------------|
| 0 | 0 | 0            |
| 0 | 1 | 1            |
| 1 | 0 | 1            |
| 1 | 1 | 0            |

Figure 1-8. The XOR Operator

The Equivalence (XNOR) operators, symbols, and truth table are shown in Figure 1-9. It is true only when both conditions are the same. Thus XNOR is the complement of XOR. Here  $x \equiv y$  is equivalent to  $x \oplus y + \overline{x} \oplus y$ .

| A | B | A $\equiv$ B |
|---|---|--------------|
| 0 | 0 | 1            |
| 0 | 1 | 0            |
| 1 | 0 | 0            |
| 1 | 1 | 1            |

Figure 1-9. The XNOR Operator

### 1-8 Boolean Operator Summary

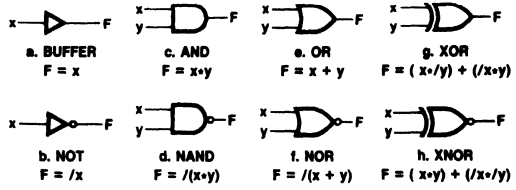


Figure 1-10. Logic Gates

| X | Y | F1 | F2 | F3 | F4 | F5       | F6       | F7       | F8       | F9       | F10      | F11      | F12      | F13      | F14      | F15      | F16 |
|---|---|----|----|----|----|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----|
| 0 | 0 | 0  | 0  | 0  | 0  | 0        | 0        | 0        | 0        | 1        | 1        | 1        | 1        | 1        | 1        | 1        | 1   |
| 0 | 1 | 0  | 0  | 0  | 0  | 1        | 1        | 1        | 1        | 0        | 0        | 0        | 0        | 0        | 1        | 1        | 1   |
| 1 | 0 | 0  | 0  | 1  | 1  | 0        | 0        | 1        | 1        | 0        | 0        | 1        | 1        | 0        | 0        | 1        | 1   |
| 1 | 1 | 0  | 1  | 0  | 1  | 0        | 1        | 0        | 1        | 0        | 1        | 0        | 1        | 0        | 1        | 0        | 1   |
|   |   | 0  | *  | X  | Y  | $\oplus$ | $\equiv$ | $\oplus$ | $\oplus$ | $\oplus$ | $\oplus$ | $\oplus$ | $\oplus$ | $\oplus$ | $\oplus$ | $\oplus$ | 1   |

Figure 1-11 Boolean Operators

## 2. Binary Systems

Binary numbers utilize a base 2 number system that consists of two digits: '0' and '1'. This number system is used in current digital computer systems because the outputs of most switching circuits can only be in one of two logical states. Also, when transistor circuits are only operating in one of two modes greater reliability can be obtained.

### 2.1 Base Conversion

Normally, decimal (base 10) numbers are written using a positional notation. In other words, the value of the number is determined by multiplying each digit by an appropriate power of 10 which is dependent on its relative position to the decimal point.

#### Example 2.1

$$714.02 = 7 \times 10^2 + 1 \times 10^1 + 4 \times 10^0 + 0 \times 10^{-1} + 2 \times 10^{-2}$$

#### 2.1.1 Base-2 to Base-10 Conversion

Similarly, binary (base-2) numbers are also position-dependent relative to the binary point: each binary digit is multiplied by an appropriate power of 2 in order to obtain the decimal equivalent. The following example shows the conversion from a base-2 number to a base-10 number.

#### Example 2.2

$$\begin{aligned} 101.01_2 &= 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 0 \times 2^{-1} + 1 \times 2^{-2} \\ &= 4 + 0 + 1 + 0 + 1/4 \\ &= 5.25_{10} \end{aligned}$$

Notice that the binary point separates the positive and the negative powers of 2. This is similar to the case of the decimal point separating the positive and negative powers of 10.

#### 2.1.2 Base-10 to Base-2 Conversion

Converting a base-10 integer to a base-2 integer requires utilizing the division method. To explain, let N represent the base-10 integer. Divide N by 2, since base-2 is desired. As a result, there should be a quotient,  $Q_0$ , and a remainder,  $R_0$ . Then divide  $Q_0$  by 2 again and continue this process until the final quotient equals zero. The desired binary digits are the remainders resulting from each division step; the least significant bit starts with  $R_0$ .

#### Example 2.3

Converts  $61_{10}$  to binary:

|                      |               |     |
|----------------------|---------------|-----|
| 61/2 = 30            | remainder = 1 | LSB |
| 30/2 = 15            | remainder = 0 |     |
| 15/2 = 7             | remainder = 1 |     |
| 7/2 = 3              | remainder = 1 |     |
| 3/2 = 1              | remainder = 1 |     |
| 1/2 = 0              | remainder = 1 | MSB |
| $61_{10} = 111101_2$ |               |     |

Converting decimal fractions to binary requires successive multiplications by 2. Let F be a decimal fraction. Multiply this number F by 2 and obtain an integer and a fraction result. Take the fraction and multiply once again by 2. Continue this process until the fraction becomes zero, or until a sufficient number of digits has been reached. The desired digits are the integer parts that were obtained at each multiplication step. The most significant digit is obtained first.

#### Example 2.4

Convert  $0.375_{10}$  to binary

|  |  |  |           |     |
|--|--|--|-----------|-----|
| $\begin{array}{r} 0.375 \\ \times 2 \\ \hline 0.750 \end{array}$ | $\begin{array}{r} 0.750 \\ \times 2 \\ \hline 1.500 \end{array}$ | $\begin{array}{r} 0.500 \\ \times 2 \\ \hline 1.000 \end{array}$ | $l_0 = 0$ | MSB |
|  |  |  | $l_1 = 1$ |     |
|  |  |  | $l_2 = 1$ | LSB |

$$0.375_{10} = 0.011$$

Note that if this procedure doesn't terminate, then the result must be a repeating fraction.

#### 2.1.3 Base-2 to Base-8 or Base-16

To convert binary to octal (base-8) or vice versa is very simple and can be done by inspection. Each octal digit corresponds to three binary digits, since it can be in one of eight states (0 to 7). Therefore, the binary number should be divided into groups of three starting from the binary point. Each group on both sides of the binary point is replaced by an octal digit representation.

#### Example 2.5

$$\begin{aligned} 101110.011_2 &= 101 \ 110 \ . \ 011 \\ &= 5 \ 6 \ . \ 3 \ 8 \end{aligned}$$

Similarly, binary to hexadecimal (base-16) and vice versa can also be done easily. This time, instead of three, the binary number is broken up into groups of four. The reason is because a hexadecimal digit can assume one of sixteen states (0 to 9, A, B, C, D, E and F). Again starting from the binary point, each group is replaced by its hexadecimal equivalent.

#### Example 2.6

$$\begin{aligned} 11100101.0011_2 &= 1110 \ 0101 \ . \ 0011 \\ &= E \ 5 \ . \ 3 \ 16 \end{aligned}$$

## 2.2 Simplicity of Binary Arithmetic

Due to the design of logic networks, it is much easier to do binary than decimal arithmetic in digital systems. Although binary arithmetic is implemented in about the same manner, the addition tables are much easier. Fortunately, numerical subtractions may be performed by addition operations between numbers. This property is of little use in the decimal system. However, much can be gained if used in the binary system. This is mainly due to the fact that in a binary system, complements of numbers are easily implemented, and the same hardware can be used for addition and subtraction operations. This allows for considerable savings in terms of system hardware design.

### 2.2.1 1's Complement

Finding the 1's complement of a binary number is easily done by inverting each digit (0 or 1).

#### Example 2.7

The 1's complement of:  
 $01011.1101 = 10100.0010$

### 2.2.2 Subtraction with 1's Complement

To subtract two positive binary numbers X and Y, (X-Y), the following procedures should be used:

1. Take the 1's complement of Y and add it to X.
2. Check results for overflow carry:
  - a. If there is an overflow carry, add it to the least significant digit of the result.
  - b. If there is no overflow carry, the result is negative. Then, complement this result and place a minus sign in front.

## Logic Tutorial

### Example 2.8

$$\begin{array}{r}
 \text{a) } 1010.11 - 1000.01 = ? \\
 \phantom{\text{a) }} 1010.11 \\
 + \underline{0111.10} \leftarrow \text{1's complement of } 1000.01 \\
 \text{overflow } 1 \quad 0010.01 \\
 + \quad \underline{\phantom{00}1} \leftarrow \text{add overflow carry} \\
 \phantom{\text{a) }} 0010.10 \rightarrow \text{answer}
 \end{array}$$

$$\begin{array}{r}
 \text{b) } 1001.10 - 1100.11 = ? \\
 \phantom{\text{b) }} 1001.10 \\
 + \underline{0011.00} \leftarrow \text{1's complement of } 1100.11 \\
 \text{no overflow} \quad 1100.10 \rightarrow -0011.01 \rightarrow \text{answer}
 \end{array}$$

### 2.2.3 2's Complement

The most widely used numbering manipulation technique in current digital computers is the 2's complement method. This method is easily implemented with any decent computer instruction set. Using the same hardware for addition and subtraction in 2's complement makes system design simpler and can lead to savings in cost.

Finding the 2's complement of a binary number requires the following:

1. Take the logical complement by inverting each digit of the binary number.
2. Add 1 to the least significant digit.

### Example 2.9

The 2's complement of 001100.01 is

$$\begin{array}{r}
 \text{step (1) } 110011.10 \leftarrow \text{logical complement of } 001100.01 \\
 \text{step (2) } + \quad \underline{\phantom{00}1} \\
 \phantom{\text{step (2) }} 110011.11 \rightarrow \text{answer}
 \end{array}$$

This technique can also be done by visual inspection. Start with the least significant digit of the number and visually scan to the left. Leave all digits unchanged until the first '1' is encountered. Then invert all the remaining digits to the left of this first '1'. Note that the binary point has no effect on this procedure.

### 2.2.4 Subtraction with 2's Complement

The steps for subtracting two binary numbers X and Y, (X-Y), are as follows:

1. Add X to the 2's complement of Y.
2. Check result for overflow carry:
  - a. If there is an overflow carry, then throw it out. The result now represents (X-Y).
  - b. If there is no overflow carry, the number is negative. Take the 2's complement of the result and place a negative sign in front of it.

### Example 2.10

$$\begin{array}{r}
 \text{a) } 1110.11 - 1011.10 = ? \\
 \phantom{\text{a) }} 1110.11 \\
 \text{overflow carry} \quad + \underline{0100.10} \leftarrow \text{2's complement of } 1011.10 \\
 \text{throw out } 1 \quad 0011.01 \rightarrow +0011.01 \rightarrow \text{answer} \\
 \text{b) } 0001.11 - 1000.10 = ? \\
 \phantom{\text{b) }} 0001.11 \\
 \text{no overflow} \quad + \underline{0111.10} \leftarrow \text{2's complement of } 1000.10 \\
 \text{carry} \quad 1001.01 \rightarrow -0110.11 \rightarrow \text{answer}
 \end{array}$$

Note that in computing systems which need to represent negative numbers, the MSB serves as a sign bit. When it is '1', the number is negative.

### 3. Karnaugh Maps

#### 3.1 Karnaugh Map Technique

There exists a technique that allows the logic designer to minimize Sum of Product terms by utilizing *Karnaugh maps*. The Karnaugh map (sometimes referred to as *K-map*) graphically displays the implicants (*minterms*) of any sum-of-products expression in a matrix. It is derived directly from the truth table of this expression. K-maps are very useful for minimizing three, four, five and even six variable functions, but it gets too complicated beyond six. For expressions with more than six variables, the numerical manipulation should be done on a computer that uses a method such as the Quine-McCluskey method. This technique will not be discussed here.

##### 3.1.1 Karnaugh Map Reading Procedure

Each minterm cell in the K-map has a value of '1' as determined by the truth table. Circle those single minterm cells that will combine with its adjacent cells to form larger groups of 1, 2, 4, 8, etc. If each single minterm cell is grouped individually, the map reading process should yield the original Sum of Product expression.

However, if two minterm cells are grouped together, at least one variable is dropped. This is because the theorem

$$X \cdot Y + X \cdot \bar{Y} = X$$

has been executed once. If a group of four adjacent minterm cells have been combined, then the theorem has been executed twice, and two variables are dropped. A group of eight adjacent cells result in three variables being dropped. Therefore, the main objective is to minimize the number of minterm cell groupings while maximizing the number of minterm cells in each grouping. By minimizing the number of cell groupings, the number of product terms is reduced. On the other hand, by maximizing the number of cells in each grouping, the number of literals in each product term is reduced.

For any product term, the variables which are included in the term are those whose values in the labels of the grouped cells are constant. The constant values give the polarity of the variables.

In example 3.1, product term 1 has cells with labels ABC = 010 and 110. B and C are constant here; B is 1 and C is 0, giving the product term  $B \cdot \bar{C}$ .

##### 3.1.2 Karnaugh Map Matrix Labels

In labeling the K-map matrix, the following rule should be followed:

Top to bottom or left to right:

| Two-variable | Three-variable | Four-variable   |
|--------------|----------------|---|
| 00           | 000            | Add a '0' MSB and use the three-variable chart for the first half. For the second half, add a '1' MSB and repeat the same chart in reverse order. |
| 01           | 001            |   |
| 11           | 011            |   |
| 10           | 010            |   |
|              | 110            |   |
|              | 111            |   |
|              | 101            |   |
|              | 100            |   |

Notice that the number of variables shown above is referring to one axis only (X or Y). However, this technique may be used for any number of variables that may be desired on each axis. For any axis greater than one variable, the second-half is

a mirror image of the first-half with the MSB equal to a '1'. This can be seen above when comparing the three-variable list to the two-variable list.

#### 3.1.3 Karnaugh Map Examples

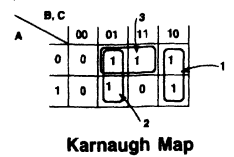
Examples of three- and four-variable K-maps are shown below. The corresponding truth tables for the examples are also shown to illustrate the derivation of the K-maps.

##### Example 3.1

Three-Variable K-map:

| A | B | C | F |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 0 |

Truth Table



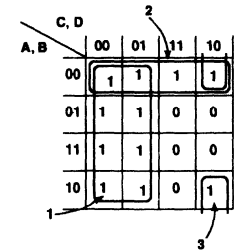
product term 1 =  $B \cdot \bar{C}$   
 product term 2 =  $\bar{B} \cdot C$   
 product term 3 =  $\bar{A} \cdot C$   
 $F = B \cdot \bar{C} + \bar{B} \cdot C + \bar{A} \cdot C$

##### Example 3.2

Four-Variable K-map:

| A | B | C | D | F |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 1 | 0 | 1 |
| 0 | 0 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 |
| 0 | 1 | 0 | 1 | 1 |
| 0 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 1 | 1 |
| 1 | 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 1 | 0 |
| 1 | 1 | 0 | 0 | 1 |
| 1 | 1 | 0 | 1 | 1 |
| 1 | 1 | 1 | 0 | 0 |
| 1 | 1 | 1 | 1 | 0 |

Truth Table



Karnaugh Map

product term 1 =  $\bar{C}$   
 product term 2 =  $\bar{A} \cdot \bar{B}$   
 product term 3 =  $\bar{B} \cdot C \cdot \bar{D}$   
 $F = \bar{C} + \bar{A} \cdot \bar{B} + \bar{B} \cdot C \cdot \bar{D}$

## 4. Combinatorial Logic

### 4.1 Logic Design Introduction

Logic design is a combination of analysis, synthesis, minimization and implementation of Boolean functions. Boolean functions must originally come from worded statements. This is a very important part of logic design because the worded statement can be ambiguous and imprecise, while the Boolean equation must be unambiguous and exact. The conversion of words to equations is called synthesis. Engineers must be careful when synthesizing a problem because many times the originator of a problem is not a technical person. It is the responsibility of the logic designer to review the synthesis of the problem with the originator to make sure the solution is suitable.

### 4.2 Combinatorial Design

Combinatorial logic is a network whose output is solely dependent upon its inputs. It has no feedback loops or memory elements.

The first step in combinatorial design is to analyze the problem and then define it in an exact manner. This will make synthesizing a Boolean equation much easier.

Synthesis usually takes several steps. Using truth tables and K-maps are common ways of specifying a problem and putting it in the minimal Boolean form.

#### Example 4.1

A seven-segment decoder decodes a BCD number and turns on the appropriate segments of a seven-segment digit. Given the seven-segment digit in Figure 4-1, develop a minimal equation for each segment by using a truth table and K-maps.

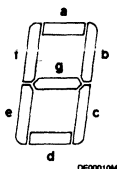


Figure 4-1. Seven-Segment Decoder

Forming a truth table from Figure 4-1 is done by writing all '10' possible inputs down, then determining which segments should be activated for each input. For example, segment 'a' is activated whenever; 2, 3, 5, 7, 8, 9 or 0 is input to the decoder. Once the table is formed, a K-map can be made for each segment. The K-maps are used to derive a Sum of Products logic equation for each segment.

K-maps are an excellent way of forming equations when three to six variables are involved in a problem. Either of the two standard algebraic forms of the function (sum-of-products or product-of-sums) can be derived. A network of AND and OR gates is obtained directly from either form.

| DECIMAL | INPUTS |   |   |   | OUTPUTS |   |   |   |   |   |   |
|---------|--------|---|---|---|---------|---|---|---|---|---|---|
|         | W      | X | Y | Z | a       | b | c | d | e | f | g |
| 0       | 0      | 0 | 0 | 0 | 1       | 1 | 1 | 1 | 1 | 1 | 0 |
| 1       | 0      | 0 | 0 | 1 | 0       | 1 | 1 | 0 | 0 | 0 | 0 |
| 2       | 0      | 0 | 1 | 0 | 1       | 1 | 0 | 1 | 1 | 0 | 1 |
| 3       | 0      | 0 | 1 | 1 | 1       | 1 | 1 | 1 | 0 | 0 | 1 |
| 4       | 0      | 1 | 0 | 0 | 0       | 1 | 1 | 0 | 0 | 1 | 1 |
| 5       | 0      | 1 | 0 | 1 | 1       | 0 | 1 | 1 | 0 | 1 | 1 |
| 6       | 0      | 1 | 1 | 0 | 0       | 0 | 1 | 1 | 1 | 1 | 1 |
| 7       | 0      | 1 | 1 | 1 | 1       | 1 | 1 | 0 | 0 | 0 | 0 |
| 8       | 1      | 0 | 0 | 0 | 1       | 1 | 1 | 1 | 1 | 1 | 1 |
| 9       | 1      | 0 | 0 | 1 | 1       | 1 | 1 | 0 | 0 | 1 | 1 |

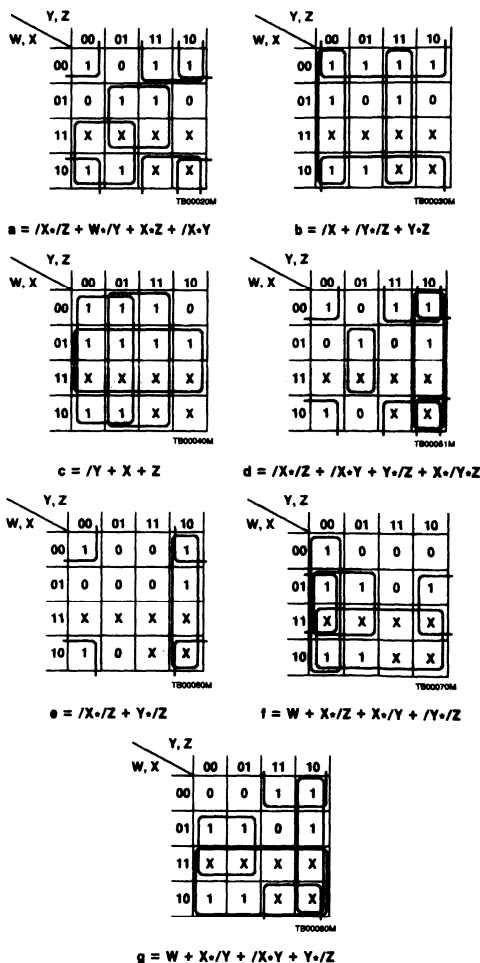


Figure 4-2

## Logic Tutorial

| ROW | A | B | C | MINTERMS                     | MAXTERMS             |
|-----|---|---|---|------------------------------|----------------------|
| 0   | 0 | 0 | 0 | $/A \cdot /B \cdot /C = m_0$ | $A + B + C = M_0$    |
| 1   | 0 | 0 | 1 | $/A \cdot /B \cdot C = m_1$  | $A + B + /C = M_1$   |
| 2   | 0 | 1 | 0 | $/A \cdot B \cdot /C = m_2$  | $A + /B + C = M_2$   |
| 3   | 0 | 1 | 1 | $/A \cdot B \cdot C = m_3$   | $A + /B + /C = M_3$  |
| 4   | 1 | 0 | 0 | $A \cdot /B \cdot /C = m_4$  | $/A + B + C = M_4$   |
| 5   | 1 | 0 | 1 | $A \cdot /B \cdot C = m_5$   | $/A + B + /C = M_5$  |
| 6   | 1 | 1 | 0 | $A \cdot B \cdot /C = m_6$   | $/A + /B + C = M_6$  |
| 7   | 1 | 1 | 1 | $A \cdot B \cdot C = m_7$    | $/A + /B + /C = M_7$ |

Figure 4-3 Minterm and Maxterm Expansions for 3 Variables

Since a minterm is a product term, an unminimized sum-of-products expression may also be written with minterms.

Each maxterm is a sum of variables. It is derived by solving a K-map for the 0-terms instead of the 1-terms. Maxterms are used in a product-of-sums solution.

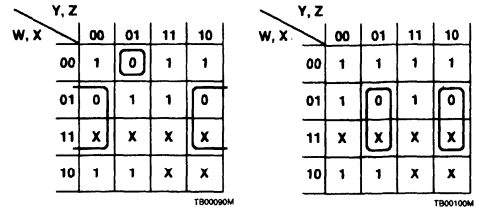
### Example 4.2

Rewriting the Sum of Products equations from example 4.1 in minterm form can be done by inspecting the truth table or K-map.

- a =  $\Sigma m(0, 2, 3, 5, 7, 8, 9, 10, 11, 12, 13, 15)$
- b =  $\Sigma m(0, 1, 2, 3, 4, 7, 8, 9, 10, 11, 12, 15)$
- c =  $\Sigma m(0, 1, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15)$
- d =  $\Sigma m(0, 2, 3, 5, 6, 8, 10, 11, 13)$
- e =  $\Sigma m(0, 2, 6, 8, 10, 14)$
- f =  $\Sigma m(0, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15)$
- g =  $\Sigma m(2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15)$

### Example 4.3

We can easily rework the first two K-maps from Example 4.1 to get a maxterm solution.



$$/a = X \cdot /Z + /W \cdot /X \cdot Y \cdot Z$$

$$a = (/X + Z) \cdot (W + X + Y + /Z)$$

$$a = \Pi M(1, 4, 8, 12, 14)$$

$$/b = X \cdot /Y + X \cdot /Z$$

$$b = (/X + Y) \cdot (/X + Z)$$

$$b = \Pi M(5, 6, 13, 14)$$

Given either canonical form, it is a simple matter of converting to the other form, or the inverse of either form.

| GIVEN FORM             | DESIRED FORM  |   |  |  |
|------------------------|---|---|--|--|
|                        | Minterm expansion of F  | Maxterm expansion of F  | Inverted Minterm expansion of F                      | Inverted Maxterm expansion of F                      |
| Minterm expansion of F | —   | Maxterm numbers are those numbers not on the minterm list for F | List minterms not present in F                       | Maxterm numbers are the same as minterm numbers of F |
| Maxterm expansion of F | Minterm numbers are those numbers not on the maxterm list for F | —   | Minterm numbers are the same as maxterm numbers of F | List maxterms not present in F                       |

Figure 4-4 Conversion of Forms Table

### 4.3 NAND Gates and NOR Gates

A set of logic operators is said to be functionally complete if any Boolean function can be expressed in terms of this set of operations. The set {AND, OR, NOT} is functionally complete. The NAND and the NOR gates are each functionally complete by themselves. Therefore they are called *universal* gates.

Conversion of AND and OR networks to NAND networks is carried out by starting with a minimal sum of products expression and then applying the theorem;  $F = /(/(F))$ . This equation can then be manipulated using DeMorgan's theorem.

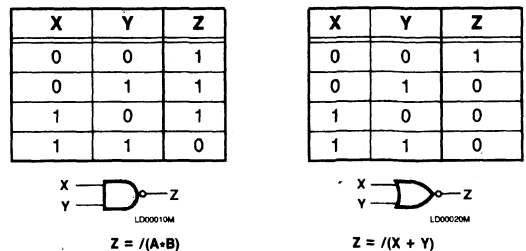


Figure 4-5. Truth Tables

## Logic Tutorial

### Example 4.4

From the K-map in Figure 4-6, we can find equations for an AND-OR, NAND-NAND, OR-NAND and NOR-OR networks.

|      |      |    |    |    |
|------|------|----|----|----|
|      | C, D |    |    |    |
| A, B | 00   | 01 | 11 | 10 |
| 00   | 1    | 0  | 1  | 0  |
| 01   | 1    | 0  | 1  | 0  |
| 11   | 1    | 1  | 1  | 1  |
| 10   | 0    | 0  | 0  | 0  |

TB00110M

Figure 4-6. Karnaugh Map

|  |  |
|--|--|
| $F = A \cdot B + /A \cdot /C \cdot /D + /A \cdot C \cdot D$ $= /[(A \cdot B + /A \cdot /C \cdot /D + /A \cdot C \cdot D)]$ $= /[(A \cdot B) \cdot /(/A \cdot /C \cdot /D) + /(/A \cdot C \cdot D)]$ $= /[(A + /B) \cdot (A + C + D) \cdot (A + /C + /D)]$ $= /[(A + /B) + /A + C + D) + /A + /C + /D)$ | AND-OR<br>NAND-NAND<br>OR-NAND<br>NOR-OR |
|--|--|

In order to get a network of NOR gates we must start with the minimum product-of-sums form of F.

### Example 4.5

From the same K-map, we can also find equations for OR-AND, NOR-NOR, AND-NOR and NAND-AND networks.

|   |  |
|---|--|
| $F = (/A + B) \cdot (A + C + /D) \cdot (A + /C + D)$ $= /[(/A + B) + /A + C + /D) + /A + /C + D)$ $= (/A \cdot /B + /A \cdot /C \cdot D + /A \cdot C \cdot /D)$ $= (/A \cdot /B) \cdot (/A \cdot /C \cdot D) \cdot (/A \cdot C \cdot /D)$ | OR-AND<br>NOR-NOR<br>AND-NOR<br>NAND-AND |
|---|--|

NAND-NAND and NOR-NOR networks are very common in industry because both the NAND and NOR gates are universal gates. Thus, these gates are made in great quantities, making them more available for designers.

A NAND-NAND network is made from a Sum of Products (SOP) solution. The AND and OR gates of the SOP solution are replaced by NAND gates with all the interconnections staying the same. Variables that are input directly to the output gate must be inverted.

A NOR-NOR network is made from a Product of Sums solution. The OR and AND gates are replaced by NOR gates with all interconnections staying the same. Any variables that are input directly to the output NOR gates must be inverted.

An easy way of forming either a NAND network from a Sum of Products solution or a NOR network from a Product of Sums solution is to place two inversion bubbles in series between the two levels as demonstrated in Figure 4-7.

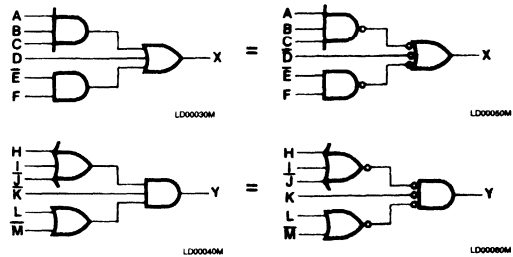


Figure 4-7. Network Conversion

## 4.4 Multiplexers

Multiplexers are circuits which select one of  $2^n$  input lines using  $n$  selector lines. For example, an eight-input multiplexer (often called a 'MUX') selects one of  $2^3$  input lines using three select lines.

### Example 4.6

Design an 8:1 multiplexer in SOP form by using a truth table.

| SELECT |   |   | MULTIPLEXER INPUTS |    |    |    |    |    |    |    | OUTPUT |
|--------|---|---|--------------------|----|----|----|----|----|----|----|--------|
| A      | B | C | D0                 | D1 | D2 | D3 | D4 | D5 | D6 | D7 | Y      |
| 0      | 0 | 0 | 0                  | X  | X  | X  | X  | X  | X  | X  | 0      |
| 0      | 0 | 0 | 1                  | X  | X  | X  | X  | X  | X  | X  | 1      |
| 0      | 0 | 1 | X                  | 0  | X  | X  | X  | X  | X  | X  | 0      |
| 0      | 0 | 1 | X                  | 1  | X  | X  | X  | X  | X  | X  | 1      |
| 0      | 1 | 0 | X                  | X  | 0  | X  | X  | X  | X  | X  | 0      |
| 0      | 1 | 0 | X                  | X  | 1  | X  | X  | X  | X  | X  | 1      |
| 0      | 1 | 1 | X                  | X  | X  | 0  | X  | X  | X  | X  | 0      |
| 0      | 1 | 1 | X                  | X  | X  | 1  | X  | X  | X  | X  | 1      |
| 1      | 0 | 0 | X                  | X  | X  | X  | 0  | X  | X  | X  | 0      |
| 1      | 0 | 0 | X                  | X  | X  | X  | 1  | X  | X  | X  | 1      |
| 1      | 0 | 1 | X                  | X  | X  | X  | X  | 0  | X  | X  | 0      |
| 1      | 0 | 1 | X                  | X  | X  | X  | X  | 1  | X  | X  | 1      |
| 1      | 1 | 0 | X                  | X  | X  | X  | X  | X  | 0  | X  | 0      |
| 1      | 1 | 0 | X                  | X  | X  | X  | X  | X  | 1  | X  | 1      |
| 1      | 1 | 1 | X                  | X  | X  | X  | X  | X  | X  | 0  | 0      |
| 1      | 1 | 1 | X                  | X  | X  | X  | X  | X  | X  | 1  | 1      |

Figure 4-8. Truth Table for 8:1 Multiplexer

As can be seen from the truth table A, B and C select one of the eight multiplexer inputs to appear on the output, Y. If A, B and C = 011, then Figure 4-9 shows that the D3 AND gate will be enabled while all the other AND gates will be disabled. This allows D3 to be 'ORed' with seven zeros and thus end up on the output Y.

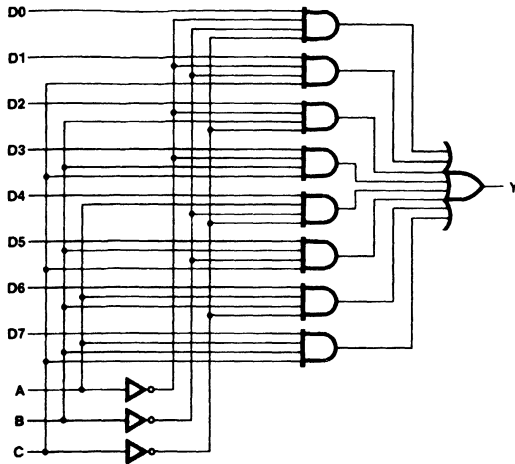


Figure 4-9. 8:1 Multiplexer Circuit

**Example 4.7**

We will design a dual 8:1 mux in a PAL device.

When selecting a PAL device, several things must be considered. Will the design need registers? How many inputs and outputs are there? Are the outputs active high or active low? For a dual 8:1 mux the select lines will be shared, but the eight data inputs to each mux are independent. Thus we need nineteen inputs and two outputs for the design. This narrows our choices down to one PAL device, the PAL20L2. The output of the PAL20L2 is active low but this causes no problems because an active high output will result by simply inverting all the data inputs. The Boolean equations are shown below; the complete logic diagram is on the next page.

Multiplexers have been widely used as logic devices as well as selector circuits. A 4:1 mux can be used to realize any three-variable function. An 8:1 mux can realize any four-variable function.

**Example 4.8**

Solve the K-map in Figure 4-10 and build the circuit with an 8:1 multiplexer.

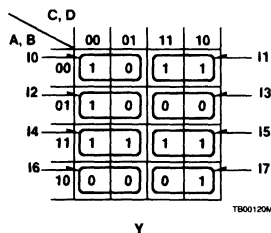


Figure 4-10. Eight One-Variable Karnaugh Maps

A, B and C are used as control inputs to the multiplexer, this leaves D as the only real variable in the problem. The 16-square K-map can thus be broken up into eight one-variable K-maps. Each map is solved for one of the eight data inputs to the 8:1 multiplexer. The solution is shown in Figure 4-11.

| A | B | C |            |
|---|---|---|------------|
| 0 | 0 | 0 | $I_0 = /D$ |
| 0 | 0 | 1 | $I_1 = 1$  |
| 0 | 1 | 0 | $I_2 = /D$ |
| 0 | 1 | 1 | $I_3 = 0$  |
| 1 | 0 | 0 | $I_4 = 1$  |
| 1 | 0 | 1 | $I_5 = 1$  |
| 1 | 1 | 0 | $I_6 = 0$  |
| 1 | 1 | 1 | $I_7 = /D$ |

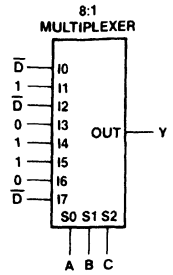


Figure 4-11

**4.5 Decoders**

On a multiplexer with n address lines, one of the 2<sup>n</sup> inputs is selected to be output. On a decoder with n address lines, one of the 2<sup>n</sup> output lines is forced either high or low, depending on the design of the decoder. Figure 4-12 shows a truth table for an active high 3-to-8 decoder.

| SELECT LINES |   |   | OUTPUT LINES |   |   |   |   |   |   |   |
|--------------|---|---|--------------|---|---|---|---|---|---|---|
| A            | B | C | f            | g | h | i | j | k | l | m |
| 0            | 0 | 0 | 1            | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0            | 0 | 1 | 0            | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0            | 1 | 0 | 0            | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0            | 1 | 1 | 0            | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 1            | 0 | 0 | 0            | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 1            | 0 | 1 | 0            | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 1            | 1 | 0 | 0            | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 1            | 1 | 1 | 0            | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

Figure 4-12. Decoder Truth Table

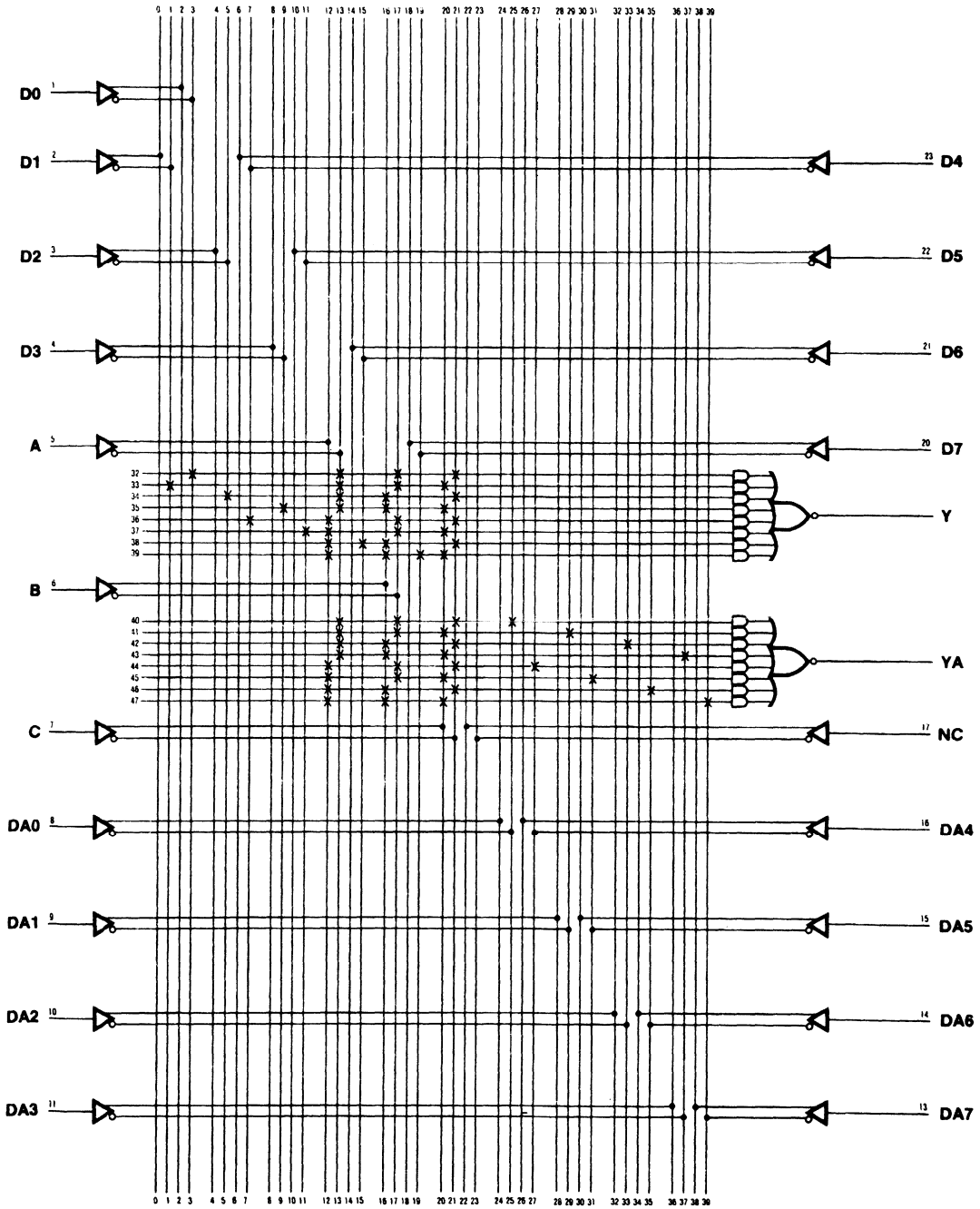
A decoder will have as many outputs as there are possible binary input combinations. It can be seen from Figure 4-12 that only one output can be equal to 1 at any time. The active output represents the minterm combination that was input to the decoder. It can also be noticed from Figure 4-12 that there is not a combination of inputs that will give all 0's on the outputs. Many designs actually need to be able to make all outputs inactive; this can be done simply by putting an enable line in all of the output AND gates. The logic design and block diagram for the 3-bit decoder in Figure 4-12 appears in Figure 4-13.



# Logic Tutorial

## Logic Diagram

PAL20L2



8

LD00090M

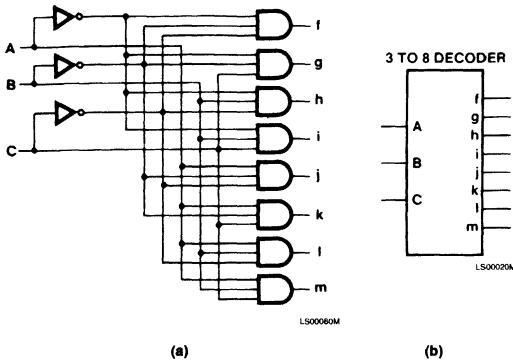


Figure 4-13. (a) Logic Diagram for 3-to-8 Decoder  
(b) Block Diagram for 3-to-8 Decoder

### 4.6 Magnitude Comparator

A magnitude comparator is combinational circuit that compares two numbers, and puts out one of three signals:  $A > B$ ,  $A = B$  or  $A < B$ .

#### Example 4.9

We can design a 3-bit magnitude comparator in a PAL device.

|            |   | B2, B1, B0 |     |     |     |     |     |     |     |
|------------|---|------------|-----|-----|-----|-----|-----|-----|-----|
| A2, A1, A0 |   | 000        | 001 | 011 | 010 | 110 | 111 | 101 | 100 |
| 000        | 0 | 0          | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 001        | 1 | 0          | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 011        | 1 | 1          | 0   | 1   | 0   | 0   | 0   | 0   | 0   |
| 010        | 1 | 1          | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 110        | 1 | 1          | 1   | 1   | 0   | 0   | 1   | 1   | 0   |
| 111        | 1 | 1          | 1   | 1   | 1   | 0   | 1   | 1   | 0   |
| 101        | 1 | 1          | 1   | 1   | 0   | 0   | 0   | 0   | 1   |
| 100        | 1 | 1          | 1   | 1   | 0   | 0   | 0   | 0   | 0   |

$$\begin{aligned}
 A > B &= A2 \cdot B2 \\
 &+ A1 \cdot B2 \cdot B1 \\
 &+ A0 \cdot B2 \cdot B1 \cdot B0 \\
 &+ A1 \cdot A0 \cdot B2 \cdot B0 \\
 &+ A2 \cdot A1 \cdot B1 \\
 &+ A2 \cdot A1 \cdot A0 \cdot B0 \\
 &+ A2 \cdot A0 \cdot B1 \cdot B0
 \end{aligned}$$

Figure 4-14

|            |   | B2, B1, B0 |     |     |     |     |     |     |     |
|------------|---|------------|-----|-----|-----|-----|-----|-----|-----|
| A2, A1, A0 |   | 000        | 001 | 011 | 010 | 110 | 111 | 101 | 100 |
| 000        | 0 | 1          | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 001        | 0 | 0          | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 011        | 0 | 0          | 0   | 0   | 1   | 1   | 1   | 1   | 1   |
| 010        | 0 | 0          | 1   | 0   | 1   | 1   | 1   | 1   | 1   |
| 110        | 0 | 0          | 0   | 0   | 0   | 1   | 0   | 0   | 0   |
| 111        | 0 | 0          | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 101        | 0 | 0          | 0   | 0   | 1   | 1   | 0   | 0   | 0   |
| 100        | 0 | 0          | 0   | 0   | 1   | 1   | 1   | 0   | 0   |

$$\begin{aligned}
 B > A &= A2 \cdot B2 \\
 &+ A2 \cdot A1 \cdot B1 \\
 &+ A2 \cdot A1 \cdot A0 \cdot B0 \\
 &+ A2 \cdot A0 \cdot B1 \cdot B0 \\
 &+ A1 \cdot B2 \cdot B1 \\
 &+ A0 \cdot B2 \cdot B1 \cdot B0 \\
 &+ A1 \cdot A0 \cdot B2 \cdot B0
 \end{aligned}$$

Of course,  $A = B$  only if not  $A < B$  and not  $A > B$   
 $(A = B) = \neg(B < A) \cdot \neg(B > A)$

Figure 4-14 (Continued)

The six-variable K-maps are used to produce Sum of Product equations for  $A > B$  and  $B < A$ . These equations are then used to form the two-level logic diagram of the 3-bit magnitude comparator and the equation for  $A = B$ , as shown in Figure 4-15.

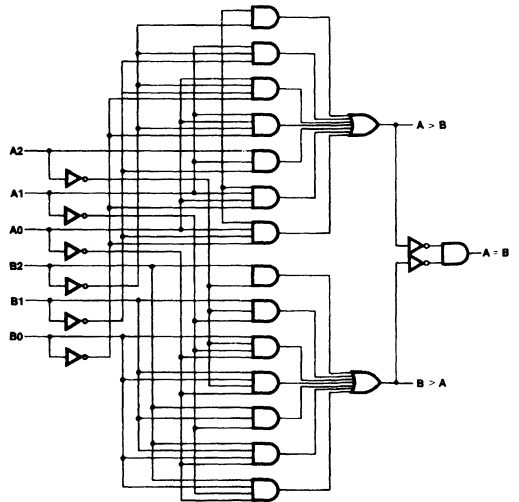


Figure 4-15

## Logic Tutorial

The logic diagram of the 3-bit comparator shows that there are six inputs and three outputs in the circuit. Each output is derived from at most seven product terms. This design can fit into a portion of a PAL16P8, as shown on page 8-18. Note that 5 outputs remain, which can be used for some other functions if needed.

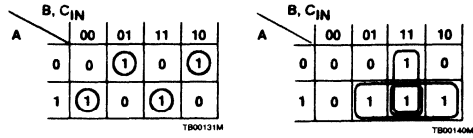
### 4.7 Adder

A binary adder takes two binary inputs, adds them, and generates the binary sum. A full adder is the basic building block of any adding network. A full adder is a 1-bit adder with a carry-in and a carry-out. The truth table is shown in Figure 4-16. The logic design and block diagram appear in Figure 4-17.

| A | B | C <sub>IN</sub> | Y | C <sub>OUT</sub> |
|---|---|-----------------|---|------------------|
| 0 | 0 | 0               | 0 | 0                |
| 0 | 0 | 1               | 1 | 0                |
| 0 | 1 | 0               | 1 | 0                |
| 0 | 1 | 1               | 0 | 1                |
| 1 | 0 | 0               | 1 | 0                |
| 1 | 0 | 1               | 0 | 1                |
| 1 | 1 | 0               | 0 | 1                |
| 1 | 1 | 1               | 1 | 1                |

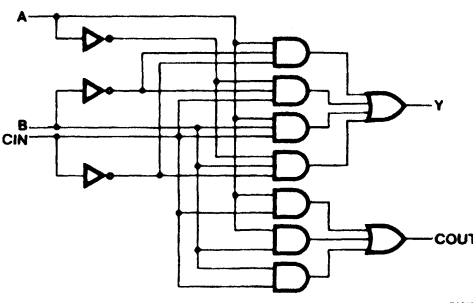
Figure 4-16. Truth Table for Full Adder

The truth table is used to form K-maps for the outputs Y and C<sub>in</sub>. These simple K-maps are solved to obtain equations for Y and C<sub>in</sub>.

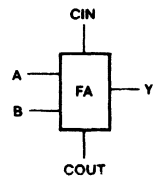


$$Y = A \cdot B \cdot C_{IN} + A \cdot B \cdot \bar{C}_{IN} + A \cdot \bar{B} \cdot C_{IN} + \bar{A} \cdot B \cdot C_{IN}$$

$$C_{OUT} = A \cdot C_{IN} + A \cdot B + B \cdot C_{IN}$$



(b)



(c)

Figure 4-17. (a) Karnaugh Maps for the Full Adder, (b) Logic Diagram, (c) Block Diagram

A parallel 4-bit adder can be designed using four full adders.

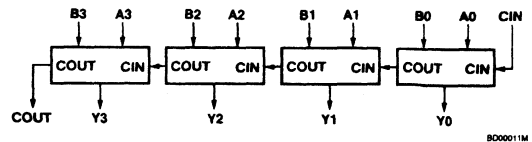
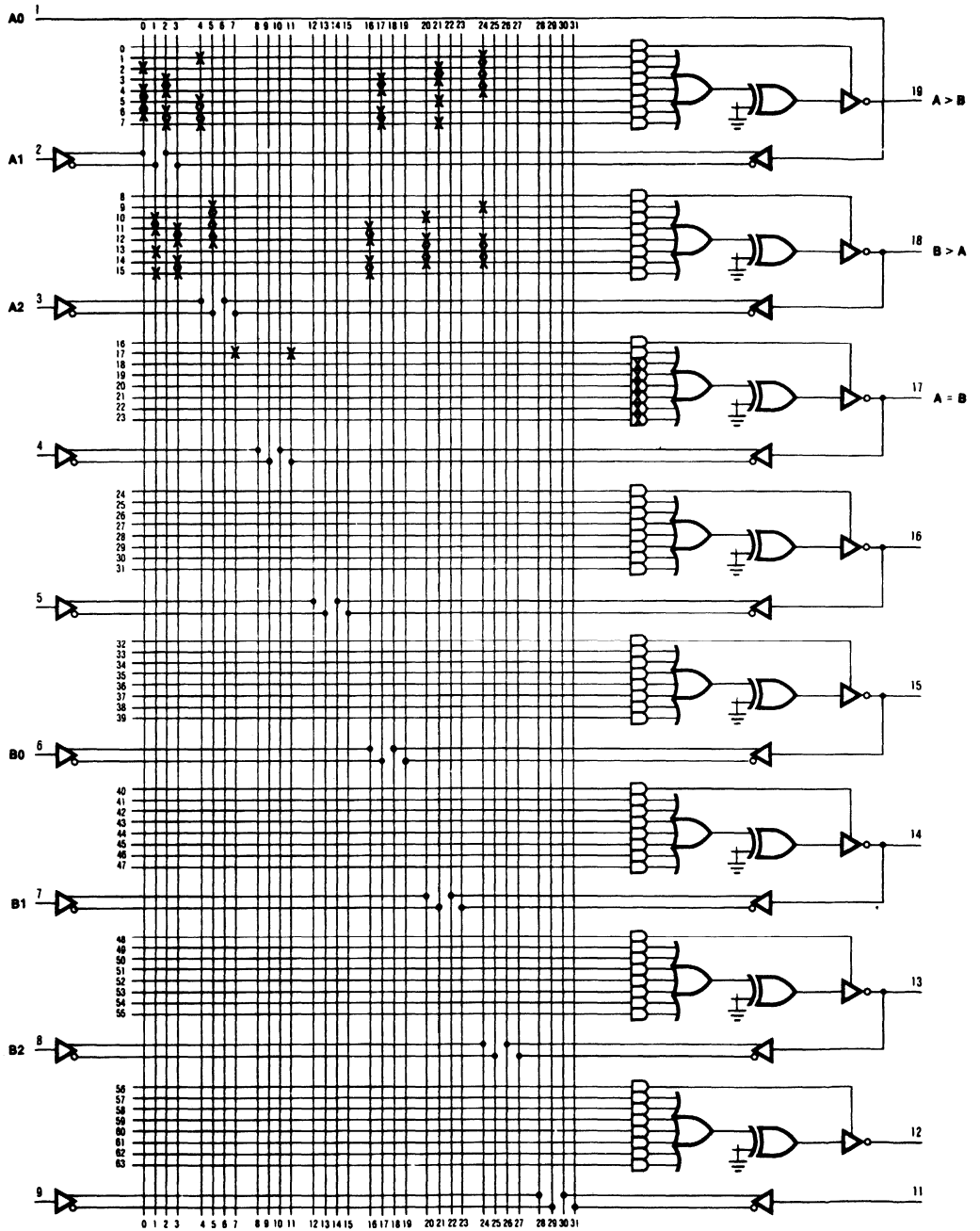


Figure 4-18. Parallel 4-Bit Adder

To implement this circuit in a PAL device, each carry-out is directly input to the next digit's carry-in. Nine inputs and eight outputs are needed. Three of the outputs (the first three carry-outs) are only needed so they can be fed back into the circuit as inputs. A PAL16L8 is the perfect PAL device for this design. The logic diagram is shown on page 8-19.

Logic Diagram

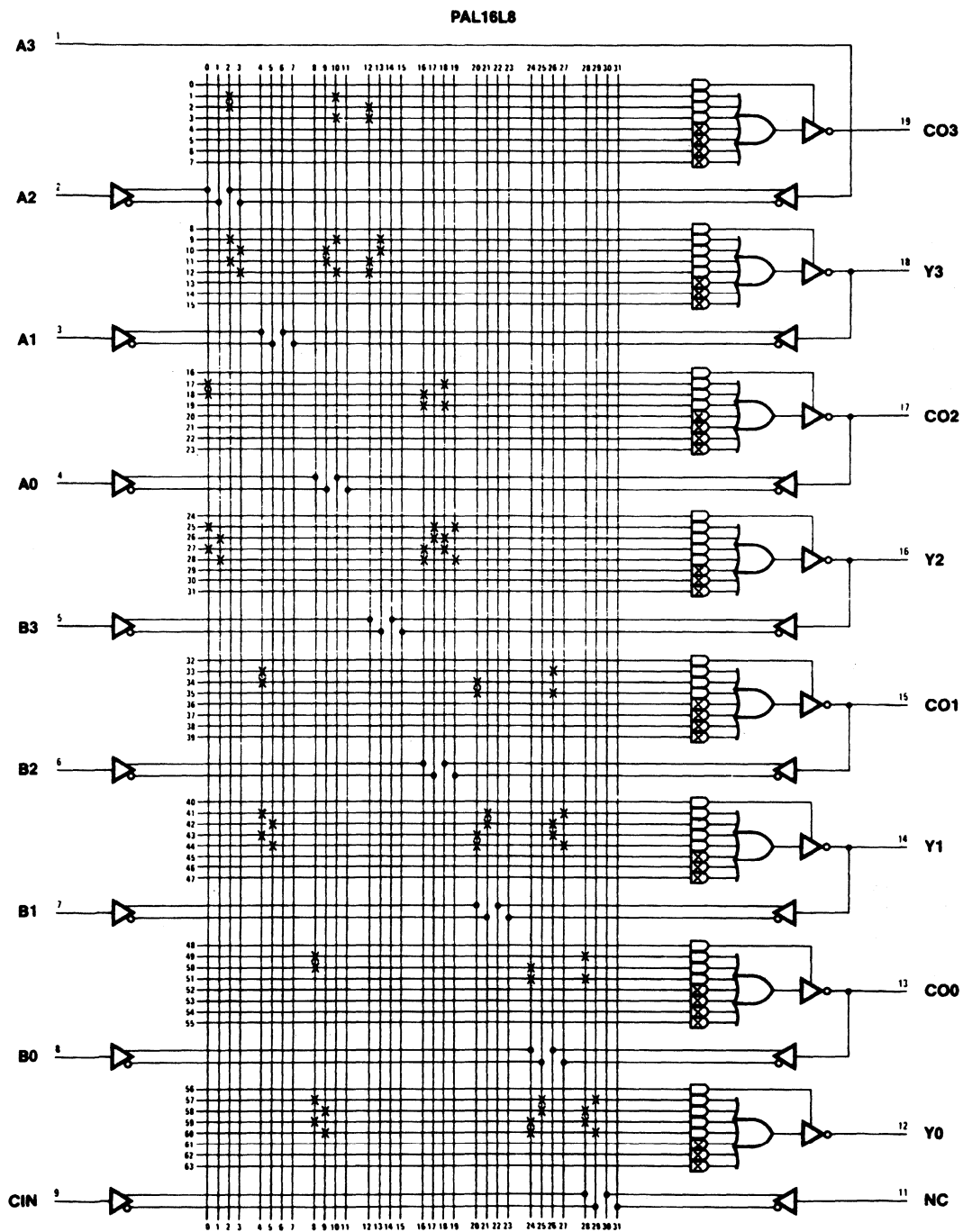
PAL16P8



LD0090M

# Logic Tutorial

## Logic Diagram



8

LD001014

### 4.8 Hazards

Even though a digital network is designed correctly, it still may have erroneous outputs at times due to *hazards*. Hazards exist because physical circuits do not behave ideally. For example, a D-type flip-flop has two outputs; Q and /Q, which should always be complements of each other. In the real world Q may be switching from 1 to 0 and /Q from 0 to 1. Unless both Q and /Q switch at exactly the same time, Q will equal /Q for some finite amount of time. In some cases this could cause the network to malfunction. The change in the flip-flop output may not cause the steady-state output of the network to change, but the transient output may have had a spurious change due to the non-ideal flip-flop. If, for instance, the network's output was the set line of a latch, the latch would set due to the hazard.

There are two types of hazards, *static* and *dynamic*. Static hazards occur when the steady-state output of a network is not supposed to change due to an input change, but a momentary change does occur as the inputs change. This is often referred to as a "glitch." Static hazards are qualified further as either static 1 hazards or static 0 hazards. Static 1 hazards exist when the steady-state output is 1, static 0 hazards exist when the steady-state output is 0.

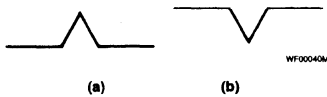


Figure 4-19. (a) Static 0 Hazard, (b) Static 1 Hazard

Dynamic hazards occur when the steady-state output is supposed to change due to an input change. The hazard occurs when the transient output changes several times before settling down.



Figure 4-20. Dynamic Hazard

There are two classifications of hazards: function hazards and logic hazards.

Function hazards can be present when more than one input variable changes. It is easy to see from the K-map in Figure 4-21 why function hazards exist.

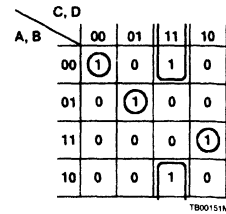


Figure 4-21. Karnaugh Map with Function Hazards

A function static 1 hazard is present when the input variables A, B, C and D go from <0000> to <0101>. If both B and D changed simultaneously no temporary erroneous pulse would appear on the output; however in the real world either B or D would change first. The transient output would have gone to 0 as a result of being momentarily in state <0100> or <0001>. Looking at the K-map, it is easy to see function static hazards and function dynamic hazards.

The easiest way to avoid function hazards is by restricting input changes to one variable at a time. This method is not always possible though, since the inputs may not be predictable.

Logic hazards exist because of the way a function is realized. Logic hazards can exist even if input changes are restricted to one variable at a time.

A K-map is a very good way of locating logic hazards. When trying to locate the static 0 and static 1 logic hazards on a K-map it is only necessary to map the 1-sets or the 0-sets.

A 1-set is a product expression derived from a grouping of 1's on the K-map. If there are two adjacent input states that produce a 1 on the output, but are not covered by the same 1-term, a static logic hazard exists. Logic hazards may be eliminated by redesigning the circuit so adjacent input states that produce ones are covered by the same 1-term.

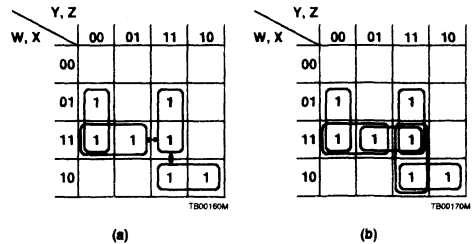


Figure 4-22. (a) Karnaugh Map with Two Logic Hazards (b) Karnaugh Map with No Logic Hazards

## 5. Sequential Logic

### 5.1 Introduction

In the previous section, combinatorial circuits were discussed — circuits whose outputs are determined completely by their present inputs. Outputs of some networks depend not only on their present inputs but also on the sequence of their past inputs. These circuits are called *sequential* switching networks. Sequential networks must be able to remember the past sequence of their inputs in order to be able to produce new outputs.

In order for a sequential circuit to remember the previous inputs, it must retain those values in some memory elements. The most basic memory element is called a *flip-flop*. Flip-flops are bistable devices with one or more inputs that affect their outputs. The term *bistable* means that the outputs are stable in either of two states.

There are two types of flip-flops: *unclocked* and *clocked*. Unclocked flip-flops are often referred to as *latches*. Clocked flip-flops are often grouped into *registers*.

### 5.2 Unclocked Flip-Flops – Latches

#### 5.2.1 S-R Latch

The circuit in Figure 5-1a is called a *SET-RESET* or an S-R latch. An S-R latch has two inputs which are used to control the state of the latch. The rules for this type of latch are:

1. If SET = RESET = 0, then the latch remains in the same state, and the output does not change.
2. A '1' on the SET input and a '0' on the RESET input will make the latch SET to '1'.
3. A '0' on the SET input and a '1' on the RESET input causes the latch to RESET to '0' state.
4. If SET = RESET = 1, then Q and /Q will be '0' at the same time, which is meaningless. When designing with an S-R latch, we should remember that SET = RESET = 1 is forbidden.

The S-R latch circuit, *state table*, *characteristic equation* and *waveforms* are shown in figure 5-1.

Latches can have more than two inputs. In Figure 5-2, we examine a latch circuit that has two SET terms instead of one. The logic diagram and the transition table are shown.

In some applications using latches, it is desirable for the input data to be effective only when another signal — usually referred to as a control signal — is active. For these applications, the S-R latch could be modified as shown in Figure 5-3.

It is apparent from Figure 5-3 that the values of SET and RESET are effective only when the control signal (C) is active. When C = 0, changes in the SET and RESET inputs do not have any effect on the output.

Of course in the input of the latch does not affect the output immediately; there is a short delay for this change to appear at the output. This delay, shown in figure 5-3(b), is caused because of the propagation delays of the gates between inputs and outputs.

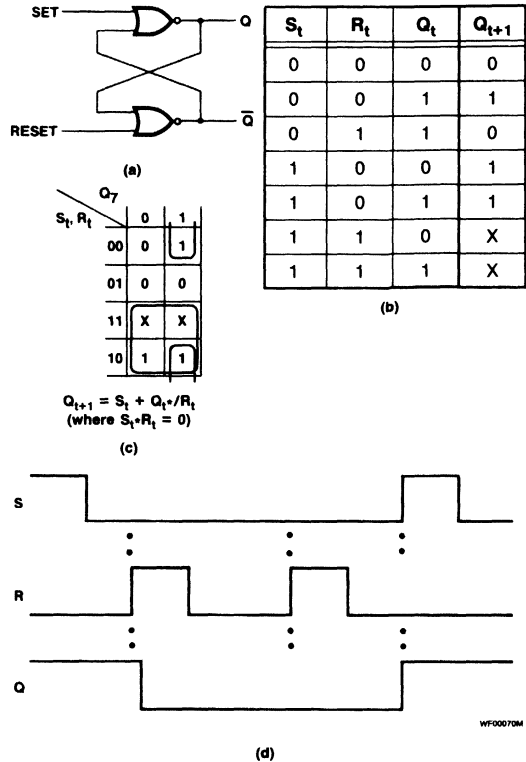


Figure 5-1. S-R Latch (a) Logic Circuit (b) State Table (c) Characteristic Equation (d) Waveforms

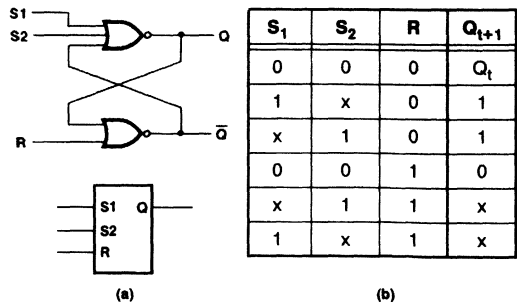


Figure 5-2. S-R Latch with two SET inputs (a) Logic diagram (b) State Table

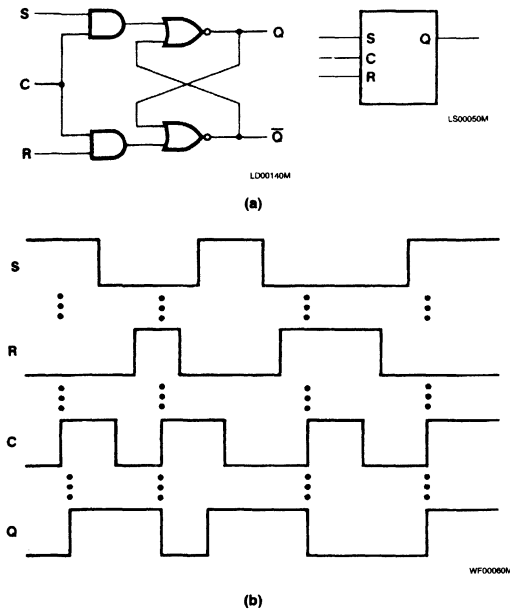


Figure 5-3. S-R Latch with Control (a) Logic Diagram (b) Waveforms

5.2.2 D-type Latch

Other kinds of latches are used in sequential circuits. One of the most popular latches is called a *delay latch*, or D-type latch. An S-R latch is modified to a D-type latch by inserting an inverter between S and R, and calling the input "D" instead of "S". The D-type latch will take the value of its input and transfer it to the output. The advantage of the D-type latch over the S-R latch is that in the former only one input is needed and there is no forbidden state. The only disadvantage of the D-type latch is that it does not have a "no change" condition. This condition can be provided by inserting a control signal, C, as an input to the latch (Figure 5-4).

This configuration is probably the most widely used one, with the control input commonly called the "Gate". Devices with active high gates and with active low gates are both commercially available.

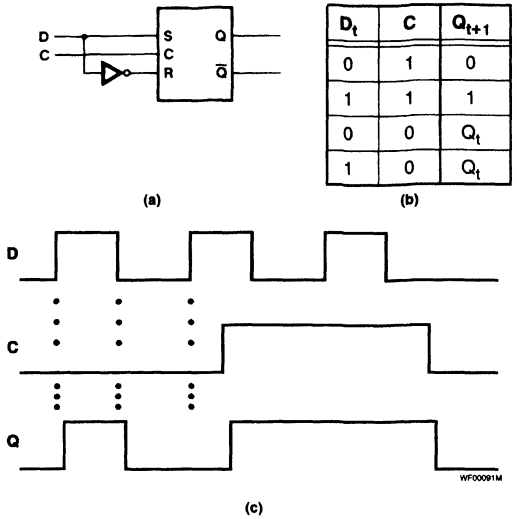


Figure 5-4. D-type Latch with Gate (a) Logic Circuit (b) State Table (c) Waveforms

5.2.3 J-K Latch

Another useful latch is the J-K latch which is shown in Figure 5-5. This latch consists of an S-R latch with two AND gates in front of the inputs. This is most useful because J-K latches act like S-R latches, and it is permissible to apply '1' to both inputs simultaneously. The state table and characteristic equation for a J-K latch are also shown in Figure 5-5.

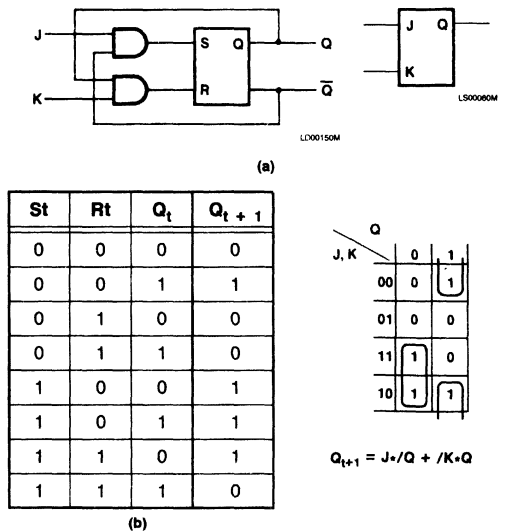
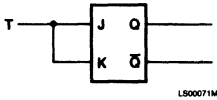


Figure 5-5. J-K Latch (a) Logic Diagram (b) State Table and Characteristic Equation



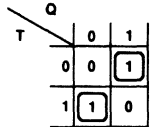
5.2.4 T-type Latch

Another type of latch is a *triggered latch*, or T-type latch, which has only one input called T. Whenever T is high, the latch changes state. A T-type latch is realized by connecting both J and K to one input, T.



(a)

| T | Q | Q <sub>t+1</sub> |
|---|---|------------------|
| 0 | 0 | 0                |
| 0 | 1 | 1                |
| 1 | 0 | 1                |
| 1 | 1 | 0                |



$$Q_{t+1} = \bar{T} \cdot Q + T \cdot \bar{Q}$$

$$= T \oplus Q$$

(b)

Figure 5-6. T-type Latch (a) Logic Diagram (b) State Table and Characteristic Equation

5.3 Clocked Flip-Flops - Registers

In the previous section, different types of latches were discussed. Clocked flip-flops of the same types are available (S-R, J-K, D and T), and the state equations are the same, except that the output change in clocked flip-flops occurs on the clock edge.

In general, clocked flip-flops are more common than unclocked flip-flops, so the word "clocked" is often left out. Thus a D-type flip-flop is a clocked element, whereas a D-type latch is unclocked. Note, however, that this is common usage, not a definition.

Figure 5-7 illustrates the difference between a D-type latch and a D-type flip-flop.

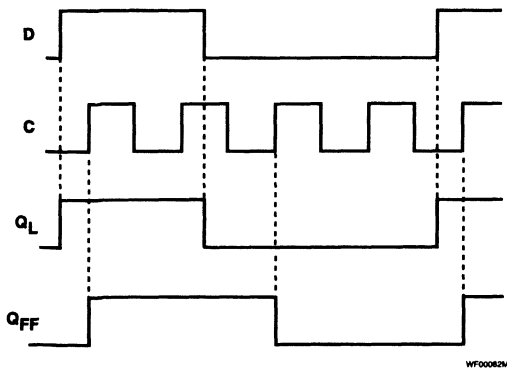


Figure 5-7. Comparison of a D-type latch and a positive edge-triggered D-type flip-flop

5.3.1 Characteristic Equations

The characteristic equations for various flip-flops are summarized as follows:

|   |                  |
|---|------------------|
| $Q_{t+1} = S + \bar{R} \cdot Q_t$                 | S-R flip-flop    |
| $Q_{t+1} = J \cdot \bar{Q}_t + \bar{K} \cdot Q_t$ | J-K flip-flop    |
| $Q_{t+1} = T + Q_t$                               | T-type flip-flop |
| $Q_{t+1} = D$                                     | D-type flip-flop |

In the above equations  $Q_{t+1}$  is the next state and  $Q_t$  is the present state. We can convert one flip-flop to another by inserting gates between the inputs and the actual flip-flop.

A group of clocked flip-flops forms a register. A register is a digital device that is used to hold several bits of information. A register may be a combination of flip-flops and gates. The gates control how and when the data from the flip-flops is transferred.

5.4 Designing Synchronous Sequential Circuits

In this section, we will familiarize ourselves with the analysis and synthesis of synchronous sequential circuits. Analysis will be covered first, since it will make the understanding of synthesis easier.

The present states of a sequential circuit depend not only on the present inputs, but also on the past states. A sequential circuit is constructed of flip-flops and gates. The gates form the combinatorial part of a sequential circuit; the flip-flops provide the memory of past states. A general block diagram of a sequential circuit is shown in Figure 5-8.

There are two basic types of sequential circuit: synchronous and asynchronous. Synchronous circuits are controlled by a common clock; these types of circuits are the easiest to design. Asynchronous circuits have independently clocked flip-flops whose clock rates may not have any relationships to each other. Such circuits may be faster than synchronous circuits, but are much harder to design.

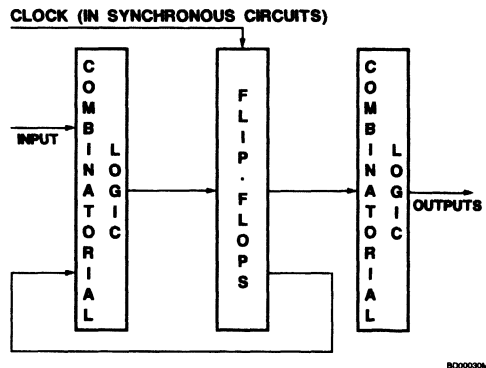


Figure 5-8. Sequential Circuit Block Diagram

The input combinatorial logic section receives external inputs and feeds information to the flip-flops. The flip-flops have a feedback path back to the input combinatorial circuit. At the rising edge of each clock pulse the information from the input combinatorial circuit is read into the flip-flops and the new

outputs are generated through the output combinatorial circuit. The outputs do not change until the next clock edge. Figure 5-9, shows an example of a sequential circuit.

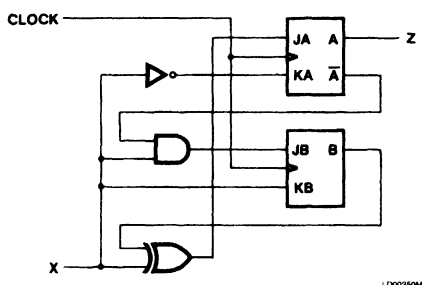


Figure 5-9. Example of a Sequential Circuit

This circuit consists of two J-K flip-flops, an inverter, an AND gate and an XOR gate. It has an external input, X, and an external output, Z.

5.4.1 State Transition Tables

The states of a sequential circuit are determined by its inputs, the outputs and states of the flip-flops. In order to examine these states, we should determine the input equations to the flip-flops. From Figure 5-9 we have:

$$J_A = X \text{ :+ : } B \quad J_B = X \text{ */ } A \quad Z = A$$

$$K_A = \text{/ } X \quad K_B = X$$

The characteristic equation for a J-K flip-flop gives:

$$A_{t+1} = J_A \text{ */ } Q + \text{/ } K_A \text{ */ } Q$$

$$= (X \text{ :+ : } B) \text{ */ } A + X \text{ */ } A$$

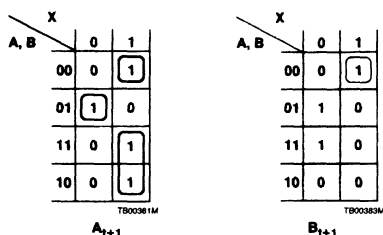
$$= (X \text{ */ } B + \text{/ } X \text{ */ } B) \text{ */ } A + X \text{ */ } A$$

$$= \text{/ } A \text{ */ } B \text{ */ } X + \text{/ } A \text{ */ } B \text{ */ } \text{/ } X + A \text{ */ } X$$

$$B_{t+1} = J_B \text{ */ } Q + \text{/ } K_B \text{ */ } Q$$

$$= \text{/ } A \text{ */ } B \text{ */ } X + B \text{ */ } \text{/ } X$$

These are called the *state equations*. The corresponding K-maps are:



Using these maps, the *state transition tables* for Figure 5-9 can be derived. There are only four different combinations that A and B can have. The next state values are derived using these four possible combinations.

The present state is the state of the flip-flop before the clock pulse; the next state is the state of flip-flop after the clock pulse has been applied. The present output, Z, is the output of the sequential circuit after the clock pulse. As mentioned

before, the circuit can have four states: AB = 00, 01, 11 and 10. At this point, we try to cover transitions for one input state. Suppose the circuit is in the 00 state. If an X = 0 input is applied, the next state will be 00. If an X = 1 is applied, the next state will be 11. The output for both cases is Z = 0.

| PRESENT STATE<br>AB | NEXT STATE<br>A <sub>t+1</sub> B <sub>t+1</sub> |       | PRESENT OUTPUT<br>Z |
|---------------------|---|-------|---------------------|
|                     | X = 0   | X = 1 |                     |
| 00                  | 00  | 11    | 0                   |
| 01                  | 11  | 00    | 0                   |
| 11                  | 01  | 10    | 1                   |
| 10                  | 00  | 10    | 1                   |

Figure 5-10. State Transition Table for Figure 5-9.

5.4.2 State Tables and State Diagrams

We can assign names to the four possible states: S<sub>0</sub> = 00, S<sub>1</sub> = 01, S<sub>2</sub> = 11 and S<sub>3</sub> = 10. Using these assignments the state transition table can be modified to the *state table* shown in Figure 5-11.

| PRESENT STATE  | NEXT STATE     |                | PRESENT OUTPUT Z |
|----------------|----------------|----------------|------------------|
|                | X = 0          | X = 1          |                  |
| S <sub>0</sub> | S <sub>0</sub> | S <sub>2</sub> | 0                |
| S <sub>1</sub> | S <sub>2</sub> | S <sub>0</sub> | 0                |
| S <sub>2</sub> | S <sub>1</sub> | S <sub>3</sub> | 1                |
| S <sub>3</sub> | S <sub>0</sub> | S <sub>3</sub> | 1                |

Figure 5-11. State Table for Figure 5-9

A state diagram can be derived using the state table. A state diagram shows transitions between states. Each state is represented by a circle, and the transitions between states are shown by arrows.

The condition under which a transition occurs is represented by X/Z. Applying an input, X, a transition from one state to the other takes place, and an output Z will be produced. The state diagram for the state table in Figure 5-11 is shown in Figure 5-12.

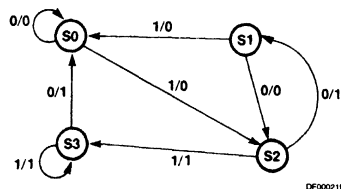


Figure 5-12. State Diagram for Figure 5-9

## Logic Tutorial

We have gone through a complete analysis procedure for the previous example. This process can be summarized as follows:

1. Using a given network, determine the input equations.
2. Derive the next state equations, using the flip-flop characteristic equations:

|   |                  |
|---|------------------|
| $Q_{t+1} = D$                                 | D-type flip-flop |
| $Q_{t+1} = T \oplus Q$                        | T-type flip-flop |
| $Q_{t+1} = J \cdot Q + \bar{K} \cdot \bar{Q}$ | J-K flip-flop    |
| $Q_{t+1} = S + \bar{R} \cdot Q$               | S-R flip-flop    |

3. Derive the corresponding K-maps and transition tables.
4. Assign state names and make the state table.
5. From the state table, draw the state diagram.

The synthesis of a sequential circuit uses the same steps, but in reverse order. A flow chart of the procedure is shown in Figure 5-13.

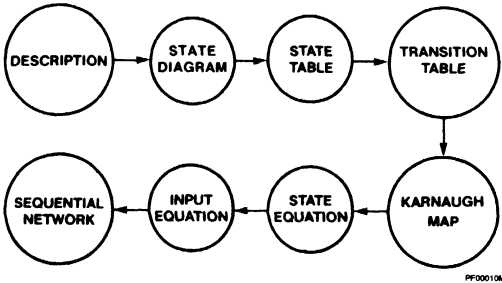


Figure 5-13. Flow Chart of Sequential Circuit Synthesis

### 5.4.3 Design Examples

Let's look at the procedure for designing sequential circuits in more detail by analyzing some design problems. The design steps will follow the flow diagram in Figure 5-13.

#### Example 5.1

We will design a clocked sequential circuit which receives an input, X, and will produce an output Z = 1 after it has received an input sequence of 0010 or 100.

#### Solution:

The first step is to make a state diagram. The state diagram will start in a state designated by S0. If X = 0 is input while in state S0, it could be the start for the 0010 sequence, so we move to state S1. If a 1 is received, the circuit will go to state S4, which could be the start for the 100 sequence.

When in the S1 state, one of two inputs could be received: X = 0 or X = 1. If X = 0, then the circuit could still follow the 0010 sequence, because so far it has received the 00 sequence; this takes us to state S2. If X = 1, then the input sequence would be 01 so far, which cannot follow the 0010 any more, but could be a start for the 100 sequence. Therefore under this condition the circuit would have a transition from state S1 to S4.

While in the S4 state, if an X = 1 is received, it would stay in the same state, because this of 11 could start a new 100 pattern. If X = 0 is received, the 100 pattern could continue, because 10 follows the 100 pattern.

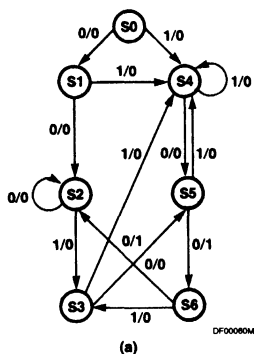
When in the S2 state, if an X = 0 is received, it will stay in the S2 state; if X = 1, then it will have a transition from the S2 to the S3 state. While in the S3 state, we will have a transition to state S4 if X = 1, because the input sequence would be 0011, which cannot follow the 0010 sequence any more, but the 1 at the end could be a beginning for the 100 sequence. If X = 0 is received then the 0010 sequence is complete and an output Z = 1 is generated. At the same time in the 0010 sequence, the 10 at the end could be the start of the 100 sequence. Therefore we move from the S3 to the S5 state.

While in the S5 state an X = 1 will transfer the circuit from S5 to S4, and an X = 0 will cause a transition from S5 to S6. Under this condition a Z = 1 is generated for the output, because the 100 sequence for the inputs has occurred.

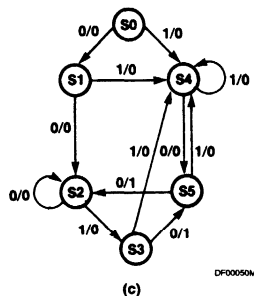
From the S6 state we will have a transition from S6 to S2 if X = 0, and a transition to S3 if X = 1. A state diagram of this design is shown in Figure 5-14a.

By analyzing the state diagram, a state table is generated (Figure 5-14b). A careful look at the state table will show that the S2 and the S6 states are equivalent, because under X = 0 they both have a transition to state S2 with Z = 0, and under X = 1 they would transfer to S3 with Z = 0. So the state table can be reduced to Figure 5-14c. After summarizing the state table, there will be a total of six states left, so at least three variables will be needed for the state assignments ( $2^3 = 8$ ). In this case only six assignments will be used. The state variables are designated by A, B and C. The state assignments are illustrated in Figure 5-14d.

# Logic Tutorial



| PRESENT STATE | NEXT STATE |       | PRESENT OUTPUT |       |
|---------------|------------|-------|----------------|-------|
|               | X = 0      | X = 1 | X = 0          | X = 1 |
| S0            | S1         | S4    | 0              | 0     |
| S1            | S2         | S4    | 0              | 0     |
| S2            | S2         | S3    | 0              | 0     |
| S3            | S5         | S4    | 1              | 0     |
| S4            | S5         | S4    | 0              | 0     |
| S5            | S6         | S4    | 1              | 0     |
| S6            | S2         | S3    | 0              | 0     |



| PRESENT STATE | NEXT STATE |       | PRESENT OUTPUT |       |
|---------------|------------|-------|----------------|-------|
|               | X = 0      | X = 1 | X = 0          | X = 1 |
| S0            | S1         | S4    | 0              | 0     |
| S1            | S2         | S4    | 0              | 0     |
| S2            | S2         | S3    | 0              | 0     |
| S3            | S5         | S4    | 1              | 0     |
| S4            | S5         | S4    | 0              | 0     |
| S5            | S2         | S4    | 1              | 0     |

Figure 5-14. Example 5.1  
 (a) State Diagram (b) State Transition Table (c) Reduced State Diagram (d) Reduced State Transition Table

From the assignment table, we derive the K-maps for each state. In this design the circuit is realized by J-K flip-flops, therefore two K-maps are needed for each state variable (shown in Figure 5-15). These can be derived from a K-map of the transition, and the J and K characteristics in figure 5-15(a).

| $Q_t \rightarrow Q_{t+1}$ | J | K |
|---------------------------|---|---|
| 0 $\rightarrow$ 0         | 0 | X |
| 0 $\rightarrow$ 1         | 1 | X |
| 1 $\rightarrow$ 0         | 0 | X |
| 1 $\rightarrow$ 1         | X | 0 |

(a)

| A, B |    | C, X |    |    |    |
|------|----|------|----|----|----|
|      |    | 00   | 01 | 11 | 10 |
| 00   | 01 | 0    | 1  | 1  | 0  |
| 01   | 11 | 0    | 0  | 1  | 1  |
| 11   | 10 | X    | X  | X  | X  |
| 10   | 00 | 1    | 1  | 1  | 0  |

TB00410M

| A, B |    | $A_{t+1}$ |    |    |    |
|------|----|-----------|----|----|----|
|      |    | 00        | 01 | 11 | 10 |
| 00   | 01 | 0         | 1  | 1  | 0  |
| 01   | 11 | 0         | 0  | 1  | 1  |
| 11   | 10 | X         | X  | X  | X  |
| 10   | 00 | X         | X  | X  | X  |

TB00440M

| A, B |    | C, X |    |    |    |
|------|----|------|----|----|----|
|      |    | 00   | 01 | 11 | 10 |
| 00   | 01 | X    | X  | X  | X  |
| 01   | 11 | X    | X  | X  | X  |
| 11   | 10 | X    | X  | X  | X  |
| 10   | 00 | 0    | 0  | 0  | 1  |

TB00450M

$$J_A = /B \cdot X + B \cdot C$$

$$K_A = C \cdot /X$$

(b)

| A, B |    | C, X |    |    |    |
|------|----|------|----|----|----|
|      |    | 00   | 01 | 11 | 10 |
| 00   | 01 | 0    | 0  | 0  | 1  |
| 01   | 11 | 1    | 1  | 0  | 0  |
| 11   | 10 | X    | X  | X  | X  |
| 10   | 00 | 0    | 0  | 0  | 1  |

TB00420M

| A, B |    | $B_{t+1}$ |    |    |    |
|------|----|-----------|----|----|----|
|      |    | 00        | 01 | 11 | 10 |
| 00   | 01 | 0         | 0  | 0  | 1  |
| 01   | 11 | X         | X  | X  | X  |
| 11   | 10 | X         | X  | X  | X  |
| 10   | 00 | 0         | 0  | 0  | 1  |

TB00320M

| A, B |    | C, X |    |    |    |
|------|----|------|----|----|----|
|      |    | 00   | 01 | 11 | 10 |
| 00   | 01 | X    | X  | X  | X  |
| 01   | 11 | 0    | 0  | 1  | 1  |
| 11   | 10 | X    | X  | X  | X  |
| 10   | 00 | X    | X  | X  | X  |

TB00350M

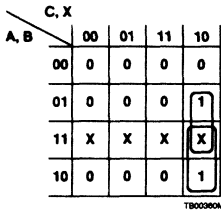
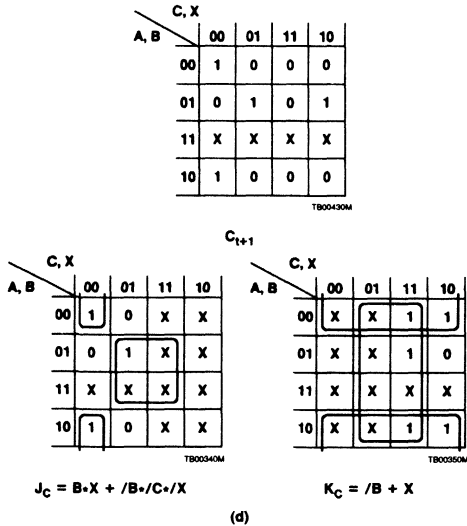
$$J_B = C \cdot /X$$

$$K_B = C$$

(c)

Figure 5-15. Karnaugh Maps for Example 5.1

## Logic Tutorial



$$Z = A \cdot C \cdot /X + B \cdot C \cdot /X$$

(e)

Figure 5-15 (Continued)

The state equations are derived from the K-maps. Using the state equations, the logic diagram in Figure 5-16 is obtained. The state equations are summarized as follows.

$$J_A = /B \cdot X + B \cdot C \quad J_B = C \cdot /X \quad J_C = B \cdot X + /B \cdot /C \cdot /X$$

$$K_A = /C \cdot /X \quad K_B = C \quad K_C = /B + X$$

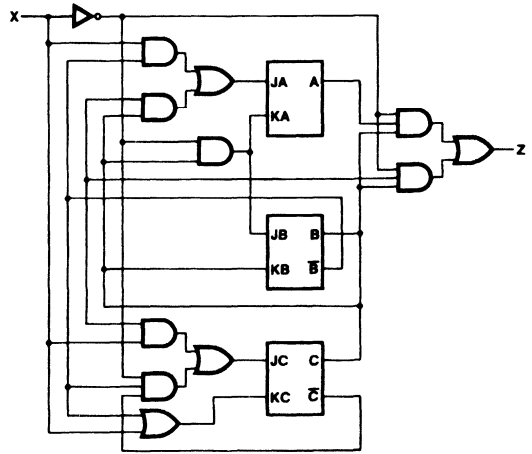


Figure 5-16. Circuit Diagram for Example 5.1

### Example 5.2

We will derive the state diagram, state transition table, and state equations of a sequential circuit which adds five to a binary number in the range of 0000 to 1010 (decimal 0 to 10). The inputs and outputs will be serial with the least significant bit arriving first. This design will be realized with J-K flip-flops.

#### Solution:

In Figure 5-17a, all the possible combinations for the input and the output are shown. The sequence will start from state A. At time  $t_0$  (when the first input is received), if  $X = 0$ , then we look at the map for all possible combinations and notice that at  $t_0$  whenever  $X = 0$ , the output is a 1. Thus, if the present state is A, under  $X = 0$  the output is  $Z = 1$ . On the other hand, if  $X = 1$  the map shows that  $Z$  will be a 0. At time  $t_1$ , if  $X = 0$  and the sequence of the inputs has been 00 then the output would be a 01. So in this transition  $Z = 0$ . Likewise, the remaining states of the state diagram can be derived by inspection of the table in Figure 5-17a. The state diagram is then completed as in Figure 5-17b. Note that the states have been labeled arbitrarily and that we have not yet determined how the states will be implemented.

The state table is determined from the state diagram. Inspecting the state table shows that some of the states are equivalent. States K, J, I, and H have the same next state under  $X = 0$  and  $X = 1$ , and produce the same outputs; therefore  $K = J = I = H$ , and they can be replaced by the H state. This allows us to reduce the state table to the table shown in Figure 5-18b. There are now a total of nine states used, so four state variables will be needed. The state variables are called A, B, C and D. A complete state transition table is shown in Figure 5-18c.

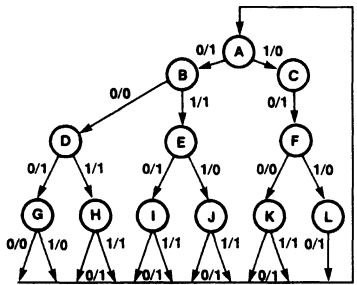
The K-maps are drawn from the state table. The state equations are derived using the K-maps.

## Logic Tutorial

$$\begin{aligned}
 J_A &= B \cdot C \cdot D \cdot X & K_A &= 1 \\
 J_B &= C + D \cdot X & K_B &= C + D \cdot X \\
 J_C &= B \cdot X + D \cdot X + /D \cdot X & K_C &= B + /D \\
 J_D &= /A \cdot B \cdot X + B \cdot /C & K_D &= B \cdot X + C \cdot X + /C \cdot X \\
 Z &= /A \cdot B \cdot C + /B \cdot D \cdot /X + /C \cdot D \cdot X + C \cdot D
 \end{aligned}$$

| INPUT X        |                |                |                | OUTPUT Z       |                |                |                |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| t <sub>3</sub> | t <sub>2</sub> | t <sub>1</sub> | t <sub>0</sub> | t <sub>3</sub> | t <sub>2</sub> | t <sub>1</sub> | t <sub>0</sub> |
| 0              | 0              | 0              | 0              | 0              | 1              | 0              | 1              |
| 0              | 0              | 0              | 1              | 0              | 1              | 1              | 0              |
| 0              | 0              | 1              | 0              | 0              | 1              | 1              | 1              |
| 0              | 0              | 1              | 1              | 1              | 0              | 0              | 0              |
| 0              | 1              | 0              | 0              | 1              | 0              | 0              | 1              |
| 0              | 1              | 0              | 1              | 1              | 0              | 1              | 0              |
| 0              | 1              | 1              | 0              | 1              | 0              | 1              | 1              |
| 0              | 1              | 1              | 1              | 1              | 1              | 0              | 0              |
| 1              | 0              | 0              | 0              | 1              | 1              | 0              | 1              |
| 1              | 0              | 0              | 1              | 1              | 1              | 1              | 0              |
| 1              | 0              | 1              | 0              | 1              | 1              | 1              | 1              |

(a)



(b)

Figure 5-17. Example 5.2 (a) Truth Table (b) State Diagram

| PRESENT STATE | NEXT STATE |       | Z     |       |
|---------------|------------|-------|-------|-------|
|               | X = 0      | X = 1 | X = 0 | X = 1 |
| A             | B          | C     | 1     | 0     |
| B             | D          | E     | 0     | 1     |
| C             | F          | —     | 1     | —     |
| D             | G          | H     | 1     | 1     |
| E             | I          | J     | 1     | 0     |
| F             | K          | L     | 0     | 0     |
| G             | A          | A     | 0     | 0     |
| H             | A          | A     | 1     | 1     |
| I             | A          | A     | 1     | 1     |
| J             | A          | A     | 1     | 1     |
| K             | A          | A     | 1     | 1     |
| L             | A          | —     | 1     | —     |

(a)

| PRESENT STATE | NEXT STATE |       | Z     |       |
|---------------|------------|-------|-------|-------|
|               | X = 0      | X = 1 | X = 0 | X = 1 |
| A             | B          | C     | 1     | 0     |
| B             | D          | E     | 0     | 1     |
| C             | F          | —     | 1     | —     |
| D             | G          | H     | 1     | 1     |
| E             | H          | H     | 1     | 0     |
| F             | H          | L     | 0     | 0     |
| G             | A          | A     | 0     | 0     |
| H             | A          | A     | 1     | 1     |
| L             | A          | —     | 1     | —     |

(b)

| PRESENT STATE ABCD | NEXT STATE |       | Z     |       |
|--------------------|------------|-------|-------|-------|
|                    | X = 0      | X = 1 | X = 0 | X = 1 |
| 0000               | 0001       | 0010  | 1     | 0     |
| 0001               | 0011       | 0100  | 0     | 1     |
| 0010               | 0101       | —     | 1     | —     |
| 0011               | 0110       | 0111  | 1     | 1     |
| 0100               | 0111       | 0111  | 1     | 0     |
| 0101               | 0111       | 1000  | 0     | 0     |
| 0110               | 0000       | 0000  | 0     | 0     |
| 0111               | 0000       | 0000  | 1     | 1     |
| 1000               | 0000       | —     | 1     | —     |

(c)

Figure 5-18. Example 5.2 (a) State Transition Table (b) Reduced State Table (c) Reduced Transition Table

### 5.5 Counters

Counters are among the most commonly used sequential circuits. In the following sections, they are covered in detail.

A register that goes through a predetermined state sequence upon receiving an input pulse is called a counter. Counters are one of the simplest sequential circuits, and are found in almost all equipment containing digital logic. The sequence of states followed determines the different types of counters (BCD, binary, etc).

The binary counter is one of the simplest counters. An n-bit binary counter is a register with n flip-flops and associated combinatorial logic that follows the sequence from 0 to  $2^n - 1$ .

#### Example 5.3

We will look at the design of a 3-bit up/down binary counter. There are three outputs from the binary counter: DA, DB and DC. The input to the counter is X; the counter will increment if  $X = 1$ , and decrement if  $X = 0$ . We will use D flip-flops for this design.

#### Solution:

This circuit will have eight different states, because the 3-bit counter cycles through  $2^3$  states. The states are called q0, q1, q2, q3, q4, q5, q6 and q7. If  $X = 1$  each state will have a transition to its next higher state. For example, q0 will go to q1, q1 will go to q2, and so on. If  $X = 0$  then each state will change to its previous state. For example, q7 will go to q6, q5 to q4, and so on.

The state diagram of this design is shown in Figure 5-22a. State transition tables, derived from the state diagram, are shown in Figure 5-22b. The K-maps and the state variables are shown in Figure 5-22c. The state equations are derived from the K-maps. The equations are summarized as follows:

$$D_A = \bar{A} \cdot \bar{B} \cdot C \cdot X + \bar{A} \cdot B \cdot C \cdot \bar{X} + A \cdot \bar{B} \cdot C + A \cdot \bar{B} \cdot \bar{X} + A \cdot C \cdot \bar{X}$$

$$D_B = \bar{B} \cdot C \cdot \bar{X} + \bar{B} \cdot C \cdot X + B \cdot \bar{C} \cdot X + B \cdot C \cdot \bar{X}$$

$$D_C = \bar{C}$$

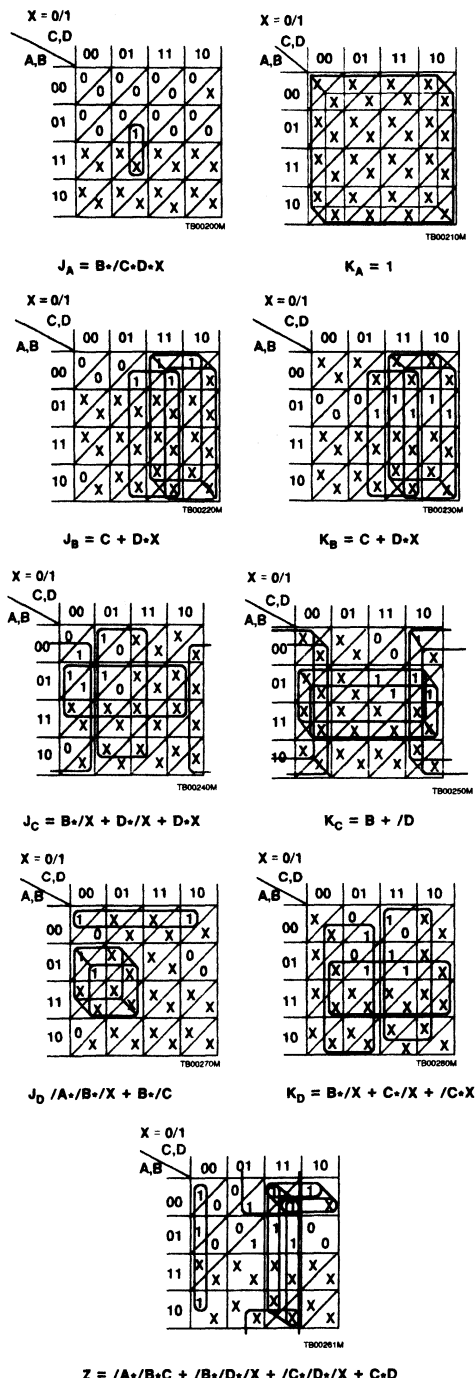
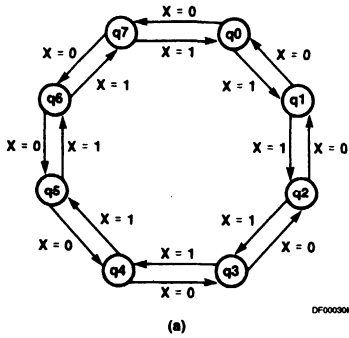


Figure 5-19. Karnaugh Maps for Example 5.2



| PRESENT STATE | NEXT STATE |       |
|---------------|------------|-------|
|               | X = 0      | X = 1 |
| q0            | q7         | q1    |
| q1            | q0         | q2    |
| q2            | q1         | q3    |
| q3            | q2         | q4    |
| q4            | q3         | q5    |
| q5            | q4         | q6    |
| q6            | q5         | q7    |
| q7            | q6         | q0    |

| PRESENT STATE | NEXT STATE |       |
|---------------|------------|-------|
|               | X = 0      | X = 1 |
| 000           | 111        | 001   |
| 001           | 000        | 010   |
| 010           | 001        | 011   |
| 011           | 010        | 100   |
| 100           | 011        | 101   |
| 101           | 100        | 110   |
| 110           | 101        | 111   |
| 111           | 110        | 000   |

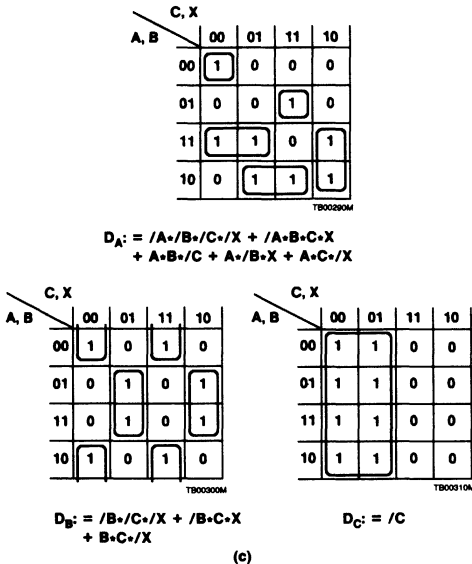


Figure 5-20. 3-Bit Up/Down Counter (a) State Diagram (b) State Transition Tables (c) Karnaugh Maps

We can easily implement this counter using a PAL device. The PAL device for this design will require at least three flip-flops. Since there is no PAL device available that has only three flip-flops, the best PAL device will be the PAL16R4, because it has four flip-flops and contains the AND-OR gates needed to realize the combinatorial circuit of the counter. The schematic of the 3-bit up/down counter using the PAL16R4 is shown on page 8-31. Note that there are plenty of unused inputs and outputs for other functions if desired.

Design of a binary counter can be complicated by adding new features to it. Counters can be made to count up or down, load new values in, or clear the present state of the counter and reset to 0's.

As we try to design bigger counters, using the state tables and K-maps becomes more difficult. In the design of the 3-bit counter, K-maps were used. If we try to design a counter bigger than this, summarizing the equations will be a very tedious process. Therefore, we try to find a general solution for solving the counter design problem. Let's try to write the equation for the most significant bit (MSB) of an n-bit binary counter ( $Q_n$ ).

First we look at the case where the counter is counting up. The new value of  $Q_n$  will depend on the carry-in from bit  $Q_{n-1}$  into  $Q_n$ . If all less significant bits (LSBs) are high when we count up, we will have a carry-in from  $Q_{n-1}$  into  $Q_n$ .

$$C_{IN} := Q_{n-1} * Q_{n-2} * \dots * Q_1 * Q_0 * UP$$

Now let's look at the following table:

| UP | $Q_n$ | CARRY-IN | NEW $Q_n$ |
|----|-------|----------|-----------|
| H  | L     | L        | L         |
| H  | L     | H        | H         |
| H  | H     | L        | H         |
| H  | H     | H        | L         |

Figure 5-21. Carry-in Table

Examining the above table, it is easily concluded that:

$$Q_n := Q_n \text{ :+ : carry-into } Q_n$$

$$Q_n := Q_n \text{ :+ : } (Q_{n-1} * Q_{n-2} * \dots * Q_0 * UP)$$

Now that we have calculated the equation for the count-up case, let's look at the count-down case. Borrow-out from  $Q_n$  to  $Q_{n-1}$  will be high if all the LSBs are low and we are counting down.

$$B_{OUT} := /Q_n - 1*/Q_{n-1} - 2*/Q_0*/UP$$

Let's look at the following table:

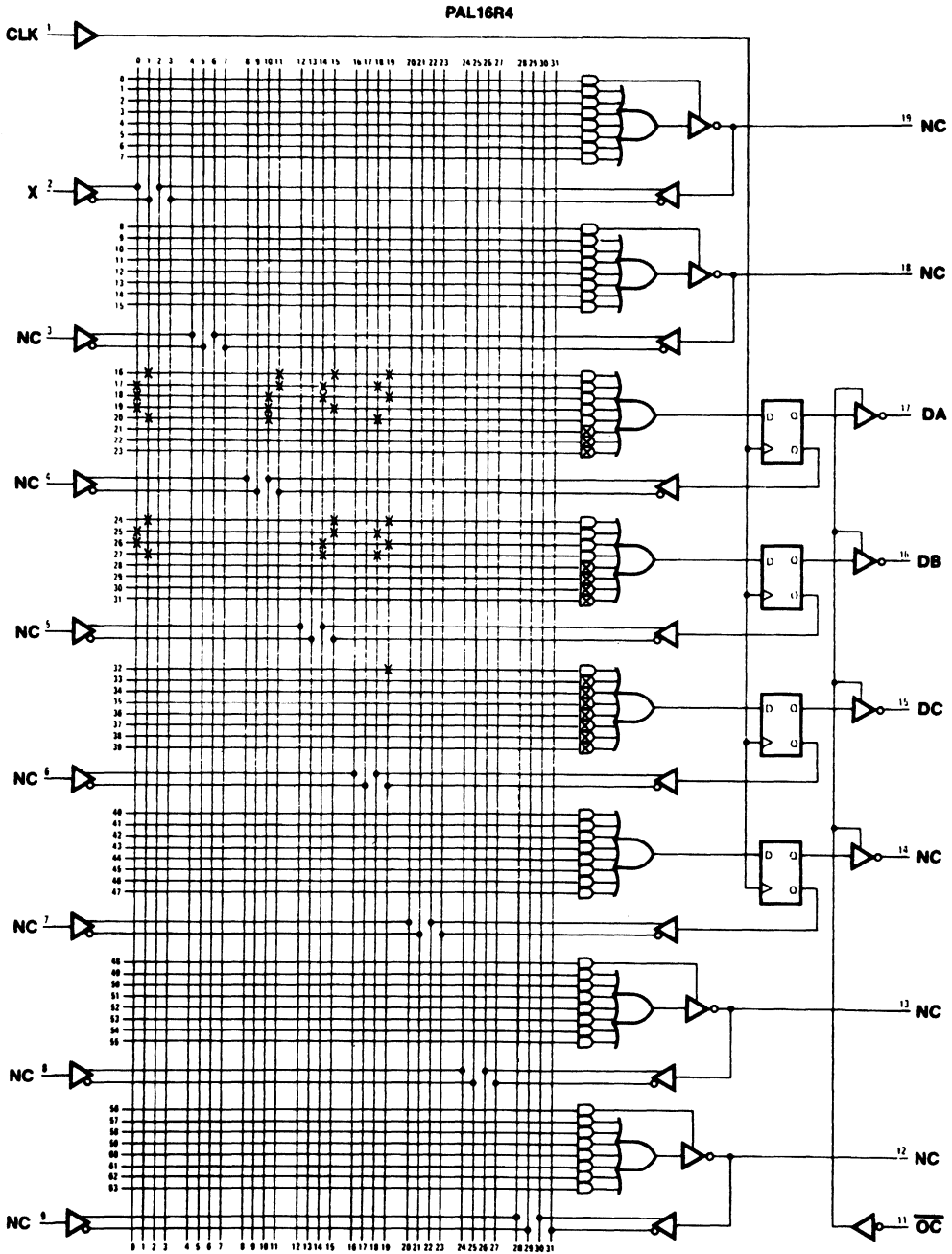
| UP | $Q_n$ | BORROW OUT | NEW $Q_n$ |
|----|-------|------------|-----------|
| L  | L     | L          | L         |
| L  | L     | H          | H         |
| L  | H     | L          | H         |
| L  | H     | H          | L         |

Figure 5-22. Borrow-out Table



# Logic Tutorial

## Logic Diagram



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## Logic Tutorial

So:

$$Q_n := Q_n :+ : \text{Borrow-out } Q_n$$

$$Q_n := Q_n :+ : (/Q_{n-1}*/ Q_{n-2}*/.../Q_1*/Q_0*/UP)$$

Therefore:

$$Q_n := Q_n :+ : (Q_{n-1} * Q_{n-2} * ... * Q_1 * Q_0 * Q_0 * UP)$$

$$+ Q_n :+ : (/Q_{n-1}*/ Q_{n-2}*/.../Q_1*/Q_0*/UP)$$

Another way to look at a counter is to formulate the following statement about the  $n^{\text{th}}$  bit of the counter:

$Q_n$  should hold UNLESS all lower order bits are HI and we are counting UP.

The "UNLESS" operation is implemented by an XOR gate. Thus this statement translates directly into

$$Q_n := Q_n :+ : (Q_{n-1} * Q_{n-2} * ... * Q_1 * Q_0 * UP)$$

This is, of course, the same equation we obtained by looking at the truth table. The expression for a down-counter can be found the same way.

This formulation makes it easy to combine these two expressions into a single equation for an up/down counter:

$Q_n$  should hold UNLESS:

- All lower order bits are HI and counting UP
- OR all lower order bits are LO and NOT counting UP.

This translates to

$$Q_n := Q_n :+ : (Q_{n-1} * Q_{n-2} * ... * Q_1 * Q_0 * UP) \quad \text{Eq. 5.1}$$

$$+ (Q_{n-1}*/Q_{n-2}*/...*/Q_1*/Q_0*/UP)$$

### Example 5.4

Using the solution discussed above, let's try to design an  $n$ -bit counter that can count up, count down, RESET and LOAD new values into the counter. RESET overrides LOAD, count and HOLD. LOAD overrides count. RESET sets all of the  $Q$ s to 0.

### Solution:

The above operations are summarized below.

| RE-SET | LD | HOLD | UP | D | Q         | OPERATION   |
|--------|----|------|----|---|-----------|-------------|
| H      | X  | X    | X  | X | X         | Set all LOW |
| L      | L  | X    | X  | D | D         | Load D      |
| L      | H  | H    | X  | X | Q         | Hold Q      |
| L      | H  | L    | L  | X | Q plus 1  | Increment   |
| L      | H  | L    | H  | X | Q minus 1 | Decrement   |

We will try to generate a general equation that can be used for any bit in the counter. If we take the  $n^{\text{th}}$  bit, we have  $D_n$  as input and  $Q_n$  as output. There are five operations that can happen for any given bit: LOAD, HOLD, RESET, count up or count down.

If RESET is HI, then all other operations are overridden. Overriding the other operations is sufficient to provide a LO into the flip-flop. So every product term will contain /RESET. We LOAD the new value in the counter's register if RESET is OFF (/RESET = H). Since  $Q_n$  is replaced by  $D_n$  if (/RESET = H, LOAD = H), the expression that will allow loading the new value will be /RESET\*LOAD\*/ $D_n$ . In order to be able to HOLD the  $Q_n$  value, we should have the following conditions: (RESET = L, LOAD = L, HOLD = H). So the expression for holding the old value is:

$$/RESET*/LOAD*/HOLD*Q_n$$

There are two more functions for the counter: count up and count down. These two functions have been calculated in Eq. 5.1. Using this equation and the calculation for the HOLD and LOAD cases, the final equation for the  $n^{\text{th}}$  bit is:

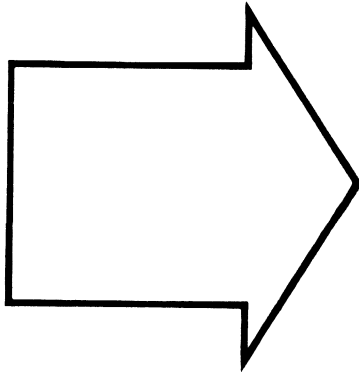
$$Q_n = /RESET*LOAD*D_n \quad \text{Eq. 5.2}$$

$$+ /RESET*/LOAD*/Q_n$$

$$+ :/RESET*/LOAD*HOLD*UP*Q_0*Q_1*... Q_{n-1}$$

$$+ /RESET*/LOAD*HOLD*/UP*/Q_0*/Q_1*/.../Q_{n-1}$$

Using the above general equation, any large counter can be designed.



|   |           |
|---|-----------|
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## PLE™ Devices

### PLE to PROM Cross Reference

| TEMP. RANGE | PLE NUMBER | INPUTS | OUTPUTS  | OUTPUT TYPE | MEMORY SIZE | PROM NUMBER       | PACKAGE                  |
|-------------|------------|--------|----------|-------------|-------------|-------------------|--------------------------|
| Com.        | PLE5P8C    | 5      | 8        | Three-State | 32 x 8      | 63S081            | 16N,J,(20),(NL)          |
|             | PLE5P8AC   | 5      | 8        | Three-State | 32 x 8      | 63S081A           | 16N,J,(20),(NL)          |
|             | PLE5P16C   | 5      | 16       | Three-State | 32 x 16     | none              | 24NS,JS,(28),(NL)        |
|             | PLE6P16C   | 6      | 16       | Two-State   | 64 x 16     | none              | 24NS,JS,(28),(NL)        |
|             | PLE8P4C    | 8      | 4        | Three-State | 256 x 4     | 63S141A           | 16N,J,(20),(NL)          |
|             | PLE8P8C    | 8      | 8        | Three-State | 256 x 8     | 63S281A           | 20N,J,NL                 |
|             | PLE9P4C    | 9      | 4        | Three-State | 512 x 4     | 63S241A           | 16N,J,(20),(NL)          |
|             | PLE9P8C    | 9      | 8        | Three-State | 512 x 8     | 63S481A           | 20N,J,NL                 |
|             | PLE10P4C   | 10     | 4        | Three-State | 1024 x 4    | 63S441A           | 18N,J,(20),(NL)          |
|             | PLE10P8C   | 10     | 8        | Three-State | 1024 x 8    | 63S881A           | 24N,J,NS,JS,(28),(NL)    |
|             | PLE11P4C   | 11     | 4        | Three-State | 2048 x 4    | 63S841A           | 18N,J,(20),(NL)          |
|             | PLE11P8C   | 11     | 8        | Three-State | 2048 x 8    | 63S1681A          | 24N,J,NS,JS,(28),(NL)    |
|             | PLE12P4C   | 12     | 4        | Three-State | 4096 x 4    | 63S1641A          | 20N,J,NL                 |
|             | PLE12P8C   | 12     | 8        | Three-State | 4096 x 8    | 63S3281A          | 24N,J,(28),(NL)          |
|             | PLE9R8C    | 9      | 8        | Register    | 512 x 8     | 63RA481A          | 24NS,JS,(28),(NL)        |
|             | PLE10R8C   | 10     | 8        | Register    | 1024 x 8    | 63RS881A          | 24NS,JS,(28),(NL)        |
|             | PLE11RA8C  | 11     | 8        | Register    | 2048 x 8    | 63RA1681A         | 24NS,JS,(28),(NL)        |
| PLE11RS8C   | 11         | 8      | Register | 2048 x 8    | 63RS1681A   | 24NS,JS,(28),(NL) |                          |
| Mil.        | PLE5P8M    | 5      | 8        | Three-State | 32 x 8      | 53S081            | 16J,W,(20),(L)           |
|             | PLE8P4M    | 8      | 4        | Three-State | 256 x 4     | 53S141A           | 16J,W,(20),(L)           |
|             | PLE8P8M    | 8      | 8        | Three-State | 256 x 8     | 53S281A           | 20J,W,L                  |
|             | PLE9P4M    | 9      | 4        | Three-State | 512 x 4     | 53S241A           | 16J,W,(20),(L)           |
|             | PLE9P8M    | 9      | 8        | Three-State | 512 x 8     | 53S481A           | 20J,F,L                  |
|             | PLE10P4M   | 10     | 4        | Three-State | 1024 x 4    | 53S441A           | 18J,W,(20),(L)           |
|             | PLE10P8M   | 10     | 8        | Three-State | 1024 x 8    | 53S881A           | 24JS,J,W,(28),(L)        |
|             | PLE11P4M   | 11     | 4        | Three-State | 2048 x 4    | 53S841A           | 18J,W,(28),(L),(20),(L)* |
|             | PLE11P8M   | 11     | 8        | Three-State | 2048 x 8    | 53S1681A          | 24JS,J,W,(28),(L)        |
|             | PLE12P4M   | 12     | 4        | Three-State | 4096 x 4    | 53S1641A          | 20J                      |
|             | PLE12P8M   | 12     | 8        | Three-State | 4096 x 8    | 53S3281A          | 24J,W,(28),(L)           |
|             | PLE9R8M    | 9      | 8        | Register    | 512 x 8     | 53RA481A          | 24JS,W,(28),(L)          |
|             | PLE10R8M   | 10     | 8        | Register    | 1024 x 8    | 53RS881A          | 24JS,J,W,(28),(L)        |
|             | PLE11RA8M  | 11     | 8        | Register    | 2048 x 8    | 53RA1681A         | 24JS,W,(28),(L)          |
| PLE11RS8M   | 11         | 8      | Register | 2048 x 8    | 53RS1681A   | 24JS,W,(28),(L)   |                          |

\*The PLE11P4M is available in a 20- or 28-pin Leadless Chip Carrier

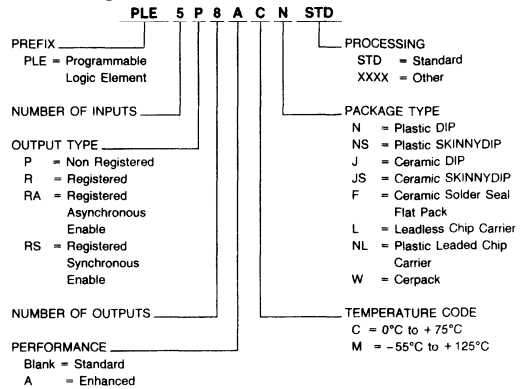
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# Programmable Logic Element PLE™ Circuit Facility

## Features/Benefits

- Programmable replacement for conventional TTL logic
- Reduces IC inventories and simplifies their control
- Expedites and simplifies prototyping and board layout
- Saves space with 0.3-inch SKINNYDIP® packages (except PLE12P8)
- Programmed on standard PROM programmers
- Test and simulation made simple with PLEASM™ software
- Low-current PNP inputs
- Three-state outputs
- Reliable TiW fuses guarantee > 98% programming yield

## Ordering Information



## PLE Circuit Selection Guide

| PART NUMBER | INPUTS | OUTPUTS | PRODUCT TERMS | OUTPUT REGISTERS | t <sub>PD</sub> (ns) MAX* |
|-------------|--------|---------|---------------|------------------|---------------------------|
| PLE5P8      | 5      | 8       | 32            |                  | 25                        |
| PLE5P8A     | 5      | 8       | 32            |                  | 15                        |
| PLE5P16     | 5      | 16      | 32            |                  | 18                        |
| PLE6P16     | 6      | 16      | 64            |                  | 20                        |
| PLE8P4      | 8      | 4       | 256           |                  | 30                        |
| PLE8P8      | 8      | 8       | 256           |                  | 28                        |
| PLE9P4      | 9      | 4       | 512           |                  | 35                        |
| PLE9P8      | 9      | 8       | 512           |                  | 30                        |
| PLE10P4     | 10     | 4       | 1024          |                  | 35                        |
| PLE10P8     | 10     | 8       | 1024          |                  | 30                        |
| PLE11P4     | 11     | 4       | 2048          |                  | 35                        |
| PLE11P8     | 11     | 8       | 2048          |                  | 35                        |
| PLE12P4     | 12     | 4       | 4096          |                  | 35                        |
| PLE12P8     | 12     | 8       | 4096          |                  | 35                        |
| PLE9R8      | 9      | 8       | 512           | 8                | 15                        |
| PLE10R8     | 10     | 8       | 1024          | 8                | 15                        |
| PLE11RA8    | 11     | 8       | 2048          | 8                | 15                        |
| PLE11RS8    | 11     | 8       | 2048          | 8                | 15                        |

\*Clock to output time for registered outputs.  
 Note: Commercial limits specified.

## Programmable Logic Element PLE™ Circuit Family

### PLE Means Programmable Logic Element

Joining the world of IdeaLogic™ is a new generation of High-speed PROMs which the designer can use as *Programmable Logic Elements*. The combination of PLE circuits as logic elements with PAL devices can greatly enhance system speed while providing almost unlimited design freedom.

Basically, PLE circuits are ideal when a large number of product terms is required. On the other hand, a PAL device is best suited for situations when many inputs are needed.

The PLE circuit transfer function is the familiar sum of products. Like the PAL device, the PLE circuit has a single array of fusible links. Unlike the PAL device, the PLE circuits have a programmable OR array driven by a fixed AND array (the PAL device is a programmed AND array driving a fixed OR array).

#### PRODUCT TERM AND INPUT LINES

|               | PLE        | PAL     |
|---------------|------------|---------|
| Product Terms | 32 to 4096 | 1 to 16 |
| Input Lines   | 5 to 12    | 6 to 64 |

The PLE family features common electrical parameters and programming algorithms, low-current PNP inputs, full Schottky clamping and three-state outputs.

The entire PLE family is programmed on conventional PROM programmers with the appropriate personality cards and socket adapters.

### Registered PLE Circuits

The registered PLE circuits have on-chip "D" type registers, versatile output enable control through synchronous and asynchronous enable inputs, and flexible start-up sequencing through programmable initialization.

Data is transferred into the output registers on the rising edge of the clock. Provided that the asynchronous ( $\bar{E}$ ) and synchronous ( $\bar{ES}$ ) enables are Low, the data will appear at the outputs. Prior to the positive clock edge, register data are not affected by changes in addressing or synchronous enable inputs.

Data control is made flexible with synchronous and asynchronous enable inputs. Outputs may be set to the high-impedance state at any time by setting  $\bar{E}$  to a High or if  $\bar{ES}$  is High when the rising clock edge occurs. When  $V_{CC}$  power is first applied the synchronous enable flip-flop will be in the set condition causing the outputs to be in the high-impedance state.

A flexible initialization feature allows start-up and time-out sequencing with 1:16 programmable words to be loaded into the output registers. With the synchronous INITIALIZE ( $\bar{IS}$ ) pin Low, one of the 16 initialize words, addressed through pins 5, 6, 7 and 8 will be set in the output registers independent of all other input pins. The unprogrammed state of  $\bar{IS}$  words are Low, presenting a CLEAR with  $\bar{IS}$  pin Low. With all  $\bar{IS}$  column words (A3-AO) programmed to the same pattern, the  $\bar{IS}$  function will be independent of both row and column addressing and may be used as a single pin control. With all  $\bar{IS}$  words programmed High a PRESET function is performed.

The PLE9R8 has asynchronous PRESET and CLEAR functions. With the chip enabled, a Low on the  $\bar{PR}$  input will cause all outputs to be set to the High state. When the  $\bar{CLR}$  input is set Low the output registers are reset and all outputs will be set to the Low state. The  $\bar{PR}$  and  $\bar{CLR}$  functions are common to all output registers and independent of all other data input states.

|     | AND   | OR    | OUTPUT OPTIONS                               |
|-----|-------|-------|--|
| PLE | Fixed | Prog  | TS, Registered Outputs, Fusible Polarity     |
| PLA | Prog  | Prog  | TS, OC, Fusible Polarity                     |
| PAL | Prog  | Fixed | TS, Registered Feedback I/O Fusible Polarity |

# Programmable Logic Element PLE™ Circuit Family

## PLEASM™ Software

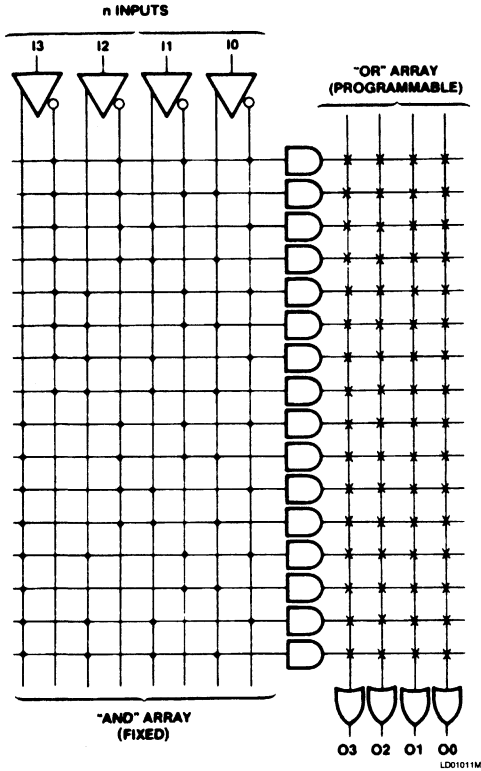
**Software that makes programmable logic easy.**

Monolithic Memories has developed a software tool to assist in designing and programming PROMs as PLE circuits. This package called "PLEASM" (PLE Assembler) is available for several computers including the VAX/VMS and IBM PC/DOS.

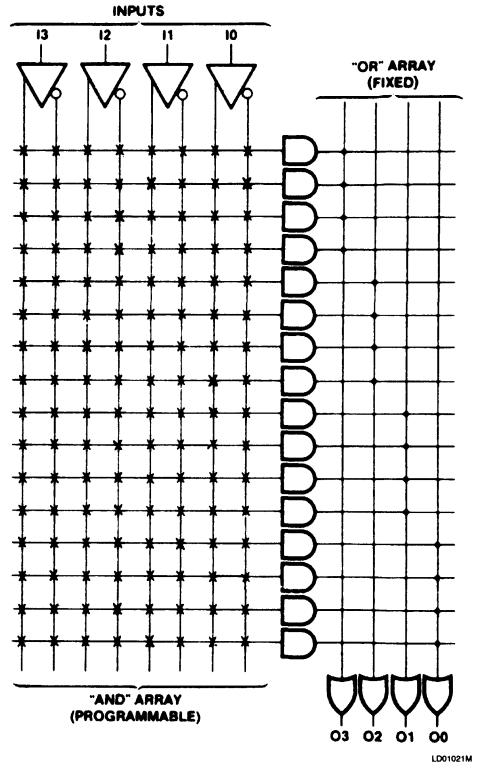
PLEASM software converts design equations (Boolean and arithmetic) into truth tables and formats compatible with PROM programmers. A simulator is also provided to test a design using a Function Table before actually programming the PLE circuit.

PLEASM software may be requested through the Monolithic Memories IdeaLogic Exchange.

**PLE (PROM)**



**PAL Device**

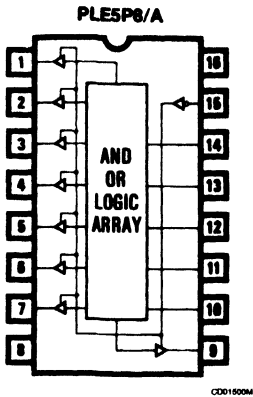


NOTE: • = hardwired connection  
X = programmable connection

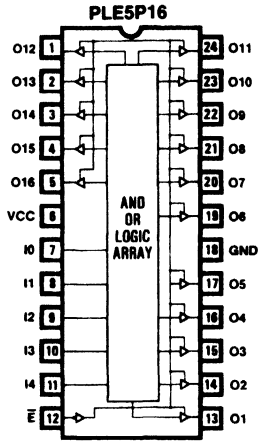


# Programmable Logic Element PLE™ Circuit Family

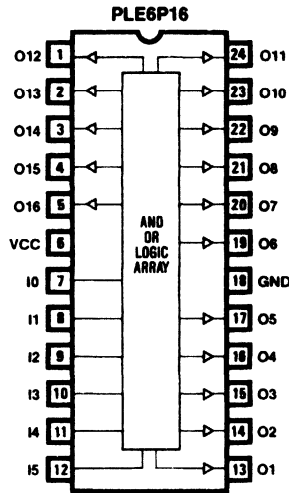
## Logic Symbols



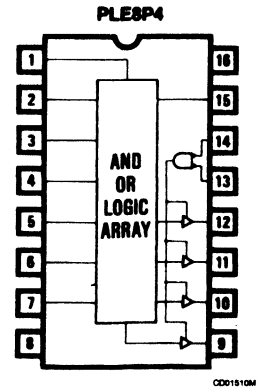
CD01500M



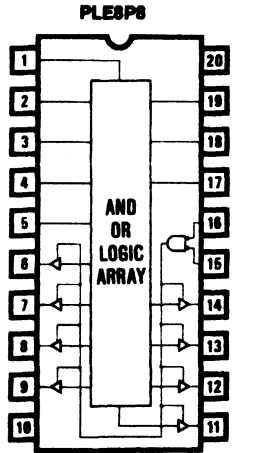
CD01070M



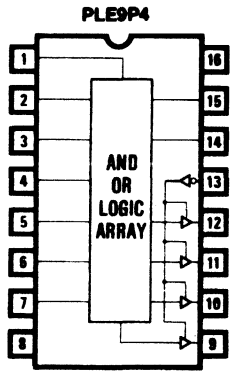
CD01080M



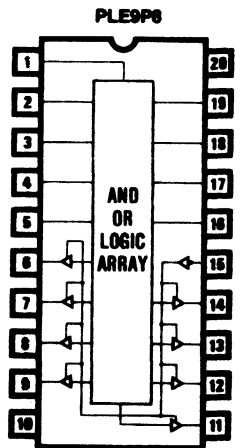
CD01510M



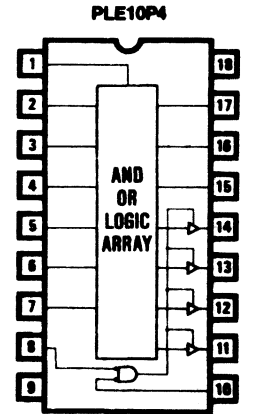
CD01520M



CD01530M



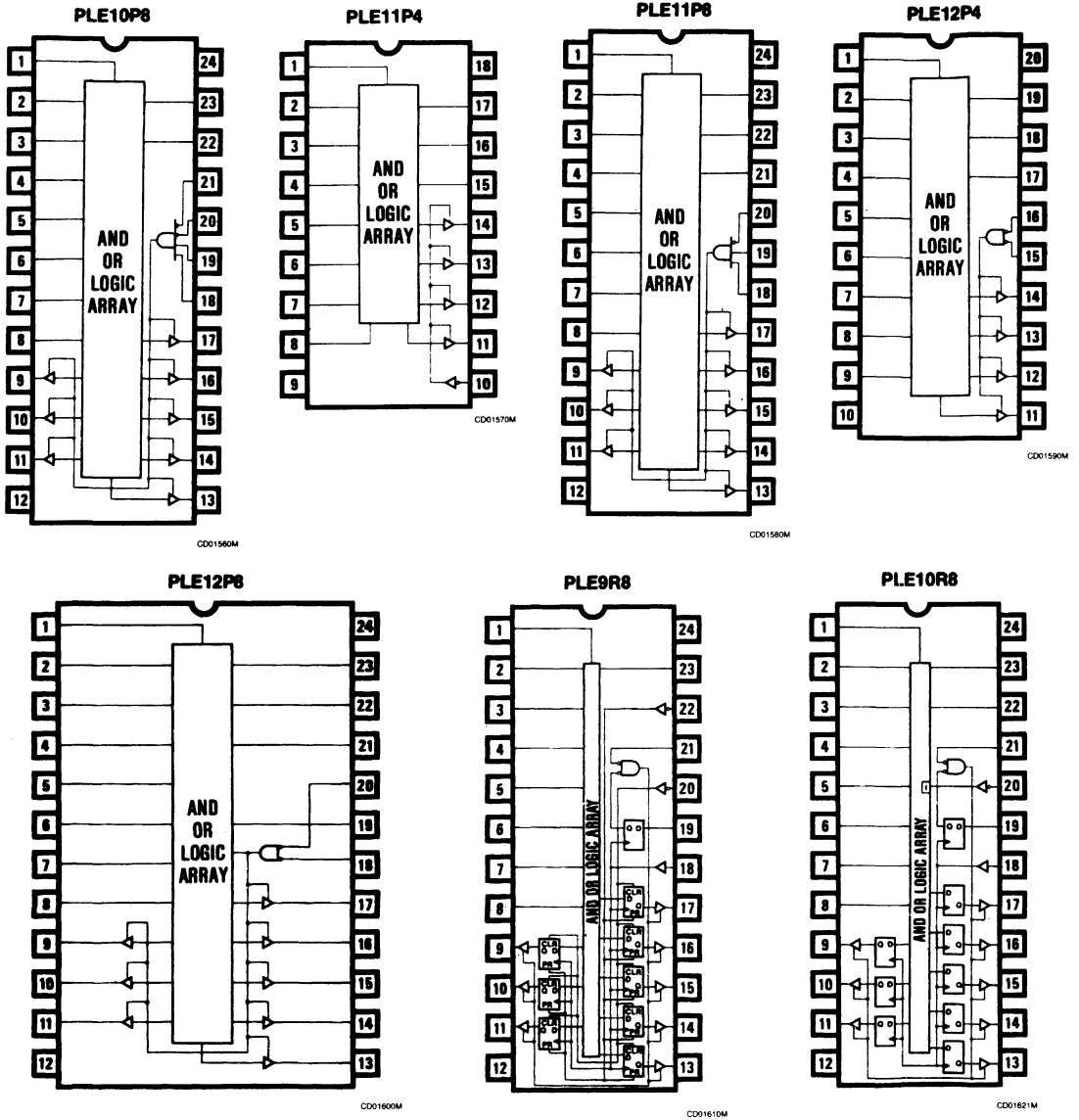
CD01540M



CD01550M

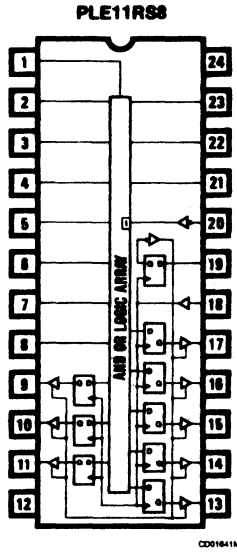
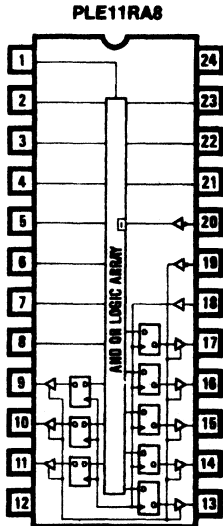
# Programmable Logic Element PLE™ Circuit Family

## Logic Symbols



# Programmable Logic Element PLE™ Circuit Family

## Logic Symbols



## Programmable Logic Element PLE™ Circuit Family

### Absolute Maximum Ratings

|                               |                    |             |
|-------------------------------|--------------------|-------------|
| Supply voltage $V_{CC}$ ..... | Operating          | Programming |
| Input voltage.....            | -0.5V to 7V.....   | 12V.....    |
| Off-state output voltage..... | -1.5V to 7V.....   | 7V.....     |
| Storage temperature.....      | -0.5V to 5.5V..... | 12V.....    |
|                               | -65° to +150°C     |             |

### Operating Conditions

| SYMBOL   | PARAMETER                      | COMMERCIAL |     |      | MILITARY |     |     | UNIT |
|----------|--------------------------------|------------|-----|------|----------|-----|-----|------|
|          |                                | MIN        | NOM | MAX  | MIN      | NOM | MAX |      |
| $V_{CC}$ | Supply Voltage                 | 4.75       | 5   | 5.25 | 4.5      | 5   | 5.5 | V    |
| $T_A$    | Operating free-air temperature | 0          | 25  | 75   | -55      | 25  | 125 | °C   |

### Electrical Characteristics Over Operating Conditions

| SYMBOL    | PARAMETER                     | TEST CONDITIONS   |  | MIN   | TYP† | MAX   | UNIT |     |
|-----------|-------------------------------|---|--|-------|------|-------|------|-----|
| $V_{IL}$  | Low-level input voltage       | Guaranteed logical low voltage for all inputs                     |  |       |      | 0.8   | V    |     |
| $V_{IH}$  | High-level input voltage      | Guaranteed logical high voltage for all inputs                    |  | 2     |      |       | V    |     |
| $V_{IC}$  | Input clamp voltage           | $V_{CC} = \text{MIN}$   | $I_I = -18\text{mA}$   |       |      | -1.5  | V    |     |
| $I_{IL}$  | Low-level input current       | $V_{CC} = \text{MAX}$   | $V_I = 0.4\text{V}$  |       |      | -0.25 | mA   |     |
| $I_{IH}$  | High-level input current      | $V_{CC} = \text{MAX}$   | $V_I = V_{CC}$   |       |      | 40    | μA   |     |
| $V_{OL}$  | Low-level output voltage      | $V_{CC} = \text{MIN}$   | $I_{OL} = 16\text{mA}$                                       | Com   |      | 0.45  | V    |     |
|           |                               |   |  | Mil   |      | 0.5   |      |     |
| $V_{OH}$  | High-level output voltage     | $V_{CC} = \text{MIN}$   | Com $I_{OH} = -3.2\text{mA}$                                 |       | 2.4  |       | V    |     |
|           |                               |   | Mil $I_{OH} = -2\text{mA}$                                   |       |      |       |      |     |
| $I_{OZL}$ | Off-state output current      | $V_{CC} = \text{MAX}$   | $V_O = 0.4\text{V}$  |       |      | -40   | μA   |     |
| $I_{OZH}$ |                               |   | $V_O = 2.4\text{V}$  |       |      | 40    |      |     |
| $I_{OS}$  | Output short-circuit current* | $V_{CC} = 5\text{V}$  | $V_O = 0\text{V}$  |       | -20  | -90   | mA   |     |
| $I_{CC}$  | Supply current                | $V_{CC} = \text{MAX}$<br>All inputs grounded;<br>all outputs open | 5P8  |       |      | 90    | 125  | mA  |
|           |                               |   | 5P8A   |       |      | 90    | 125  |     |
|           |                               |   | 5P16   |       |      | 140   | 180  |     |
|           |                               |   | 6P16   |       |      | 150   | 190  |     |
|           |                               |   | 8P4  |       |      | 80    | 130  |     |
|           |                               |   | 8P8  |       |      | 90    | 140  |     |
|           |                               |   | 9P4  |       |      | 80    | 130  |     |
|           |                               |   | 9P8  |       |      | 104   | 155  |     |
|           |                               |   | 10P4   |       |      | 95    | 140  |     |
|           |                               |   | 10P8   |       |      | 92    | 160  |     |
|           |                               |   | 11P4   |       |      | 110   | 150  |     |
|           |                               |   | 11P8   |       |      | 135   | 185  |     |
|           |                               |   | 12P4   |       |      | 130   | 175  |     |
|           |                               |   | 12P8   |       |      | 150   | 190  |     |
|           |                               |   | $V_{CC} = \text{MAX}$<br>All inputs TTL;<br>all outputs open |       | 9R8  |       |      |     |
|           |                               |   |  | 10R8  |      |       | 130  | 180 |
|           |                               |   |  | 11RA8 |      |       | 140  | 185 |
|           |                               |   |  | 11RS8 |      |       | 140  | 185 |

† Typical at 5.0V  $V_{CC}$  and 25°C  $T_A$ .

\* Not more than one output should be shorted at a time and duration of the short circuit should not exceed one second.

## Programmable Logic Element PLE™ Circuit Family

### Switching Characteristics Over Commercial Operating Conditions

| DEVICE TYPE | $t_{PD}(ns)$<br>PROPAGATION DELAY<br>MAX | $t_{PZX}$ AND $t_{PXZ}$ (ns)<br>INPUT TO OUTPUT<br>ENABLE/DISABLE TIME<br>MAX |
|-------------|--|---|
| 5P8AC       | 15                                       | 20  |
| 5P8C        | 25                                       | 20  |
| 5P16C       | 18                                       | 15  |
| 6P16C       | 20                                       | 15  |
| 8P4C        | 30                                       | 20  |
| 8P8C        | 28                                       | 25  |
| 9P4C        | 35                                       | 20  |
| 9P8C        | 30                                       | 25  |
| 10P4C       | 35                                       | 25  |
| 10P8C       | 30                                       | 25  |
| 11P4C       | 35                                       | 25  |
| 11P8C       | 35                                       | 25  |
| 12P4C       | 35                                       | 25  |
| 12P8C       | 35                                       | 30  |

### Switching Characteristics Over Military Operating Conditions

| DEVICE TYPE | $t_{PD}(ns)$<br>PROPAGATION DELAY<br>MAX | $t_{PZX}$ AND $t_{PXZ}$ (ns)<br>INPUT TO OUTPUT<br>ENABLE/DISABLE TIME<br>MAX |
|-------------|--|---|
| 5P8M        | 35                                       | 30  |
| 8P4M        | 40                                       | 30  |
| 8P8M        | 40                                       | 30  |
| 9P4M        | 45                                       | 30  |
| 9P8M        | 40                                       | 30  |
| 10P4M       | 50                                       | 30  |
| 10P8M       | 45                                       | 30  |
| 11P4M       | 50                                       | 30  |
| 11P8M       | 50                                       | 30  |
| 12P4M       | 50                                       | 30  |
| 12P8M       | 40                                       | 35  |

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## PLE9R8

### Operating Conditions

| SYMBOL                  | PARAMETER   | MILITARY |      |     | COMMERCIAL |      |     | UNIT |
|-------------------------|---|----------|------|-----|------------|------|-----|------|
|                         |   | MIN      | TYP* | MAX | MIN        | TYP* | MAX |      |
| $t_w$                   | Width of clock (High or Low)                              | 20       | 10   |     | 20         | 10   |     | ns   |
| $t_{prw}$<br>$t_{clrw}$ | Width of preset or clear<br>(LOW) to Output (High or Low) | 20       | 10   |     | 20         | 10   |     | ns   |
| $t_{pr}$<br>$t_{clr}$   | Recovery from preset or clear<br>(LOW) to clock HIGH      | 25       | 11   |     | 20         | 11   |     | ns   |
| $t_{su}$                | Setup time from input to clock                            | 35       | 22   |     | 30         | 22   |     | ns   |
| $t_s(\overline{ES})$    | Setup time from $\overline{ES}$ to clock                  | 15       | 7    |     | 10         | 7    |     | ns   |
| $t_h$                   | Hold time from input to clock                             | 0        | -5   |     | 0          | -5   |     | ns   |
| $t_h(\overline{ES})$    | Hold time from $\overline{ES}$ to clock                   | 5        | -3   |     | 5          | -3   |     | ns   |

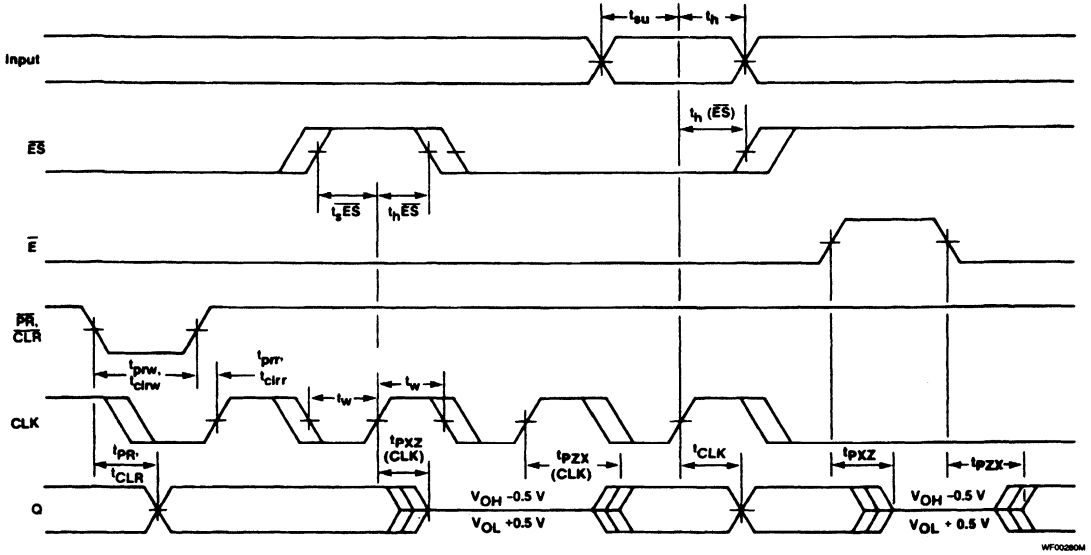
### Switching Characteristics Over Operating Conditions and using Standard Test Load

| SYMBOL                | PARAMETER                    | MILITARY |      |     | COMMERCIAL |      |     | UNIT |
|-----------------------|------------------------------|----------|------|-----|------------|------|-----|------|
|                       |                              | MIN      | TYP* | MAX | MIN        | TYP* | MAX |      |
| $t_{CLK}$             | Clock to output delay        |          | 11   | 20  |            | 11   | 15  | ns   |
| $t_{PR}$              | Preset to output delay       |          | 15   | 25  |            | 15   | 25  | ns   |
| $t_{CLR}$             | Clear to output delay        |          | 18   | 35  |            | 18   | 25  | ns   |
| $t_{PZX}(\text{CLK})$ | Clock to output enable time  |          | 14   | 30  |            | 14   | 25  | ns   |
| $t_{PXZ}(\text{CLK})$ | Clock to output disable time |          | 14   | 30  |            | 14   | 25  | ns   |
| $t_{PZX}$             | Input to output enable time  |          | 10   | 25  |            | 10   | 20  | ns   |
| $t_{PXZ}$             | Input to output disable time |          | 10   | 25  |            | 10   | 20  | ns   |

\* Typical at 5.0V  $V_{CC}$  and 25°C  $T_A$ .

# PLE9R8

## Definition of Waveforms



- NOTES:
1. Input pulse amplitude 0V to 3.0V.
  2. Input rise and fall times 2-5ns from 0.8V to 2.0V.
  3. Input access measured at the 1.5V level.
  4. Switch  $S_1$  is closed.  $C_L = 30pF$  and outputs measured at 1.5V level for all tests except  $t_{pZ}$  and  $t_{pZx}$ .
  5.  $t_{pZ}$  and  $t_{pZx(CLK)}$  are measured at the 1.5V output level with  $C_L = 30pF$ .  $S_1$  is open for high impedance to "1" test and closed for high impedance to "0" test.
- $t_{pZ}$  and  $t_{pZx(CLK)}$  are tested with  $C_L = 5pF$ .  $S_1$  is open for "1" to high impedance test, measured at  $V_{OH} - 0.5V$  output level;  $S_1$  is closed for "0" to high impedance test measured at  $V_{OL} + 0.5V$  output level.

# PLE10R8, 11RA8, 11RS8

## Operating Conditions

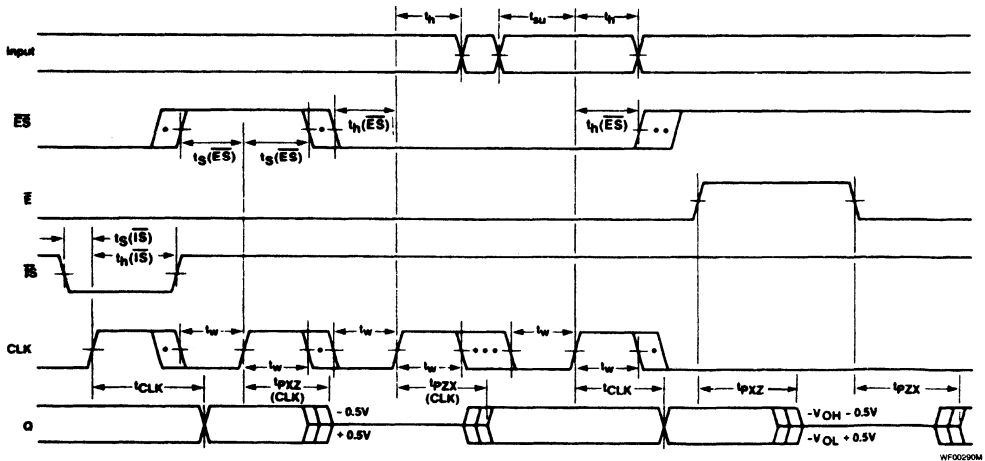
| SYMBOL               | PARAMETER   | MILITARY |      |     | COMMERCIAL |      |     | UNIT |
|----------------------|---|----------|------|-----|------------|------|-----|------|
|                      |   | MIN      | TYP* | MAX | MIN        | TYP* | MAX |      |
| $t_w$                | Width of clock (High or Low)                            | 20       | 10   |     | 20         | 10   |     | ns   |
| $t_{su}$             | Setup time from input to clock (10R8)                   | 40       | 25   |     | 30         | 25   |     | ns   |
| $t_{su}$             | Setup time from input to clock (11RA8, 11RS8)           | 40       | 28   |     | 35         | 28   |     | ns   |
| $t_s(\overline{ES})$ | Setup time from $\overline{ES}$ to clock (except 11RA8) | 15       | 8    |     | 15         | 8    |     | ns   |
| $t_s(\overline{IS})$ | Setup time from $\overline{IS}$ to clock                | 30       | 20   |     | 25         | 20   |     | ns   |
| $t_h$                | Hold time input to clock                                | 0        | -5   |     | 0          | -5   |     | ns   |
| $t_h(\overline{ES})$ | Hold time ( $\overline{ES}$ ) (except 11RA8)            | 5        | -3   |     | 5          | -3   |     | ns   |
| $t_h(\overline{IS})$ | Hold time ( $\overline{IS}$ )                           | 0        | -5   |     | 0          | -5   |     | ns   |

## Switching Characteristics Over Operating Conditions and using Standard Test Load

| SYMBOL         | PARAMETER                                   | MILITARY |      |     | COMMERCIAL |      |     | UNIT |
|----------------|---|----------|------|-----|------------|------|-----|------|
|                |   | MIN      | TYP* | MAX | MIN        | TYP* | MAX |      |
| $t_{CLK}$      | Clock to output delay                       |          | 10   | 20  |            | 10   | 15  | ns   |
| $t_{PZX}(CLK)$ | Clock to output enable time (except 11RA8)  |          | 18   | 30  |            | 18   | 25  | ns   |
| $t_{PXZ}(CLK)$ | Clock to output disable time (except 11RA8) |          | 17   | 30  |            | 17   | 25  | ns   |
| $t_{PZX}$      | Input to output enable time (except 11RS8)  |          | 17   | 30  |            | 17   | 25  | ns   |
| $t_{PXZ}$      | Input to output disable time (except 11RS8) |          | 17   | 30  |            | 17   | 25  | ns   |

\*Typicals at 5.0V  $V_{CC}$  and 25°C  $T_A$ .

## Definition of Waveforms

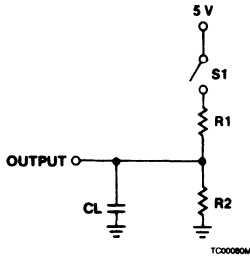


- NOTES:
1. Input pulse amplitude 0V to 3.0V.
  2. Input rise and fall times 2-5ns from 0.8V to 2.0V.
  3. Input access measured at the 1.5V level.
  4. Switch  $S_1$  is closed.  $C_L = 30pF$  and outputs measured at 1.5V level for all tests except  $t_{PZX}$  and  $t_{PXZ}$ .
  5.  $t_{PZX}$  and  $t_{PZX}(CLK)$  are measured at the 1.5V output level with  $C_L = 30pF$ .  $S_1$  is open for high impedance to "1" test and closed for high impedance to "0" test.
- $t_{PXZ}$  and  $t_{PXZ}(CLK)$  are tested with  $C_L = 5pF$ .  $S_1$  is open for "1" to high impedance test, measured at  $V_{OH} - 0.5V$  output level;  $S_1$  is closed for "0" to high impedance test measured at  $V_{OL} + 0.5V$  output level.



## PLE10R8, 11RA8, 11RS8

### Switching Test Load

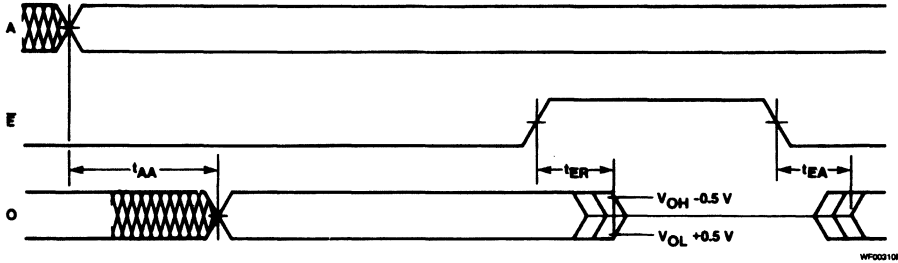


### Definition of Timing Diagram

| WAVEFORM | INPUTS                          | OUTPUTS                                |
|----------|---------------------------------|--|
|          | DON'T CARE;<br>CHANGE PERMITTED | CHANGING;<br>STATE UNKNOWN             |
|          | NOT<br>APPLICABLE               | CENTER LINE IS<br>HIGH IMPEDANCE STATE |
|          | MUST BE STEADY                  | WILL BE STEADY                         |

WF00030M

### Definition of Waveforms



NOTES: Apply to electrical and switching characteristics. Typical at 5.0V  $V_{CC}$  and 25°C  $T_A$ . Measurements are absolute voltages with respect to the ground pin on the device and includes all overshoots due to system and/or tester noise. In all PLE devices unused inputs must be tied to either ground or  $V_{CC}$ . The series resistor required for unused inputs on standard TTL is NOT required for PLE devices, thus using less parts. \*Not more than one output should be shorted at a time and duration of the short-circuit should not exceed one second. For commercial operating range  $R_1 = 200\Omega$ ,  $R_2 = 390\Omega$ . For military operating range  $R_1 = 300\Omega$ ,  $R_2 = 600\Omega$ .

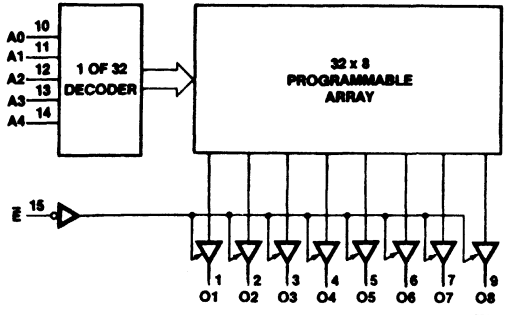
1. Input pulse amplitude 0V to 3.0V.
2. Input rise and fall times 2-5ns from 0.8 to 2.0V.
3. Input access measured at the 1.5V level.
4. Data delay is tested with switch  $S_1$  closed.  $C_L = 30pF$  and measured at 1.5V output level.
5.  $t_{PZX}$  is measured at the 1.5V output level with  $C_L = 30pF$ .  $S_1$  is open for high-impedance to "1" test and closed for high-impedance to "0" test.  $t_{PZX}$  is measured  $C_L = 5pF$ .  $S_1$  is open for "1" to high-impedance test, measured at  $V_{OH} - 0.5V$  output level;  $S_1$  is closed for "0" to high-impedance test measured at  $V_{OL} + 0.5V$  output level.

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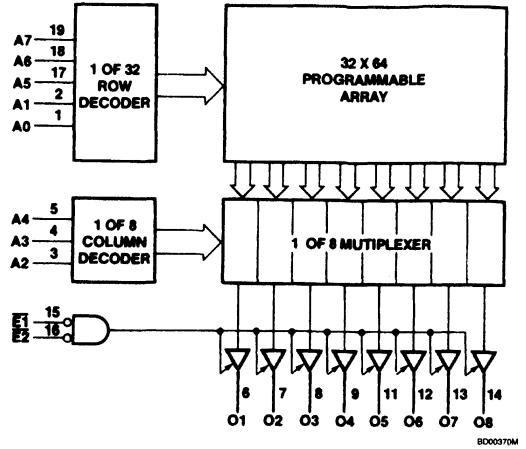
PLE10R8, 11RA8, 11RS8

Block Diagrams

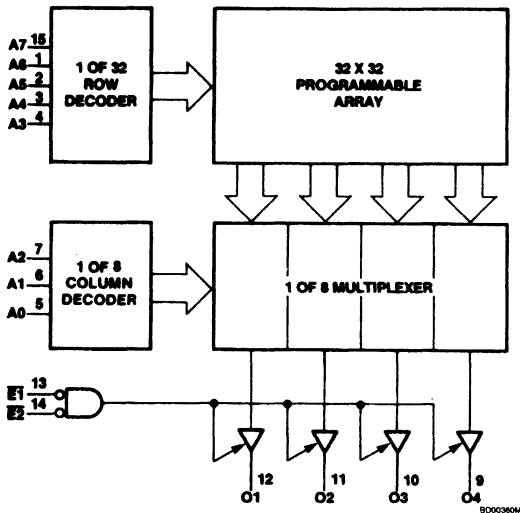
PLE8P8/A



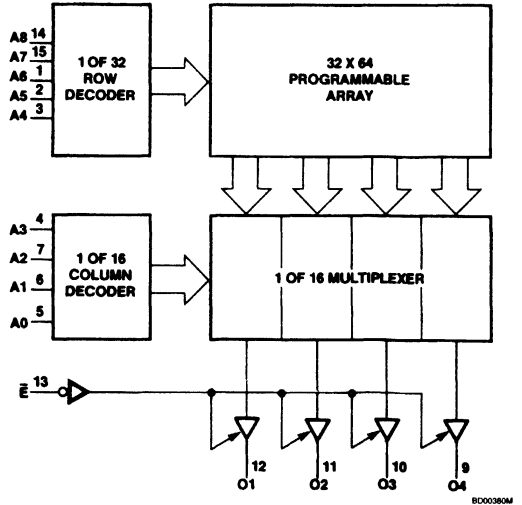
PLE8P8



PLE8P4



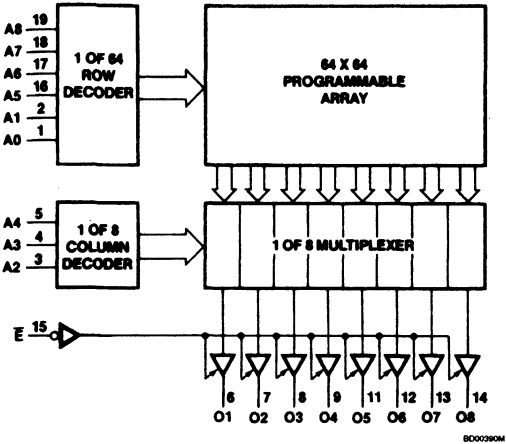
PLE9P4



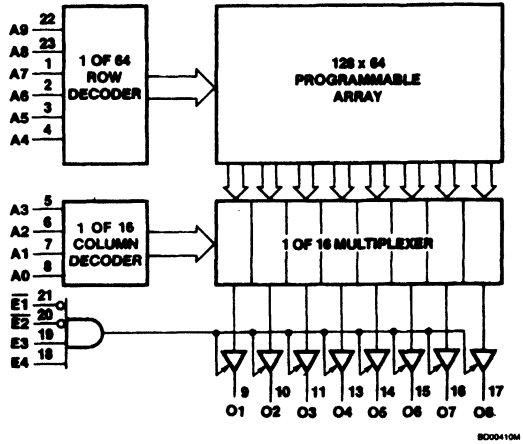
**PLE10R8, 11R8, 11R58**

**Block Diagrams**

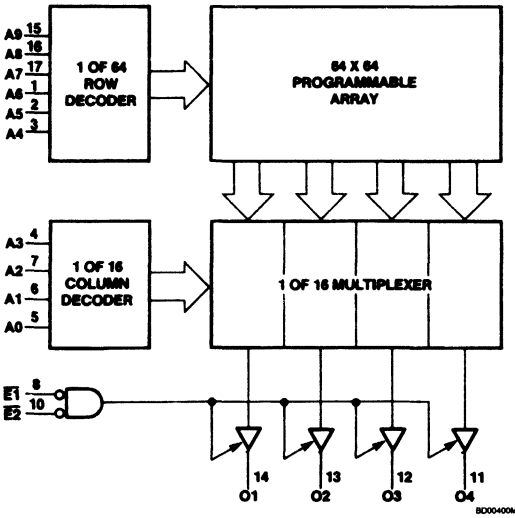
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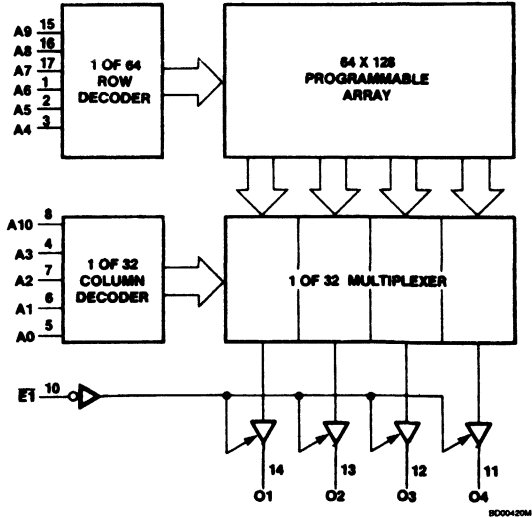
**PLE10P8**



**PLE10P4**

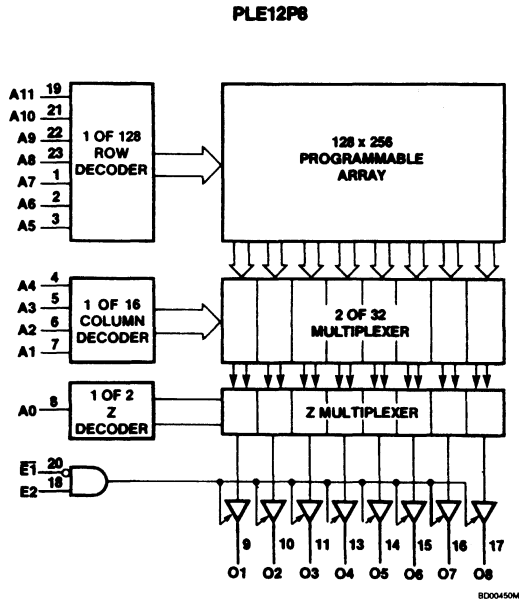
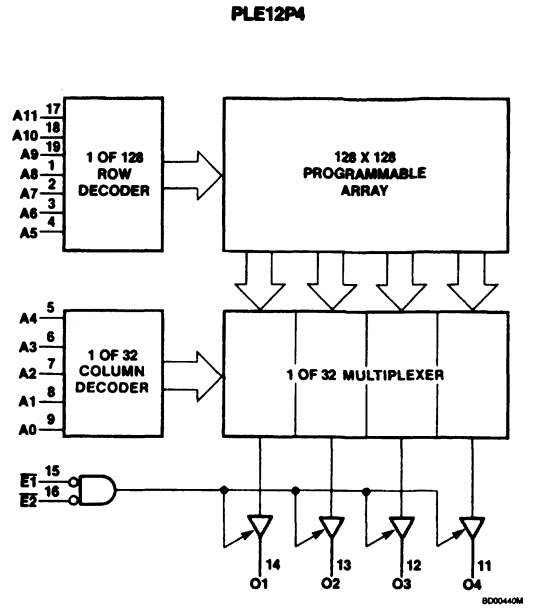
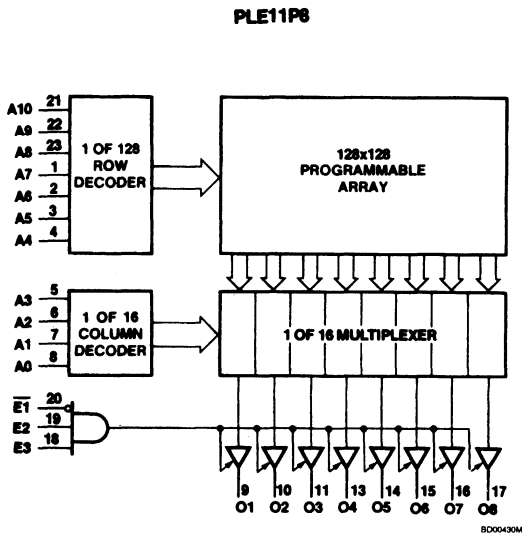


**PLE11P4**



PLE10R8, 11RA8, 11RS8

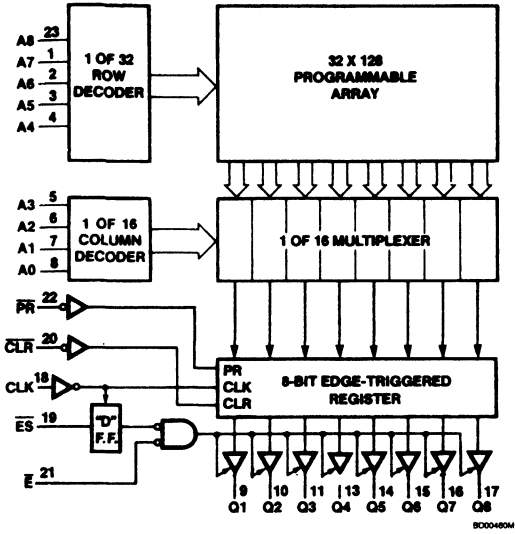
Block Diagrams



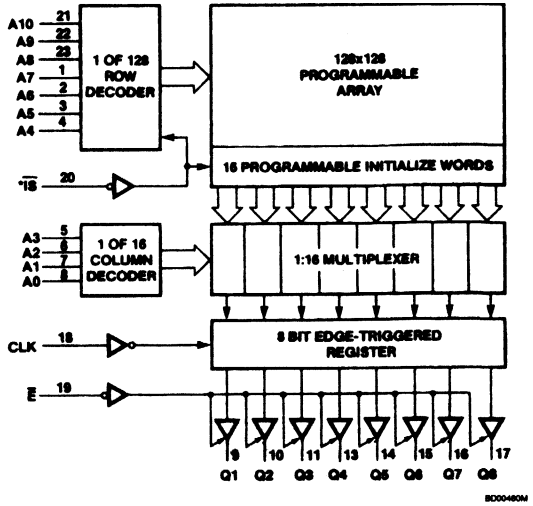
# PLE10R8, 11RA8, 11RS8

## Block Diagrams

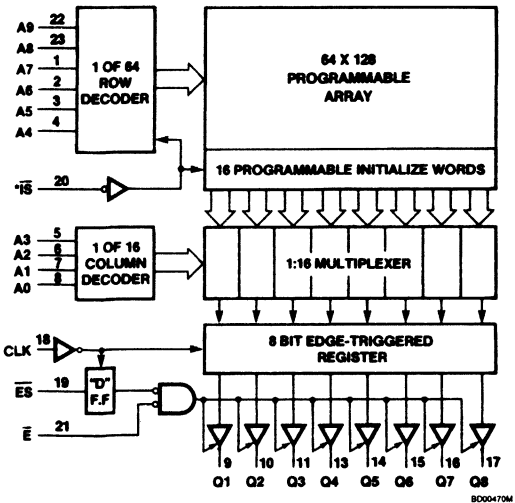
**PLE9R8**



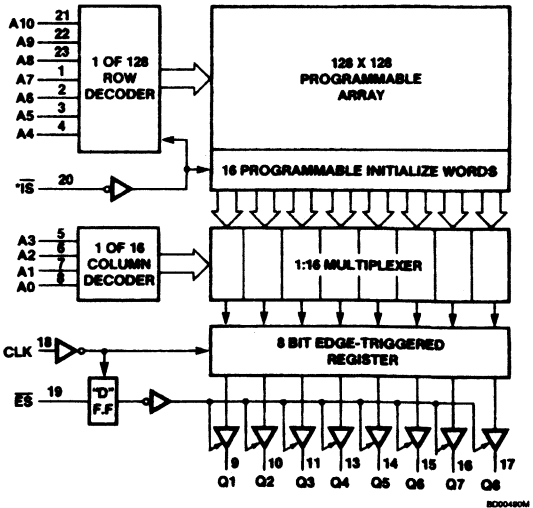
**PLE11RA8**



**PLE10R8**



**PLE11RS8**



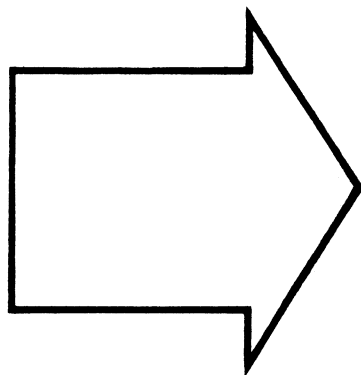
9

**PLE10R8, 11RA8, 11RS8**

**Monolithic Memories PLE Programmer Reference Chart**

|   |  |   |   |   |   |
|---|--|---|---|---|---|
| <b>SOURCE AND LOCATION</b>                        | Data I/O Corp.<br>10525 Willows Rd.<br>N.E.<br>P.O. Box 97046<br>Redmond<br>WA 98073-9746            | Kontron<br>Electronics Inc.<br>1230 Charleston<br>Rd.<br>Mountain View<br>CA 94039-7230 | Stag<br>Microsystems Inc.<br>528-5 Weddell Dr.<br>Sunnyvale<br>CA 94089 | Digelec Inc.<br>1602 Lawrence<br>Ave.<br>Suite 113<br>Ocean<br>NJ 07712 | Varix Corp.<br>1210 E. Campbell<br>Rd.<br>Suite 100<br>Richardson<br>TX 75081 |
| <b>Programmer Model(s)</b>                        | Model 19/29A/29B<br>Model 22   | Model MMP-80S   | Model PPX<br>Model PPZ  | UP803   | OMNI  |
| <b>MMI Generic Bipolar PLE Personality Module</b> | UniPak Rev 10<br>UniPak II Rev 07<br>(Not all PLE devices are supported by earlier UniPak revisions) | MOD16   | Zm 2000   | FAM Mod. No. 12   |   |
| <b>Socket Adapter(s) and Device Code</b>          |  |   |   |   |   |
| <b>PLE5P8/<br/>PLE5P8A</b>                        | F18 P02<br>Model 22A-<br>Adapter 351A-064  | SA3   | AM110-2<br>Code 21  | DA No. 2 Pinout<br>1A<br>Switch Pos. 0-6                                | 63S081  |
| <b>PLE8P4</b>                                     | F18 P01<br>Model 22A-<br>Adapter 351A-064  | SA4-2   | AM130-2<br>Code 21  | DA No. 1 Pinout<br>1B<br>Switch Pos. 0-6                                | 63S141  |
| <b>PLE9P4</b>                                     | F18 P03<br>Model 22A-<br>Adapter 351A-064  | SA4-1   | AM130-3<br>Code 21  | DA No. 1 Pinout<br>1D<br>Switch Pos. 2-14                               | 63S241  |
| <b>PLE8P8</b>                                     | F18 P08<br>Model 22A-<br>Adapter 351A-064  | SA6-1   | Code 21   | †   | 63S281  |
| <b>PLE10P4</b>                                    | F18 P05<br>Model 22A-<br>Adapter 351A-064  | SA4   | AM140-2<br>Code 21  | DA No. 3 Pinout<br>1E<br>Switch Pos. 0-6                                | 63S441  |
| <b>PLE9P8</b>                                     | F18 P08<br>Model 22A-<br>Adapter 351A-064  | SA6   | Code 21   | †   | 63S481  |
| <b>PLE9R8</b>                                     | FEC P65<br>Model 22A-<br>Adapter 351A-074  | SA31-2  | Code 21   | Pinout 1H<br>Switch Pos. 5-14   | 63RA481   |
| <b>PLE11P4</b>                                    | F18 P06<br>Model 22A-<br>Adapter 351A-064  | SA4-4   | AM140-3<br>Code 21  | DA No. 3 Pinout<br>1L<br>Switch 5-14                                    | 63S841  |
| <b>PLE10R8</b>                                    | F18 P86<br>Model 22A-<br>Adapter 351A-074<br>(300 mil pkg)   | †   | Code 21   | DA No. 64†<br>Switch Pos. 0-12  | 63RS881   |
| <b>PLE12P4</b>                                    | F18 P53<br>Model 22A-<br>Adapter 351A-064  | SA20  | AM120-6<br>Code 21  | DA No. 70<br>Switch Pos. 4-12   | 63S1641   |
| <b>PLE11RA8<br/>PLE11RS8</b>                      | F18 PA3  | †   | Code 21   | DA No. 64   | 63RA1681<br>63RS1681  |
| <b>PLE11P8</b>                                    | F18P21   | SA5-4   | AM100-5<br>Code 21  | DA No.7   | 63S1681   |
| <b>PLE12P8</b>                                    | F18P63   | †   | Code 21   | DA No. 64 Pinout<br>47<br>Switch Pos. 0-4                               | 63S3281   |

† Contact manufacturer for availability and programming information.



|   |           |
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## Random Logic Replacement

### Random Logic Replacement

PROMs, as logic elements, have been providing solutions as replacements of random logic. This is the concept of PROM as a Programmable Logic Element (PLE) device.

The usages of PLE devices include simple multiplexer/demultiplexer/encoder/decoder, control signal generators, data communications support like CRC, and arithmetic elements like ALUs, multipliers, sine and inverse look-up tables, and applications in signal processing.

The advantages of PLE devices over SSI/MSI logic devices are the flexibility of design and the fast turnaround time which non-programmable devices cannot offer. For example, if a decoder is used to select between memory pages and I/O ports, once a design is done, it will be fixed — it is not easy to find a part to be put just in the same place without modification of PC board layout in case the designer wants to expand the memory or to increase the I/O. For a PLE device, what is needed is to program another PLE device and place it in the same socket where the old part was placed. In addition, it can allow designers to define their logic functions in a component.

The AND-OR planar structure of the PLE circuit array lends itself naturally to being viewed as a two-level logic circuit. The fixed AND plane contains all possible combinations of the literals of its inputs. Each combination (product term) is fuse-connected to each output in the programmable OR plane.

A common PLE device application in the control path is to customize logic functions. An  $n$  input exclusive OR function is quite commonly required in comparator and adder circuits. It contains  $2^n - 1$  product terms, which becomes quite large for large values of  $n$ . Therefore, it is very convenient to implement large XOR functions in PLE devices.

The PLE logic circuit implementation of a 4-input XOR is shown below.

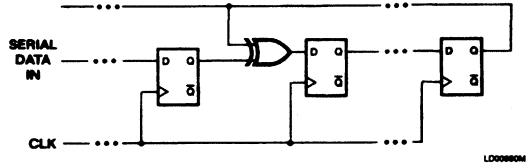
|    |    |    |    |    |    |
|----|----|----|----|----|----|
|    | cd |    |    |    |    |
|    |    | 00 | 01 | 11 | 10 |
| ab | 00 | 0  | 1  | 0  | 1  |
|    | 01 | 1  | 0  | 1  | 0  |
|    | 11 | 0  | 1  | 0  | 1  |
|    | 10 | 1  | 0  | 1  | 0  |

TB01070M

Although it seems that XOR functions may be replaced by SSIs, in most applications, the XOR functions will not be alone by themselves, PLE circuits can provide the flexibility of adding in additional functions without using additional packages.

In the data path, a PLE device can be used to implement complex functions such as a Pseudo Random Number (PRN) Generator. Random number sequences are useful in encoding and decoding of information in signal processing and communications systems. They are used for data encryption, image quantization, waveform synchronization, and white noise generation, etc.

There are many techniques for generating PRN sequences. The most common technique, however, is to use ' $n$ ' stages of linear shift registers with feedback through a logic function. The function  $f$  is an arbitrary function chosen for a specific application. A most general linear function is an ' $m$ ' input XOR ( $m \leq n$ ).



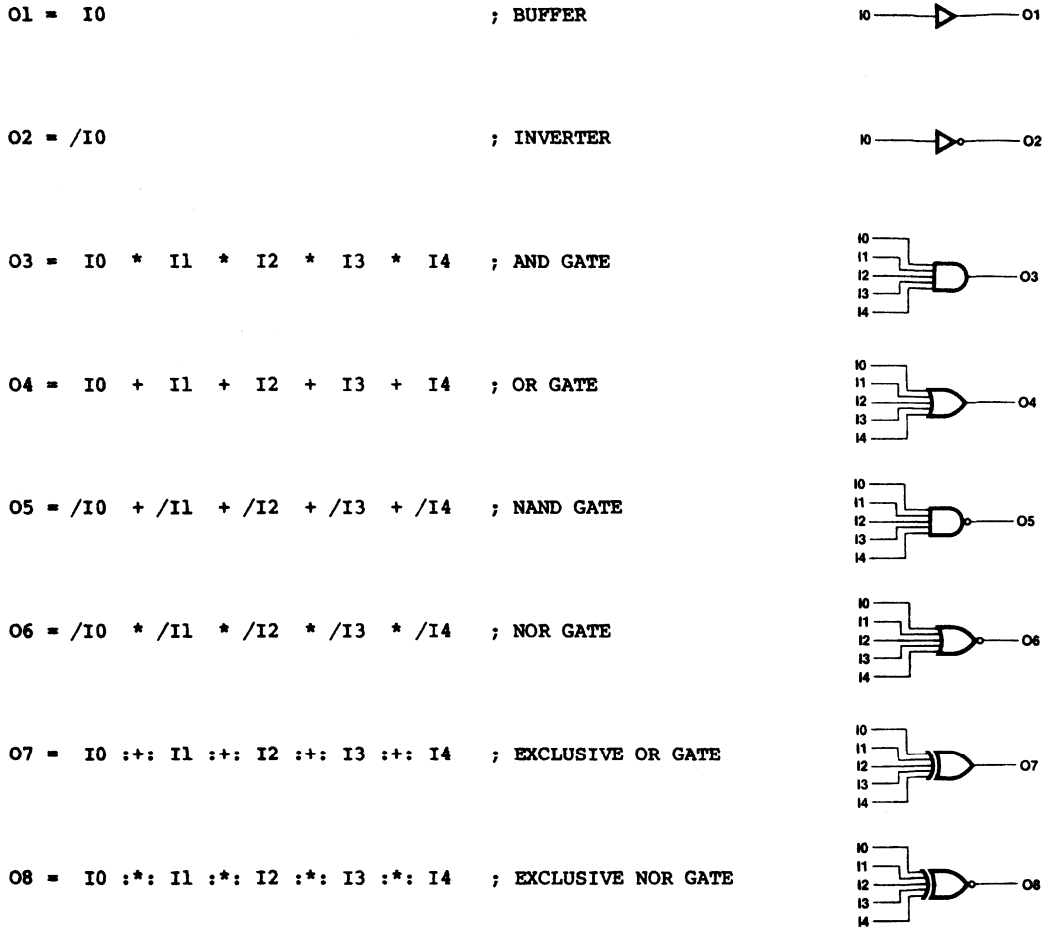
There are a number of examples in the following session which shows how a PLE device can be used to replace SSI/MSI logic devices using PLEASM software.

# Random Logic

PLE5P8  
P5000  
BASIC GATES  
MMI SANTA CLARA, CALIFORNIA  
.ADD I0 I1 I2 I3 I4  
.DAT O1 O2 O3 O4 O5 O6 O7 O8

PLE CIRCUIT DESIGN SPECIFICATION

VINCENT COLI 10/03/83



T8010904

## Random Logic

### FUNCTION TABLE

I0 I1 I2 I3 I4 O1 O2 O3 O4 O5 O6 O7 O8

| ;INPUT |   | - - OUTPUTS FROM BASIC GATES - - |     |     |    |      |     |     |      |                   |
|--------|---|----------------------------------|-----|-----|----|------|-----|-----|------|-------------------|
| ;01234 |   | BUF                              | INV | AND | OR | NAND | NOR | XOR | XNOR | COMMENTS          |
| LLLLL  | L | H                                | L   | L   | H  | H    | L   | L   | L    | ALL ZEROS         |
| HHHHH  | H | L                                | H   | H   | L  | L    | H   | H   | H    | ALL ONES          |
| HLHLH  | H | L                                | L   | H   | H  | L    | H   | H   | H    | ODD CHECKERBOARD  |
| LHLHL  | L | H                                | L   | H   | H  | L    | L   | L   | L    | EVEN CHECKERBOARD |

### DESCRIPTION

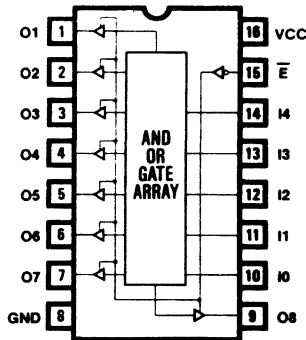
THIS EXAMPLE ILLUSTRATES THE USE OF PLE DEVICES TO IMPLEMENT THE BASIC GATES: BUFFER, INVERTER, AND GATE, OR GATE, NAND GATE, NOR GATE, EXCLUSIVE OR GATE, AND EXCLUSIVE NOR GATE.

NOTE ALSO THAT THREE-STATE OUTPUTS ARE PROVIDED WITH ONE ACTIVE LOW OUTPUT ENABLE CONTROL (/E).

PLEASM SOFTWARE GENERATES THE PROM TRUTH TABLE FROM THE LOGIC EQUATIONS AND SIMULATES THE FUNCTION TABLE IN THE LOGIC EQUATIONS.

### BASIC GATES

#### PLE5P8



TB01060M

10

## Random Logic

PLE8P8  
 P5001  
 MEMORY ADDRESS DECODER  
 MMI SANTA CLARA, CALIFORNIA  
 .ADD A11 A12 A13 A14 A15 /MREQ  
 .DAT /CE1 /CE2 /CE3 /CE4 /CE5 /CE6 /CE7 /CE8

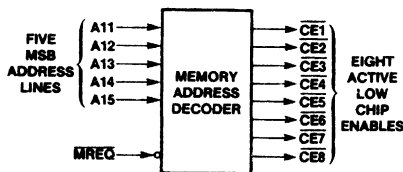
PLE CIRCUIT DESIGN SPECIFICATION  
 ULRIK MUELLER 05/01/84

CE1 = /A11\*/A12\*/A13\*/A14\*/A15\* MREQ ; SELECTS ADDRESS RANGE 0K-2K  
 CE2 = A11\*/A12\*/A13\*/A14\*/A15\* MREQ ; SELECTS ADDRESS RANGE 2K-4K  
 CE3 = /A11\* A12\*/A13\*/A14\*/A15\* MREQ ; SELECTS ADDRESS RANGE 4K-6K  
 CE4 = A11\* A12\*/A13\*/A14\*/A15\* MREQ ; SELECTS ADDRESS RANGE 6K-8K  
 CE5 = /A11\*/A12\* A13\*/A14\*/A15\* MREQ ; SELECTS ADDRESS RANGE 8K-10K  
 CE6 = A11\*/A12\* A13\*/A14\*/A15\* MREQ ; SELECTS ADDRESS RANGE 10K-12K  
 CE7 = /A11\* A12\* A13\*/A14\*/A15\* MREQ ; SELECTS ADDRESS RANGE 12K-14K  
 CE8 = A11\* A12\* A13\*/A14\*/A15\* MREQ ; SELECTS ADDRESS RANGE 14K-16K

### FUNCTION TABLE

A11 A12 A13 A14 A15 /MREQ /CE1 /CE2 /CE3 /CE4 /CE5 /CE6 /CE7 /CE8

| ; ADD LINES |       | CHIP ENABLES |          | COMMENTS                     |
|-------------|-------|--------------|----------|------------------------------|
| ;           | 11111 | 12345        | 12345678 |                              |
|             |       | /MREQ        |          |                              |
| LLLL        | L     |              | LHHHHHHH | SELECT ADDRESS RANGE 0-2K    |
| HLLL        | L     |              | HLHHHHHH | SELECT ADDRESS RANGE 2K-4K   |
| LHLL        | L     |              | HHLHHHHH | SELECT ADDRESS RANGE 4K-6K   |
| HHLL        | L     |              | HHHLHHHH | SELECT ADDRESS RANGE 6K-8K   |
| LLHL        | L     |              | HHHHLHHH | SELECT ADDRESS RANGE 8K-10K  |
| HLHL        | L     |              | HHHHHLHH | SELECT ADDRESS RANGE 10K-12K |
| LHHL        | L     |              | HHHHHLHL | SELECT ADDRESS RANGE 12K-14K |
| HHHL        | L     |              | HHHHHHLH | SELECT ADDRESS RANGE 14K-16K |
| XXXX        | H     |              | HHHHHHHH | NO MEMORY SELECT (/MREQ=H)   |



TB01100M

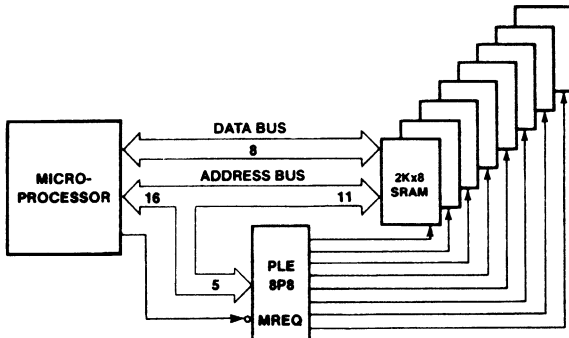
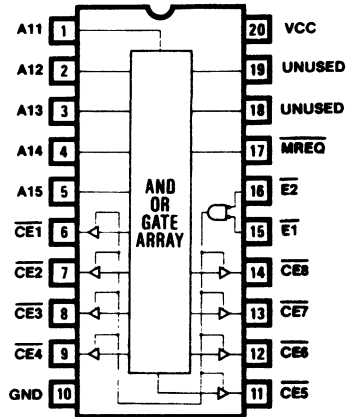
## Random Logic

### DESCRIPTION

THIS PLE8P8 PROVIDES A SINGLE CHIP ADDRESS DECODER FOR USE WITH MANY POPULAR 8-BIT MICROPROCESSORS SUCH AS THE Z80 AND 8080. THE FIVE MSB ADDRESS LINES (A11-A15) AND THE MEMORY REQUEST LINE (/MREQ) FROM THE Z80 MICROPROCESSOR ARE DECODED TO PRODUCE EIGHT ACTIVE LOW CHIP ENABLES (/CE1-/CE8) TO SELECT A RANGE OF 2K BYTES FROM A BANK OF EIGHT 2Kx8 STATIC RAMS. THIS BANK OF STATIC RAMS WILL OCCUPY THE LOWEST 16K BYTES OF ADDRESS SPACE LEAVING THE UPPER 48K BYTE SPACE AVAILABLE FOR OTHER MEMORIES AND I/O. THE PLE8P8 HAS THREE ADDITIONAL INPUTS WHICH CAN BE RESERVED FOR FUTURE SYSTEM EXPANSION.

| CHIP ENABLE | ADDRESS MAP |
|-------------|-------------|
| CE1         | 0K          |
| CE2         | 2K          |
| CE3         | 4K          |
| CE4         | 6K          |
| CE5         | 8K          |
| CE6         | 10K         |
| CE7         | 12K         |
| CE8         | 14K         |
|             | 16K         |

**MEMORY ADDRESS  
DECODER  
PLE8P8**



TB01110M

**10**

## Random Logic

PLE8P4

PLE CIRCUIT DESIGN SPECIFICATION

P5029

VINCENT COLI 10/13/84

6809 ADDRESS DECODER

MMI SANTA CLARA, CALIFORNIA

.ADD A8 A9 A10 A11 A12 A13 A14 A15

.DAT /DRAM /IO /SRAM /PROM

```

DRAM = /A8*           A12* A13*/A14* A15 ; SELECTS ADDRESS RANGE 0000-BEFF
+       /A9*           A12* A13*/A14* A15
+         /A10*        A12* A13*/A14* A15
+           /A11* A12* A13*/A14* A15
+             /A12*    /A14
+               /A13*/A14
+                 /A15

IO    = A8* A9* A10* A11* A12* A13*/A14* A15 ; SELECTS ADDRESS RANGE BF00-BFFF

SRAM  =                               /A13* A14* A15 ; SELECTS ADDRESS RANGE C000-DFFF

PROM  =                               A13* A14* A15 ; SELECTS ADDRESS RANGE E000-FFFF
    
```

### FUNCTION TABLE

A8 A9 A10 A11 A12 A13 A14 A15 /DRAM /IO /SRAM /PROM

; ADDRESS LINES

; 11 1111

; 8901 2345 /DRAM /IO /SRAM /PROM COMMENTS

|      |      | /DRAM | /IO | /SRAM | /PROM | COMMENTS                   |
|------|------|-------|-----|-------|-------|----------------------------|
| LLLL | LLLL | L     | H   | H     | H     | 00XX HEX SELECTS DRAMS     |
| LLLL | HHLH | L     | H   | H     | H     | B0XX HEX SELECTS DRAMS     |
| HHHH | HHLH | H     | L   | H     | H     | BFXX HEX SELECTS I/O PORTS |
| LLLL | LLHH | H     | H   | L     | H     | C0XX HEX SELECTS SRAM      |
| LLLL | HLHH | H     | H   | L     | H     | D0XX HEX SELECTS SRAM      |
| LLLL | LHHH | H     | H   | H     | L     | E0XX HEX SELECTS PROM      |
| HHHH | HHHH | H     | H   | H     | L     | FFXX HEX SELECTS PROM      |

### DESCRIPTION

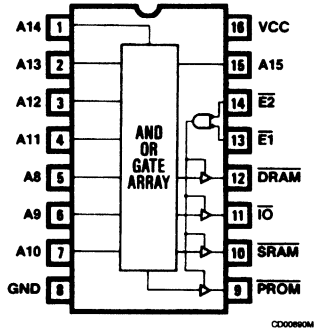
THIS PLE8P4 PROVIDES A SINGLE CHIP ADDRESS DECODER FOR USE WITH MANY POPULAR 8-BIT MICROPROCESSORS SUCH AS THE MOTOROLA 6809. THIS PLE DEVICE DECODES THE EIGHT MSB ADDRESS LINES (A8-A15) FROM THE MICROPROCESSOR TO PROVIDE FOUR ACTIVE LOW CHIP ENABLES (/DRAM, /IO, /SRAM, AND /PROM).

THE 64K MEMORY MAP OF THE SYSTEM IS DIVIDED UP INTO FOUR SECTIONS: DRAM, IO PORTS, SRAM, AND PROM. EACH OF THESE FOUR SECTIONS CAN CONTAIN ONE OR MORE BLOCKS OF MEMORY. EACH OF THESE BLOCKS CAN START AND STOP ON ANY 256 BIT BOUNDARY

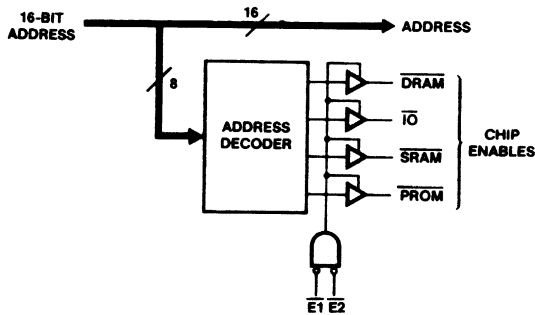
T801120M

## Random Logic

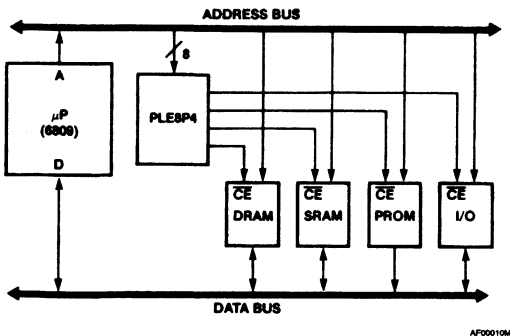
**6809 Address Decoder  
PLE8P4**



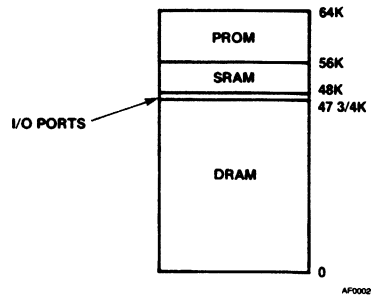
### Block Diagram



### System Diagram



### Memory Map



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## Random Logic

PLE8P8

PLE CIRCUIT DESIGN SPECIFICATION

P5002

JOEL ROSENBERG 10/26/83

6-BIT TRUE/COMPLEMENT AND CLEAR/SET LOGIC FUNCTIONS

MMI SANTA CLARA, CALIFORNIA

.ADD I1 I2 D1 D2 D3 D4 D5 D6

.DAT Y1 Y2 Y3 Y4 Y5 Y6

```

Y1 = /I1*/I2*/D1      ; OUTPUT /D1 (INVERT)
    + /I1* I2* D1     ; OUTPUT D1 (TRUE)
    + I1*/I2          ; CLEAR Y1

Y2 = /I1*/I2*/D2      ; OUTPUT /D2 (INVERT)
    + /I1* I2* D2     ; OUTPUT D2 (TRUE)
    + I1*/I2          ; CLEAR Y2

Y3 = /I1*/I2*/D3      ; OUTPUT /D3 (INVERT)
    + /I1* I2* D3     ; OUTPUT D3 (TRUE)
    + I1*/I2          ; CLEAR Y3

Y4 = /I1*/I2*/D4      ; OUTPUT /D4 (INVERT)
    + /I1* I2* D4     ; OUTPUT D4 (TRUE)
    + I1*/I2          ; CLEAR Y4

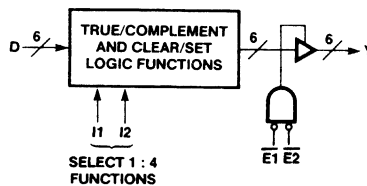
Y5 = /I1*/I2*/D5      ; OUTPUT /D5 (INVERT)
    + /I1* I2* D5     ; OUTPUT D5 (TRUE)
    + I1*/I2          ; CLEAR Y5

Y6 = /I1*/I2*/D6      ; OUTPUT /D6 (INVERT)
    + /I1* I2* D6     ; OUTPUT D6 (TRUE)
    + I1*/I2          ; CLEAR Y6
    
```

### FUNCTION TABLE

I1 I2 D1 D2 D3 D4 D5 D6 Y1 Y2 Y3 Y4 Y5 Y6

| CONTROL | INPUT D | OUTPUT Y | COMMENTS        |
|---------|---------|----------|-----------------|
| ; LINES | 123456  | 123456   |                 |
| LL      | LHLHLH  | HLHLHL   | INVERT FUNCTION |
| LH      | LHLHLH  | LHLHLH   | TRUE FUNCTION   |
| HL      | XXXXXX  | HHHHHH   | CLEAR FUNCTION  |
| HH      | XXXXXX  | LLLLLL   | SET FUNCTION    |



T801130M



## Random Logic

### DESCRIPTION

THIS PLE8P8 IS A 6-BIT TRUE/COMPLEMENT AND CLEAR/SET LOGIC FUNCTIONS. THE CONTROL LINES (I1 AND I2) SELECT ONE OF FOUR LOGIC FUNCTIONS FOR THE 6-BIT INPUT DATA (D1-D6) AND THE 6-BIT OUTPUT FUNCTION (Y1-Y6).

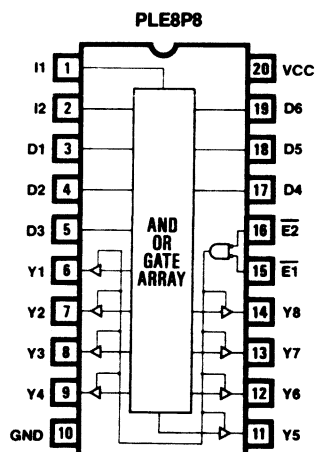
WHEN I1 IS FALSE (I1=LOW) THE FUNCTION IS INVERT IF I2 IS FALSE (I2=LOW) OR TRUE IF I2 IS TRUE (I2=HIGH).

WHEN I1 IS TRUE (I1=HIGH) THE FUNCTION IS CLEAR IF I2 IS FALSE (I2=LOW) OR SET IF I2 IS TRUE (I2=HIGH).

THE PLE8P8 ALSO FEATURES THREE-STATE OUTPUTS WITH TWO ACTIVE LOW OUTPUT ENABLE CONTROLS (/E1 AND /E2).

| I1 | I2 | D1-D6 | Y1-Y6 | FUNCTION |
|----|----|-------|-------|----------|
| L  | L  | D     | /D    | INVERT   |
| L  | H  | D     | D     | TRUE     |
| H  | L  | X     | H     | CLEAR    |
| H  | H  | X     | L     | SET      |

### 6-BIT TRUE/COMPLEMENT ZERO/ONE LOGIC FUNCTIONS



TB01140M

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## Random Logic

PLE5P8

P5003

EXPANDABLE 3-TO-8 DEMULTIPLEXER

MMI SANTA CLARA, CALIFORNIA

.ADD S0 S1 S2 DI PO

.DAT Y0 Y1 Y2 Y3 Y4 Y5 Y6 Y7

PLE CIRCUIT DESIGN SPECIFICATION

FRANK LEE 04/15/84

```
Y0 = PO * DI * /S2 * /S1 * /S0      ; ACTIVE HIGH, SELECT 0
    + /PO * DI                       ; ACTIVE LOW, DI INACTIVE
    + /PO * S2                        ; ACTIVE LOW, SELECT 4-7
    + /PO * S1                        ; ACTIVE LOW, SELECT 2,3,6,7
    + /PO * S0                        ; ACTIVE LOW, SELECT 1,3,5,7

Y1 = PO * DI * /S2 * /S1 * S0      ; ACTIVE HIGH, SELECT 1
    + /PO * DI                       ; ACTIVE LOW, DI INACTIVE
    + /PO * S2                        ; ACTIVE LOW, SELECT 4,5,6,7
    + /PO * S1                        ; ACTIVE LOW, SELECT 2,3,6,7
    + /PO * /S0                       ; ACTIVE LOW, SELECT 0,2,4,6

Y2 = PO * DI * /S2 * S1 * /S0     ; ACTIVE HIGH, SELECT 2
    + /PO * DI                       ; ACTIVE LOW, DI INACTIVE
    + /PO * S2                        ; ACTIVE LOW, SELECT 4-7
    + /PO * /S1                       ; ACTIVE LOW, SELECT 0,1,4,5
    + /PO * S0                        ; ACTIVE LOW, SELECT 1,3,5,7

Y3 = PO * DI * /S2 * S1 * S0     ; ACTIVE HIGH, SELECT 3
    + /PO * DI                       ; ACTIVE LOW, DI INACTIVE
    + /PO * S2                        ; ACTIVE LOW, SELECT 4-7
    + /PO * /S1                       ; ACTIVE LOW, SELECT 0,1,4,5
    + /PO * /S0                       ; ACTIVE LOW, SELECT 0,2,4,6

Y4 = PO * DI * S2 * /S1 * /S0     ; ACTIVE HIGH, SELECT 4
    + /PO * DI                       ; ACTIVE LOW, DI INACTIVE
    + /PO * /S2                       ; ACTIVE LOW, SELECT 0-3
    + /PO * S1                        ; ACTIVE LOW, SELECT 2,3,6,7
    + /PO * S0                        ; ACTIVE LOW, SELECT 1,3,5,7

Y5 = PO * DI * S2 * /S1 * S0     ; ACTIVE HIGH, SELECT 5
    + /PO * DI                       ; ACTIVE LOW, DI INACTIVE
    + /PO * /S2                       ; ACTIVE LOW, SELECT 0-3
    + /PO * S1                        ; ACTIVE LOW, SELECT 2,3,6,7
    + /PO * /S0                       ; ACTIVE LOW, SELECT 0,2,4,6

Y6 = PO * DI * S2 * S1 * /S0     ; ACTIVE HIGH, SELECT 6
    + /PO * DI                       ; ACTIVE LOW, DI INACTIVE
    + /PO * /S2                       ; ACTIVE LOW, SELECT 0-3
    + /PO * /S1                       ; ACTIVE LOW, SELECT 0,1,4,5
    + /PO * S0                        ; ACTIVE LOW, SELECT 1,3,5,7

Y7 = PO * DI * S2 * S1 * S0     ; ACTIVE HIGH, SELECT 7
    + /PO * DI                       ; ACTIVE LOW, DI INACTIVE
    + /PO * /S2                       ; ACTIVE LOW, SELECT 0-3
    + /PO * /S1                       ; ACTIVE LOW, SELECT 0,1,4,5
    + /PO * /S0                       ; ACTIVE LOW, SELECT 0,2,4,6
```

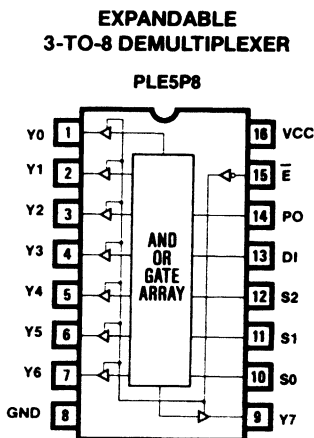
TB01150M

## Random Logic

### FUNCTION TABLE

PO DI S2 S1 S0 Y7 Y6 Y5 Y4 Y3 Y2 Y1 Y0

| ;          |   | SSS      | YYYYYYYY |                 |
|------------|---|----------|----------|-----------------|
| ;PO DI 210 |   | 76543210 |          | COMMENTS        |
| -----      |   |          |          |                 |
| H          | L | XXX      | LLLLLLLL | DATA INPUT = 0  |
| H          | H | LLL      | LLLLLLLH | SELECT OUTPUT 0 |
| H          | H | LLH      | LLLLLLHL | SELECT OUTPUT 1 |
| H          | H | LHL      | LLLLLHLL | SELECT OUTPUT 2 |
| H          | H | LHH      | LLLLHLLL | SELECT OUTPUT 3 |
| H          | H | HLL      | LLLHLLLL | SELECT OUTPUT 4 |
| H          | H | HLH      | LLHLLLLL | SELECT OUTPUT 5 |
| H          | H | HHL      | LHLLLLLL | SELECT OUTPUT 6 |
| H          | H | HHH      | HLLLLLLL | SELECT OUTPUT 7 |
| L          | H | XXX      | HHHHHHHH | DATA INPUT = 0  |
| L          | L | LLL      | HHHHHHHL | SELECT OUTPUT 0 |
| L          | L | LLH      | HHHHHHLH | SELECT OUTPUT 1 |
| L          | L | LHL      | HHHHHLHH | SELECT OUTPUT 2 |
| L          | L | LHH      | HHHHLHHH | SELECT OUTPUT 3 |
| L          | L | HLL      | HHHLHHHH | SELECT OUTPUT 4 |
| L          | L | HLH      | HHLHHHHH | SELECT OUTPUT 5 |
| L          | L | HHL      | HLHHHHHH | SELECT OUTPUT 6 |
| L          | L | HHH      | LHHHHHHH | SELECT OUTPUT 7 |



### DESCRIPTION

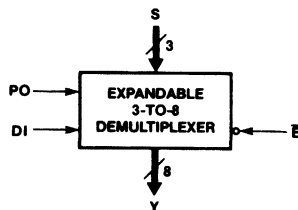
THIS PLE5P8 IMPLEMENTS AN EXPANDABLE 3-TO-8 DEMULTIPLEXER. THE DEVICE DEMULTIPLEXES THREE SELECT INPUT SIGNALS (S2-S0) INTO EIGHT OUTPUTS (Y7-Y0) USING THE INPUT DI WITH POLARITY SELECT PO. SINCE THE DEVICE HAS THREE-STATE OUTPUTS, IT CAN BE EXPANDED USING THE ACTIVE LOW ENABLE PIN (/E).

### PIN ASSIGNMENTS:

1. PO HIGH INDICATES OUTPUT IS ACTIVE HIGH. LOW INDICATES OUTPUT IS ACTIVE LOW.
2. DI DATA INPUT (DEMULTIPLEXING INPUT). ACTIVE LOW IF PO IS LOW.
3. S2-S0 SELECT PINS. S2 IS THE MOST SIGNIFICANT BIT. ACTIVE HIGH REGARDLESS OF PO.
4. Y7-Y0 OUTPUTS. CAN BE ACTIVE HIGH OR ACTIVE LOW DEPENDING ON PO. ACTIVE LOW IF PO IS LOW.

### OPERATIONS TABLE:

| PO | DI | S2-S0 | Y7-Y0  | OPERATION         |
|----|----|-------|--------|-------------------|
| L  | H  | X     | H      | OUTPUTS HIGH      |
| H  | H  | S     | DEMUX  | DEMUX ACTIVE HIGH |
| L  | L  | S     | /DEMUX | DEMUX ACTIVE LOW  |
| H  | L  | X     | L      | OUTPUTS LOW       |



TB01190M

## Random Logic

**PLE10P4**  
**P5004**

PLE CIRCUIT DESIGN SPECIFICATION  
ULRIK MUELLER 04/01/83

**DUAL 2:1 MULTIPLEXER**

MMI SANTA CLARA, CALIFORNIA

.ADD SX SY A1 B1 C1 D1 A2 B2 C2 D2

.DAT X1 Y1 X2 Y2

X1 = /SX\* A1 ; SELECT INPUT A1  
+ SX\* B1 ; SELECT INPUT B1

Y1 = /SY\* C1 ; SELECT INPUT C1  
+ SY\* D1 ; SELECT INPUT D1

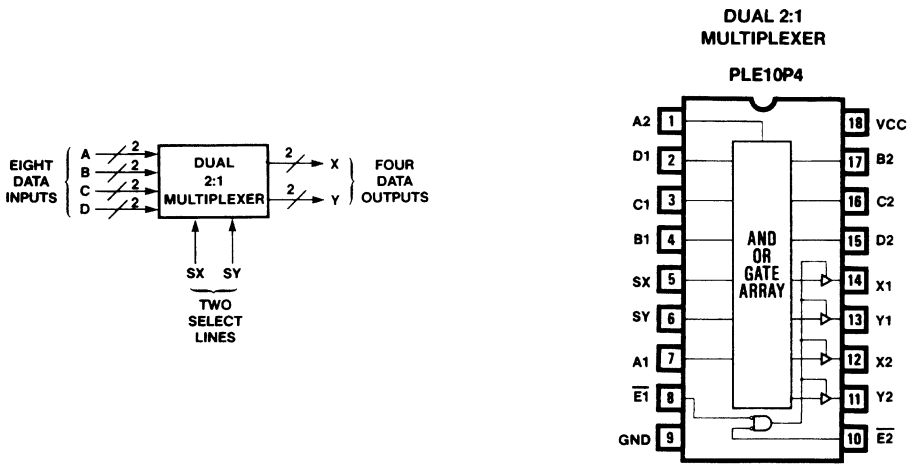
X2 = /SX\* A2 ; SELECT INPUT A2  
+ SX\* B2 ; SELECT INPUT B2

Y2 = /SY\* C2 ; SELECT INPUT C2  
+ SY\* D2 ; SELECT INPUT D2

**DESCRIPTION**

THIS IS AN EXAMPLE OF TWO INDEPENDENT 2-TO-1 MULTIPLEXERS USING A PLE10P4. THE DEVICE WILL SWITCH BETWEEN TWO PAIRS OF 2-BIT INPUTS (A, B AND C, D), AS DETERMINED BY THE TWO SELECT LINES (SX, SY), FOR OUTPUT THROUGH TWO PAIRS OF 2-BIT OUTPUTS (X AND Y). THREE-STATE OUTPUTS ARE ALSO PROVIDED WITH TWO ACTIVE LOW ENABLE PINS (/E1 AND /E2). THE FUNCTIONS OF THE DEVICE ARE SUMMARIZED IN THE TABLE BELOW:

| SELECT LINES |   | INPUT A, B |    |    |    | INPUT C, D |    |    |    | OUTPUT X, Y |    |    |    | FUNCTION |             |
|--------------|---|------------|----|----|----|------------|----|----|----|-------------|----|----|----|----------|-------------|
| S            | S | A          | A  | B  | B  | C          | C  | D  | D  | X           | Y  | X  | Y  |          |             |
| X            | Y | 1          | 2  | 1  | 2  | 1          | 2  | 1  | 2  | !           | 1  | 1  | 2  | 2        |             |
| L            | L | A1         | A2 | X  | X  | C1         | C2 | X  | X  | !           | A1 | C1 | A2 | C2       | SELECT A, C |
| L            | H | A1         | A2 | X  | X  | X          | X  | D1 | D2 | !           | A1 | D1 | A2 | D2       | SELECT A, D |
| H            | L | X          | X  | B1 | B2 | C1         | C2 | X  | X  | !           | B1 | B2 | C1 | C2       | SELECT B, C |
| H            | H | X          | X  | B1 | B2 | X          | X  | D1 | D2 | !           | B1 | D1 | B2 | D2       | SELECT B, D |



TB01170M

## Random Logic

```

PLE10P4                PLE CIRCUIT DESIGN SPECIFICATION
P5005                  S. HORIKO 04/29/84
QUAD 2:1 MULTIPLEXER WITH POLARITY CONTROL
MMI JAPAN
.ADD SEL POL A0 A1 A2 A3 B0 B1 B2 B3
.DAT Y0 Y1 Y2 Y3
    
```

```

Y0 = /SEL*/POL*/A0      ; SELECT INPUT /A0 (COMP)
    + /SEL* POL* A0     ; SELECT INPUT A0 (TRUE)
    + SEL*/POL*/B0     ; SELECT INPUT /B0 (COMP)
    + SEL* POL* B0     ; SELECT INPUT B0 (TRUE)

Y1 = /SEL*/POL*/A1      ; SELECT INPUT /A1 (COMP)
    + /SEL* POL* A1     ; SELECT INPUT A1 (TRUE)
    + SEL*/POL*/B1     ; SELECT INPUT /B1 (COMP)
    + SEL* POL* B1     ; SELECT INPUT B1 (TRUE)

Y2 = /SEL*/POL*/A2      ; SELECT INPUT /A2 (COMP)
    + /SEL* POL* A2     ; SELECT INPUT A2 (TRUE)
    + SEL*/POL*/B2     ; SELECT INPUT /B2 (COMP)
    + SEL* POL* B2     ; SELECT INPUT B2 (TRUE)

Y3 = /SEL*/POL*/A3      ; SELECT INPUT /A3 (COMP)
    + /SEL* POL* A3     ; SELECT INPUT A3 (TRUE)
    + SEL*/POL*/B3     ; SELECT INPUT /B3 (COMP)
    + SEL* POL* B3     ; SELECT INPUT B3 (TRUE)
    
```

### FUNCTION TABLE

SEL POL A0 A1 A2 A3 B0 B1 B2 B3 Y0 Y1 Y2 Y3

| ; SELECT |     | AAAA | BBBB | YYYY | COMMENTS                |
|----------|-----|------|------|------|-------------------------|
| ;SEL     | POL | 0123 | 0123 | 0123 |                         |
| L        | L   | LLLL | XXXX | HHHH | SELECT COMP INPUT /A=00 |
| L        | L   | LHLH | XXXX | HLHL | SELECT COMP INPUT /A=05 |
| L        | L   | HLHL | XXXX | LHLH | SELECT COMP INPUT /A=10 |
| L        | L   | HHHH | XXXX | LLLL | SELECT COMP INPUT /A=15 |
| L        | H   | LLLL | XXXX | LLLL | SELECT TRUE INPUT A=00  |
| L        | H   | LHLH | XXXX | LHLH | SELECT TRUE INPUT A=05  |
| L        | H   | HLHL | XXXX | HLHL | SELECT TRUE INPUT A=10  |
| L        | H   | HHHH | XXXX | HHHH | SELECT TRUE INPUT A=15  |
| H        | L   | XXXX | LLLL | HHHH | SELECT COMP INPUT /B=00 |
| H        | L   | XXXX | LHLH | HLHL | SELECT COMP INPUT /B=05 |
| H        | L   | XXXX | HLHL | LHLH | SELECT COMP INPUT /B=10 |
| H        | L   | XXXX | HHHH | LLLL | SELECT COMP INPUT /B=15 |
| H        | H   | XXXX | LLLL | LLLL | SELECT TRUE INPUT B=00  |
| H        | H   | XXXX | HLHL | HLHL | SELECT TRUE INPUT B=05  |
| H        | H   | XXXX | LHLH | LHLH | SELECT TRUE INPUT B=10  |
| H        | H   | XXXX | HHHH | HHHH | SELECT TRUE INPUT B=15  |

T801190M

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## Random Logic

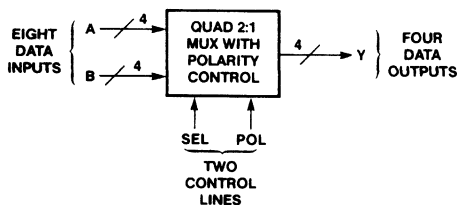
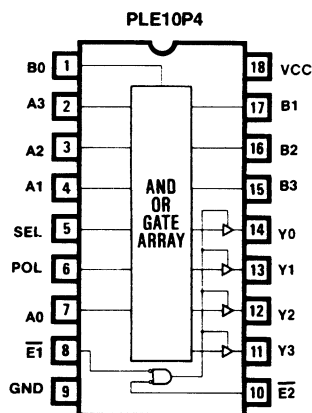
### DESCRIPTION

THIS IS AN EXAMPLE OF A QUAD 2:1 MULTIPLEXER WITH POLARITY CONTROL IMPLEMENTED IN A PLE10P4. THE DEVICE SELECTS BETWEEN TWO 4-BIT INPUTS (A1-A4 AND B1-B4) WHICH ARE DIRECTED TO ONE 4-BIT OUTPUT (Y1-Y4) AS DETERMINED BY ONE INPUT SELECT LINE (SEL) AND POLARITY CONTROL (POL). WHEN POLARITY IS TRUE (POL=HIGH), THE TRUE OF THE INPUT SIGNAL IS SELECTED. WHEN POLARITY IS FALSE (POL=LOW), THE COMPLEMENT OF THE INPUT SIGNAL IS SELECTED.

THE PLE10P4 ALSO FEATURES THREE-STATE OUTPUTS WITH TWO ACTIVE LOW ENABLE PINS (/E1 AND /E2). THE FUNCTION IS SUMMARIZED BELOW:

| SEL | POL | A1-A4 | B1-B4 | Y1-Y4 |
|-----|-----|-------|-------|-------|
| L   | H   | A     | X     | A     |
| L   | L   | A     | X     | /A    |
| H   | H   | X     | B     | B     |
| H   | L   | X     | B     | /B    |

### QUAD 2:1 MULTIPLEXER WITH POLARITY CONTROL



7901190M

## Random Logic

PLE5P8  
P5006  
HEXADECIMAL TO SEVEN SEGMENT DECODER  
MMI SANTA CLARA, CALIFORNIA  
.ADD A B C D LT  
.DAT /OA /OB /OC /OD /OE /OF /OG /DP

PLE CIRCUIT DESIGN SPECIFICATION  
ULRIK MUELLER 04/29/84

OA = B\* /D ; SEGMENT A  
+ B\* C  
+ /A\* /C\*/D  
+ A\* C\*/D  
+ /A\* D  
+ /B\*/C\* D  
+ LT ; IF LT=H MAKE BLANK TEST ON SEGMENT A

OB = /C\*/D ; SEGMENT B  
+ A\* B\* /D  
+ /A\*/B\* /D  
+ A\*/B\* D  
+ /A\* /C  
+ LT ; IF LT=H MAKE BLANK TEST ON SEGMENT B

OC = /C\* D ; SEGMENT C  
+ A\*/B  
+ C\*/D  
+ A\* /D  
+ /B\* /D  
+ LT ; IF LT=H MAKE BLANK TEST ON SEGMENT C

OD = /A\*/B\*/C ; SEGMENT D  
+ /B\* D  
+ A\*/B\* C  
+ A\* B\*/C  
+ /A\* B\* C  
+ /A\* B\* /D  
+ LT ; IF LT=H MAKE BLANK TEST ON SEGMENT D

OE = /A\* /C ; SEGMENT E  
+ C\* D  
+ /A\* B  
+ A\* B\* D  
+ LT ; IF LT=H MAKE BLANK TEST ON SEGMENT E

OF = /A\*/B ; SEGMENT F  
+ /B\* C\*/D  
+ /C\* D  
+ B\* D  
+ /A\* B\* C  
+ LT ; IF LT=H MAKE BLANK TEST ON SEGMENT F

OG = B\*/C ; SEGMENT G  
+ /A\* B  
+ /C\* D  
+ A\* D  
+ /B\* C\*/D  
+ LT ; IF LT=H MAKE BLANK TEST ON SEGMENT G

DP = LT ; TURNS DP ON ONLY WHEN LT=H

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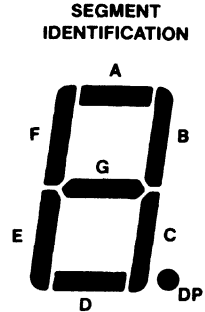
T801200M

## Random Logic

### DESCRIPTION

THIS EXAMPLE ILLUSTRATES THE USE OF A PLE5P8 AS A HEXADECIMAL TO SEVEN SEGMENT DECODER. THE DEVICE DECODES A 4-BIT BINARY INPUT (D,C,B,A) INTO THE SEVEN SEGMENT OUTPUTS NEEDED TO DRIVE AN LED DISPLAY. NOTE THAT THIS DESIGN IS AN IMPROVEMENT FROM THE 74LS47 SINCE ALL 16 HEXADECIMAL DIGITS (0-F) CAN BE DISPLAYED. A LAMP TEST IS PROVIDED TO ILLUMINATE ALL SEVEN SEGMENTS AND THE DECIMAL POINT (IF DP IS CONNECTED) BY BRINGING LAMP TEST HIGH (LT=HIGH) REGARDLESS OF THE OTHER BINARY INPUTS. THREE-STATE OUTPUTS ARE ALSO PROVIDED WITH ONE ACTIVE LOW ENABLE PIN (/E).

| INPUT DIGIT | LT | INPUT D | INPUT C | INPUT B | INPUT A | SEGMENT ON | OUTPUT DISPLAY |
|-------------|----|---------|---------|---------|---------|------------|----------------|
| 0           | L  | L       | L       | L       | L       | ABCDEF     | 0              |
| 1           | L  | L       | L       | L       | H       | BC         | 1              |
| 2           | L  | L       | L       | H       | L       | ABDEG      | 2              |
| 3           | L  | L       | L       | H       | H       | ABCDG      | 3              |
| 4           | L  | L       | H       | L       | L       | BCDFG      | 4              |
| 5           | L  | L       | H       | L       | H       | ACDFG      | 5              |
| 6           | L  | L       | H       | H       | L       | ACDEFG     | 6              |
| 7           | L  | L       | H       | H       | H       | ABC        | 7              |
| 8           | L  | H       | L       | L       | L       | ABCDEFG    | 8              |
| 9           | L  | H       | L       | L       | H       | ABCFG      | 9              |
| A           | L  | H       | L       | H       | L       | ABCEFG     | A              |
| B           | L  | H       | L       | H       | H       | CDEFG      | b              |
| C           | L  | H       | H       | L       | L       | ADEF       | C              |
| D           | L  | H       | H       | L       | H       | BCDEG      | d              |
| E           | L  | H       | H       | H       | L       | ADEFG      | E              |
| F           | L  | H       | H       | H       | H       | AEFG       | F              |
| X           | H  | X       | X       | X       | X       | ABCDEFG    | 8 *            |

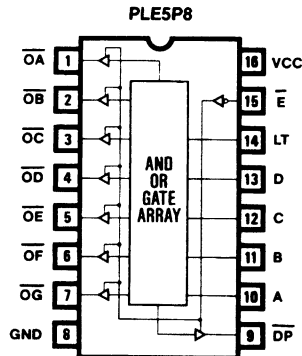


CHARACTER SET



\* BLANK TEST OF DISPLAY

### HEXADECIMAL TO SEVEN-SEGMENT DECODER

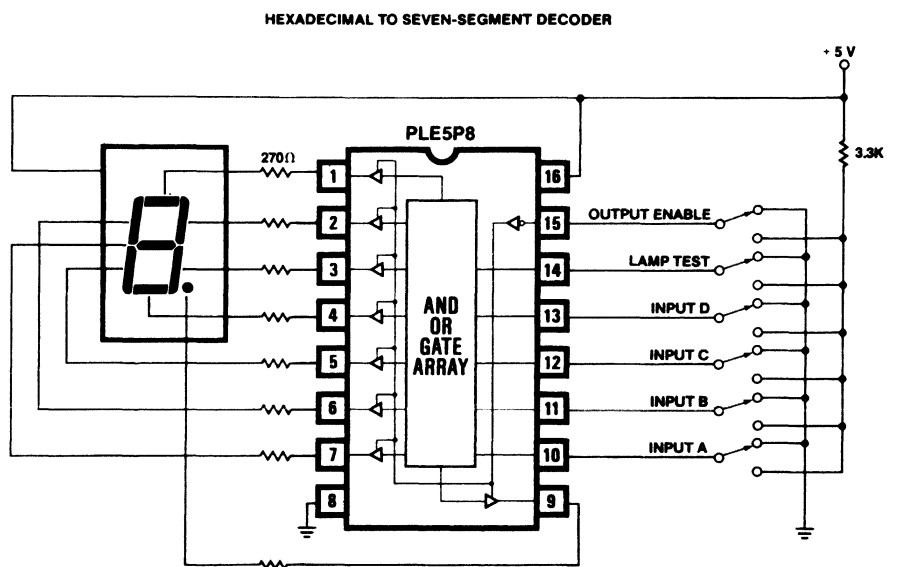


TB01210M



## Random Logic

### HEXADECIMAL TO SEVEN-SEGMENT DECODER (cont'd)



T00010M

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## Random Logic

PLE5P8  
P5007

PLE CIRCUIT DESIGN SPECIFICATION  
VINCENT COLI 02/03/82

5-BIT BINARY TO BCD CONVERTER

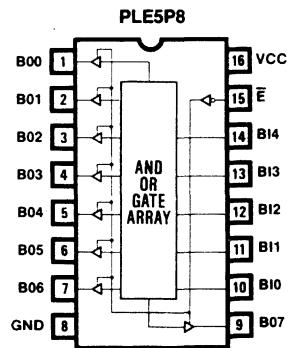
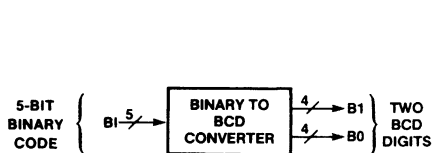
MMI SANTA CLARA, CALIFORNIA

.ADD BI0 BI1 BI2 BI3 BI4

.DAT B00 B01 B02 B03 B10 B11 B12 B13

|  |   |
|--|---|
| $B00 = BI0$  | ; CONVERT FIRST BIT OF 0 DECIMAL (LSB)  |
| $B01 = \begin{aligned} &/BI4*/BI3* \quad BI1 \\ &+ /BI4* BI3* BI2*/BI1 \\ &+ BI4* BI3*/BI2* BI1 \\ &+ BI4*/BI3*/BI2*/BI1 \\ &+ \quad \quad /BI3* BI2* BI1 \end{aligned}$ | ; CONVERT SECOND BIT OF 0 DECIMAL       |
| $B02 = \begin{aligned} &/BI4*/BI3* BI2 \\ &+ /BI4* \quad BI2* BI1 \\ &+ BI4* BI3*/BI2 \\ &+ BI4*/BI3*/BI2*/BI1 \end{aligned}$  | ; CONVERT THIRD BIT OF 0 DECIMAL        |
| $B03 = \begin{aligned} &/BI4* BI3*/BI2*/BI1 \\ &+ BI4* BI3* BI2*/BI1 \\ &+ BI4*/BI3*/BI2* BI1 \end{aligned}$   | ; CONVERT FOURTH BIT OF 0 DECIMAL       |
| $B10 = \begin{aligned} &/BI4* BI3* \quad BI1 \\ &+ /BI4* BI3* BI2 \\ &+ \quad BI3* BI2* BI1 \\ &+ BI4*/BI3*/BI2 \end{aligned}$   | ; CONVERT FIRST BIT OF 1 DECIMAL        |
| $B11 = \begin{aligned} &BI4* BI3 \\ &+ BI4* \quad BI2 \end{aligned}$   | ; CONVERT SECOND BIT OF 1 DECIMAL       |
| $B12 = BI4*/BI4$   | ; CONVERT THIRD BIT OF 1 DECIMAL        |
| $B13 = BI4*/BI4$   | ; CONVERT FOURTH BIT OF 1 DECIMAL (MSB) |

### 5-BIT BINARY TO BCD CONVERTER



## Random Logic

### FUNCTION TABLE

BI4 BI3 BI2 BI1 BI0 B13 B12 B11 B10 B03 B02 B01 B00

| ;ADDRESS<br>;BINARY<br>;43 210 | ----DATA----  |               | DESCRIPTION<br>(DECIMAL VALUE) |
|--------------------------------|---------------|---------------|--------------------------------|
|                                | BCD 1<br>3210 | BCD 0<br>3210 |                                |
| LL LLL                         | LLLL          | LLLL          | 0                              |
| LL LLH                         | LLLL          | LLLH          | 1                              |
| LL LHH                         | LLLL          | LLHH          | 3                              |
| LL LHL                         | LLLL          | LLHL          | 2                              |
| LL HHL                         | LLLL          | LHHL          | 6                              |
| LL HHH                         | LLLL          | LHHH          | 7                              |
| LL HLH                         | LLLL          | LHLH          | 5                              |
| LL HLL                         | LLLL          | LHLL          | 4                              |
| ;                              |               |               |                                |
| LH LLL                         | LLLL          | HLLL          | 8                              |
| LH LLH                         | LLLL          | HLLH          | 9                              |
| LH LHH                         | LLLH          | LLLH          | 1 1                            |
| LH LHL                         | LLLH          | LLLL          | 1 0                            |
| LH HHL                         | LLLH          | LHLL          | 1 4                            |
| LH HHH                         | LLLH          | LHLH          | 1 5                            |
| LH HLH                         | LLLH          | LLHH          | 1 3                            |
| LH HLL                         | LLLH          | LLHL          | 1 2                            |
| ;                              |               |               |                                |
| HL LLL                         | LLLH          | LHHL          | 1 6                            |
| HL LLH                         | LLLH          | LHHH          | 1 7                            |
| HL LHH                         | LLLH          | HLLH          | 1 9                            |
| HL LHL                         | LLLH          | HLLL          | 1 8                            |
| HL HHL                         | LLHL          | LLHL          | 2 2                            |
| HL HHH                         | LLHL          | LLHH          | 2 3                            |
| HL HLH                         | LLHL          | LLLH          | 2 1                            |
| HL HLL                         | LLHL          | LLLL          | 2 0                            |
| ;                              |               |               |                                |
| HH LLL                         | LLHL          | LHLL          | 2 4                            |
| HH LLH                         | LLHL          | LHLH          | 2 5                            |
| HH LHH                         | LLHL          | LHHH          | 2 7                            |
| HH LHL                         | LLHL          | LHHL          | 2 6                            |
| HH HHL                         | LLHH          | LLLL          | 3 0                            |
| HH HHH                         | LLHH          | LLLH          | 3 1                            |
| HH HLH                         | LLHL          | HLLH          | 2 9                            |
| HH HLL                         | LLHL          | HLLL          | 2 8                            |

### DESCRIPTION

THIS 5-BIT BINARY TO 2-DIGIT BCD CONVERTER IS IMPLEMENTED IN A PLE5P8 LOGIC CIRCUIT. THE DEVICE ACCEPTS A 5-BIT BINARY INPUT (BI) AND CONVERTS THIS INTO TWO 4-BIT BINARY CODED DECIMAL (BCD) OUTPUTS (B1 AND B0).

THREE-STATE OUTPUTS ARE ALSO PROVIDED WITH ONE ACTIVE LOW ENABLE PIN (/E).

TB012204

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## Random Logic

PLE5P8  
P5008

PLE CIRCUIT DESIGN SPECIFICATION  
VINCENT COLI 10/16/81

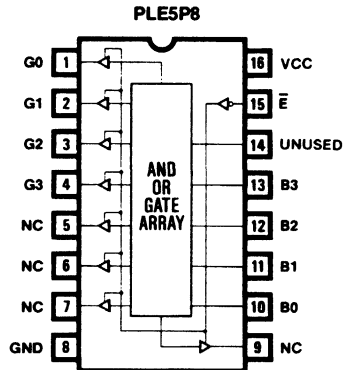
4-BIT BCD TO GRAY CODE CONVERTER  
MMI SANTA CLARA, CALIFORNIA  
.ADD B0 B1 B2 B3  
.DAT G0 G1 G2 G3

```
G0 = B0 :+: B1           ; CONVERT G0 (LSB)
G1 = B1 :+: B2           ; CONVERT G1
G2 = B2 :+: B3           ; CONVERT G2
G3 = B3                   ; CONVERT G3 (MSB)
```

### DESCRIPTION

THIS PLE5P8 WILL CONVERT A 4-BIT BCD INPUT (B3-B0) INTO A 4-BIT GRAY CODE REPRESENTATION (G3-G0) FOR OUTPUT.

### 4-BIT BCD TO GRAY CODE CONVERTER



T801240M

## Random Logic

PLE5P8

PLE CIRCUIT DESIGN SPECIFICATION

P5009

VINCENT COLI 03/16/84

4-BIT GRAY CODE TO BCD CONVERTER

MMI SANTA CLARA, CALIFORNIA

.ADD G0 G1 G2 G3

.DAT B0 B1 B2 B3

B0 = G0 :+: G1 :+: G2 :+: G3 ; CONVERT B0 (LSB)

B1 = G1 :+: G2 :+: G3 ; CONVERT B1

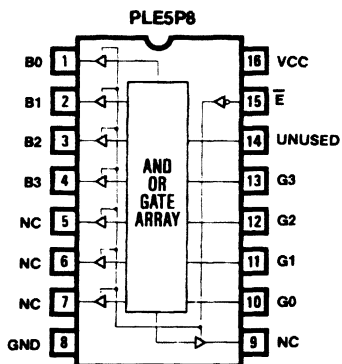
B2 = G2 :+: G3 ; CONVERT B2

B3 = G3 ; CONVERT B3 (MSB)

### DESCRIPTION

THIS PLE5P8 WILL CONVERT A 4-BIT GRAY CODE INPUT (G3-G0) INTO A 4-BIT BINARY REPRESENTATION (B3-B0) FOR OUTPUT.

### 4-BIT GRAY CODE TO BCD CONVERTER



TB01250M

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## Random Logic

**PLE8P4**  
**P5010**  
**8-BIT PRIORITY ENCODER**  
**MMI SANTA CLARA, CALIFORNIA**  
**.ADD I0 I1 I2 I3 I4 I5 I6 I7**  
**.DAT S0 S1 S2 EN**

**PLE CIRCUIT DESIGN SPECIFICATION**  
**FRANK LEE/ULRIK MUELLER 05/14/84**

```

S0 = I7           ; I7-I0 = 1XXXXXXX
    + /I6* I5     ; I7-I0 = X01XXXXX
    + /I6*/I4* I3 ; I7-I0 = X0X01XXX
    + /I6*/I4*/I2* I1 ; I7-I0 = X0X0X01X

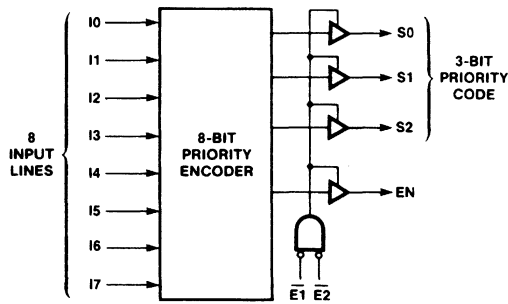
S1 = I7           ; I7-I0 = 1XXXXXXX
    + I6          ; I7-I0 = X1XXXXXX
    + /I5*/I4* I3 ; I7-I0 = XX001XXX
    + /I5*/I4* I2 ; I7-I0 = XX00X1XX

S2 = I7           ; I7-I0 = 1XXXXXXX
    + I6          ; I7-I0 = X1XXXXXX
    + I5          ; I7-I0 = XX1XXXXX
    + I4          ; I7-I0 = XXX1XXXX

EN = /I0*/I1*/I2*/I3*/I4*/I5*/I6*/I7 ; ALL LOWS ENABLE NEXT PRIORITY ENCODER
    
```

**FUNCTION TABLE**

| I7                | I6 | I5 | I4 | I3 | I2 | I1 | I0 | EN | S2 | S1 | S0 | COMMENT                    |   |   |   |  |
|-------------------|----|----|----|----|----|----|----|----|----|----|----|----------------------------|---|---|---|--|
| ; --INPUT LINES-- |    |    |    |    |    |    |    |    |    |    |    |                            |   |   |   |  |
| ; I I I I I I I I |    |    |    |    |    |    |    |    |    |    |    | E                          | S | S | S |  |
| ; 7 6 5 4 3 2 1 0 |    |    |    |    |    |    |    |    |    |    |    | N                          | 2 | 1 | 0 |  |
| -----             |    |    |    |    |    |    |    |    |    |    |    |                            |   |   |   |  |
| H                 | X  | X  | X  | X  | X  | X  | X  | L  | H  | H  | H  | I7 = HIGH                  |   |   |   |  |
| L                 | H  | X  | X  | X  | X  | X  | X  | L  | H  | H  | L  | I6 = HIGH                  |   |   |   |  |
| L                 | L  | H  | X  | X  | X  | X  | X  | L  | H  | L  | H  | I5 = HIGH                  |   |   |   |  |
| L                 | L  | L  | H  | X  | X  | X  | X  | L  | H  | L  | L  | I4 = HIGH                  |   |   |   |  |
| L                 | L  | L  | L  | H  | X  | X  | X  | L  | L  | H  | H  | I3 = HIGH                  |   |   |   |  |
| L                 | L  | L  | L  | L  | H  | X  | X  | L  | L  | H  | L  | I2 = HIGH                  |   |   |   |  |
| L                 | L  | L  | L  | L  | L  | H  | X  | L  | L  | L  | H  | I1 = HIGH                  |   |   |   |  |
| L                 | L  | L  | L  | L  | L  | L  | H  | L  | L  | L  | L  | I0 = HIGH                  |   |   |   |  |
| L                 | L  | L  | L  | L  | L  | L  | L  | H  | L  | L  | L  | I7-I0 = LOW THEN CARRY OUT |   |   |   |  |
| -----             |    |    |    |    |    |    |    |    |    |    |    |                            |   |   |   |  |



T801260M

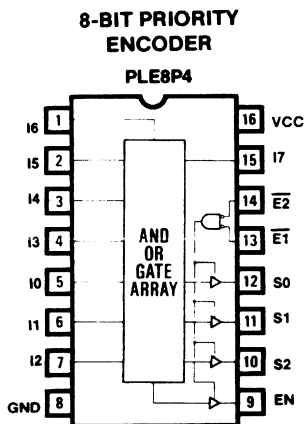
## Random Logic

### DESCRIPTION

THIS 8-BIT PRIORITY ENCODER SCANS FOR THE FIRST HIGH INPUT LINE (I7-I0) FROM I7 (WHICH HAS THE HIGHEST PRIORITY) TO I0 (WHICH HAS THE LOWEST PRIORITY). IT WILL GENERATE A BINARY ENCODED OUTPUT (S2-S0) WHICH WILL POINT TO THE HIGHEST PRIORITY INPUT WHICH IS AT A HIGH STATE.

IF NO INPUT LINES ARE HIGH (I7-I0=LOW), THEN THE BINARY ENCODED OUTPUTS WILL BE ZERO (S2-S0=LOW) AND THE ENABLE OUTPUT WILL BE HIGH (EN=HIGH) INDICATING A CARRY OUT TO THE NEXT PRIORITY ENCODER. THE OUTPUT ENABLE WILL BE LOW (EN=LOW) IF ANY OF THE INPUT LINES ARE HIGH.

THE PLE8P4 ALSO HAS THREE-STATE OUTPUTS WITH TWO ACTIVE-LOW OUTPUT ENABLE CONTROL PINS (/E1 AND /E2).



TB01270M

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## Random Logic

PLE8P4

PLE CIRCUIT DESIGN SPECIFICATION

P5011

ULRIK MUELLER 04/01/83

4-BIT MAGNITUDE COMPARATOR  
MMI SANTA CLARA, CALIFORNIA  
.ADD A0 A1 A2 A3 B0 B1 B2 B3  
.DAT EQ NE LT GT

EQ = A3:\*:B3 \* A2:\*:B2 \* A1:\*:B1 \* A0:\*:B0 ; A = B

NE = A3+:B3 + A2+:B2 + A1+:B1 + A0+:B0 ; A NOT = B

LT = /A3 \* B3 ; A3 LT B3  
+ A3:\*:B3 \* /A2 \* B2 ; A2 LT B2  
+ A3:\*:B3 \* A2:\*:B2 \* /A1 \* B1 ; A1 LT B1  
+ A3:\*:B3 \* A2:\*:B2 \* A1:\*:B1 \* /A0 \* B0 ; A0 LT B0

GT = A3 \*/B3 ; A3 GT B3  
+ A3:\*:B3 \* A2 \*/B2 ; A2 GT B2  
+ A3:\*:B3 \* A2:\*:B2 \* A1 \*/B1 ; A1 GT B1  
+ A3:\*:B3 \* A2:\*:B2 \* A1:\*:B1 \* A0 \*/B0 ; A0 GT B0

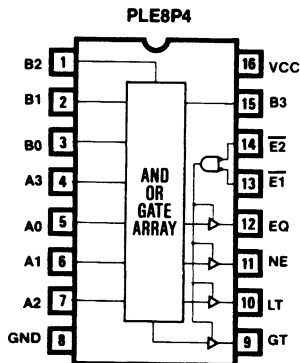
### DESCRIPTION

THIS PLE8P4 COMPARES TWO 4-BIT NUMBERS (A3-A0 AND B3-B0) TO ESTABLISH IF THEY ARE EQUAL (A = B THEN EQ=H), NOT EQUAL (A NOT = B THEN NE=H), LESS THAN (A LT B THEN LT=H), OR GREATER THAN (A GT B THEN GT=H) AND REPORTS THE COMPARISON STATUS ON THE OUTPUTS (EQ, NE, LT, GT) AS ILLUSTRATED IN THE OPERATIONS TABLE BELOW.

THE PLE8P4 ALSO FEATURES THREE-STATE OUTPUTS WITH TWO ACTIVE-LOW OUTPUT ENABLE CONTROL PINS (/E1 AND /E2).

| INPUT NUMBERS |       | COMPARISON STATUS |    |    |    | OPERATION                |
|---------------|-------|-------------------|----|----|----|--------------------------|
| A3-A0         | B3-B0 | EQ                | NE | LT | GT |                          |
| A = B         |       | H                 | L  | L  | L  | COMPARE A EQUAL TO B     |
| A NOT = B     |       | L                 | H  | X  | X  | COMPARE A NOT EQUAL TO B |
| A LT B        |       | L                 | H  | H  | L  | COMPARE A LESS THAN B    |
| A GT B        |       | L                 | H  | L  | H  | COMPARE A GREATER THAN B |

### 4-BIT MAGNITUDE COMPARATOR



TB012904



## Random Logic

PLE12P4  
P5012

PLE CIRCUIT DESIGN SPECIFICATION  
VINCENT COLI 10/16/83

6-BIT MAGNITUDE COMPARATOR  
MMI SANTA CLARA, CALIFORNIA

.ADD A0 A1 A2 A3 A4 A5 B0 B1 B2 B3 B4 B5  
.DAT EQ NE LT GT

```
EQ = A5:*B5 * A4:*B4 * A3:*B3 * A2:*B2 * A1:*B1 * A0:*B0 ; A = B

NE = A5:+B5 + A4:+B4 + A3:+B3 + A2:+B2 + A1:+B1 + A0:+B0 ; A NOT= B

LT = /A5 * B5 ; A5 LT B5
    + A5:*B5 * /A4 * B4 ; A4 LT B4
    + A5:*B5 * A4:*B4 * /A3 * B3 ; A3 LT B3
    + A5:*B5 * A4:*B4 * A3:*B3 * /A2 * B2 ; A2 LT B2
    + A5:*B5 * A4:*B4 * A3:*B3 * A2:*B2 * /A1 * B1 ; A1 LT B1
    + A5:*B5 * A4:*B4 * A3:*B3 * A2:*B2 * A1:*B1 * /A0 * B0 ; A0 LT B0

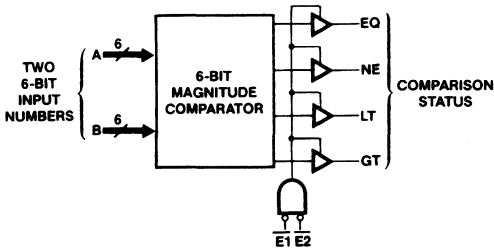
GT = A5 */B5 ; A5 GT B5
    + A5:*B5 * A4 */B4 ; A4 GT B4
    + A5:*B5 * A4:*B4 * A3 */B3 ; A3 GT B3
    + A5:*B5 * A4:*B4 * A3:*B3 * A2 */B2 ; A2 GT B2
    + A5:*B5 * A4:*B4 * A3:*B3 * A2:*B2 * A1 */B1 ; A1 GT B1
    + A5:*B5 * A4:*B4 * A3:*B3 * A2:*B2 * A1:*B1 * A0 */B0 ; A0 GT B0
```

### DESCRIPTION

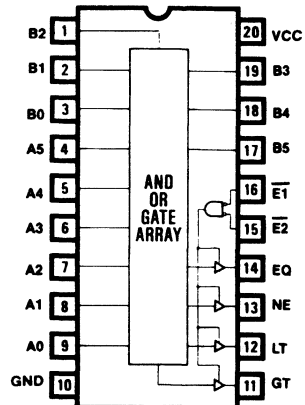
THIS PLE12P4 COMPARES TWO 6-BIT NUMBERS (A5-A0 AND B5-B0) TO ESTABLISH IF THEY ARE EQUAL (A = B THEN EQ=H), NOT EQUAL (A NOT = B THEN NE=H), LESS THAN (A LT B THEN LT=H), OR GREATER THAN (A GT B THEN GT=H) AND REPORTS THE COMPARISON STATUS ON THE OUTPUTS (EQ, NE, LT, GT) AS ILLUSTRATED IN THE OPERATIONS TABLE BELOW.

THE PLE12P4 ALSO FEATURES THREE-STATE OUTPUTS WITH TWO ACTIVE-LOW OUTPUT ENABLE CONTROL PINS (/E1 AND /E2).

| INPUT NUMBERS |       | COMPARISON STATUS |    |    |    | OPERATION                |
|---------------|-------|-------------------|----|----|----|--------------------------|
| A5-A0         | B5-B0 | EQ                | NE | LT | GT |                          |
| A = B         |       | H                 | L  | L  | L  | COMPARE A EQUAL TO B     |
| A NOT = B     |       | L                 | H  | X  | X  | COMPARE A NOT EQUAL TO B |
| A LT B        | B     | L                 | H  | H  | L  | COMPARE A LESS THAN B    |
| A GT B        | B     | L                 | H  | L  | H  | COMPARE A GREATER THAN B |



**6-BIT MAGNITUDE  
COMPARATOR**  
PLE12P4



TB01290M

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## Random Logic

PLE9P4  
P5011A

PLE CIRCUIT DESIGN SPECIFICATION  
COLI/MUELLER 09/09/84

4-BIT MAGNITUDE COMPARATOR WITH POLARITY CONTROL

MMI SANTA CLARA, CALIFORNIA

.ADD A0 A1 A2 A3 B0 B1 B2 B3 POL

.DAT EQ NE LT GT

```

EQ =  A3*:B3* POL *  A2*:B2* POL *  A1*:B1* POL *  A0*:B0* POL  ; A EQ B
+   A3+:B3*/POL *  A2+:B2*/POL *  A1+:B1*/POL *  A0+:B0*/POL  ; A /EQ B

NE =  A3+:B3* POL +  A2+:B2* POL +  A1+:B1* POL +  A0+:B0* POL  ; A NE B
+   A3*:B3*/POL +  A2*:B2*/POL +  A1*:B1*/POL +  A0*:B0*/POL  ; A /NE B

LT =  /A3 * B3* POL                                     ; A3 LT B3
+   A3*:B3* POL * /A2 * B2* POL                         ; A2 LT B2
+   A3*:B3* POL *  A2*:B2* POL * /A1 * B1* POL         ; A1 LT B1
+   A3*:B3* POL *  A2*:B2* POL *  A1*:B1* POL * /A0 * B0* POL ; A0 LT B0
+   A3 */B3*/POL                                         ; A3 /LT B3
+   A3*:B3*/POL *  A2 */B2*/POL                         ; A2 /LT B2
+   A3*:B3*/POL *  A2*:B2*/POL *  A1 */B1*/POL         ; A1 /LT B1
+   A3*:B3*/POL *  A2*:B2*/POL *  A1*:B1*/POL *  A0 */B0*/POL ; A0 /LT B0
+   A3*:B3*/POL +  A2*:B2*/POL +  A1*:B1*/POL +  A0*:B0*/POL  ; A /LT B

GT =  A3 */B3* POL                                       ; A3 GT B3
+   A3*:B3* POL *  A2 */B2* POL                         ; A2 GT B2
+   A3*:B3* POL *  A2*:B2* POL *  A1 */B1* POL         ; A1 GT B1
+   A3*:B3* POL *  A2*:B2* POL *  A1*:B1* POL *  A0 */B0* POL ; A0 GT B0
+   /A3 * B3*/POL                                       ; A3 /GT B3
+   A3*:B3*/POL * /A2 * B2*/POL                         ; A2 /GT B2
+   A3*:B3*/POL *  A2*:B2*/POL * /A1 * B1*/POL         ; A1 /GT B1
+   A3*:B3*/POL *  A2*:B2*/POL *  A1*:B1*/POL * /A0 * B0*/POL ; A0 /GT B0
+   A3*:B3*/POL +  A2*:B2*/POL +  A1*:B1*/POL +  A0*:B0*/POL  ; A /GT B
    
```

### DESCRIPTION

THIS PLE9P4 COMPARES TWO 4-BIT NUMBERS (A3-A0 AND B3-B0) TO ESTABLISH IF THEY ARE EQUAL (A EQ B), NOT EQUAL (A NE B), LESS THAN (A LT B), OR GREATER THAN (A GT B). THE COMPARISON STATUS IS REPORTED WITH ACTIVE-HIGH POLARITY (EQ, NE, LT, GT) WHEN THE POLARITY CONTROL INPUT IS TRUE (POL=H) AND WITH ACTIVE-LOW POLARITY (/EQ, /NE, /LT, /GT) WHEN THE POLARITY CONTROL INPUT IS FALSE (POL=L).

THE PLE8P4 ALSO FEATURES THREE-STATE OUTPUTS WITH ONE ACTIVE-LOW OUTPUT ENABLE CONTROL PIN (/E).

### OPERATIONS TABLE:

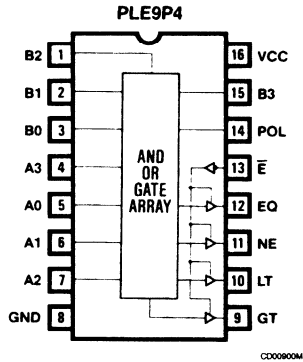
| INPUT NUMBERS |       | POLARITY<br>POL * | COMPARISON STATUS |    |    |    | OPERATION                |
|---------------|-------|-------------------|-------------------|----|----|----|--------------------------|
| A3-A0         | B3-B0 |                   | EQ                | NE | LT | GT |                          |
| A             | EQ B  | H                 | H                 | L  | L  | L  | COMPARE A EQUAL TO B     |
| A             | NE B  | H                 | L                 | H  | X  | X  | COMPARE A NOT EQUAL TO B |
| A             | LT B  | H                 | L                 | H  | H  | L  | COMPARE A LESS THAN B    |
| A             | GT B  | H                 | L                 | H  | L  | H  | COMPARE A GREATER THAN B |

\* COMPARISON STATUS WILL BE ACTIVE-LOW (I.E., /EQ, /NE, /LT, /GT) WHEN POL=L.

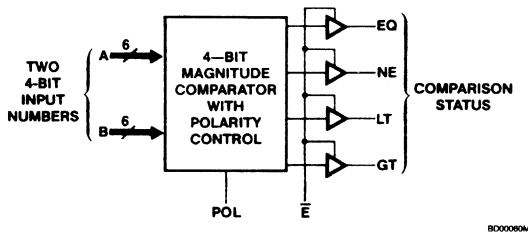
TB01300M

## Random Logic

### 4-Bit Magnitude Comparator with Polarity Control



### Block Diagram



## Random Logic

PLE11P8

PLE CIRCUIT DESIGN SPECIFICATION

P5013

VINCENT COLI 06/12/84

8-BIT BARREL SHIFTER

MMI SANTA CLARA, CALIFORNIA

.ADD D0 D1 D2 D3 D4 D5 D6 D7 S0 S1 S2

.DAT O0 O1 O2 O3 O4 O5 O6 O7

O0 = /S0\*/S1\*/S2\* D0 ; SHIFT 0 PLACES  
+ S0\*/S1\*/S2\* D1 ; SHIFT 1 PLACES  
+ /S0\* S1\*/S2\* D2 ; SHIFT 2 PLACES  
+ S0\* S1\*/S2\* D3 ; SHIFT 3 PLACES  
+ /S0\*/S1\* S2\* D4 ; SHIFT 4 PLACES  
+ S0\*/S1\* S2\* D5 ; SHIFT 5 PLACES  
+ /S0\* S1\* S2\* D6 ; SHIFT 6 PLACES  
+ S0\* S1\* S2\* D7 ; SHIFT 7 PLACES

O1 = /S0\*/S1\*/S2\* D1 ; SHIFT 0 PLACES  
+ S0\*/S1\*/S2\* D2 ; SHIFT 1 PLACES  
+ /S0\* S1\*/S2\* D3 ; SHIFT 2 PLACES  
+ S0\* S1\*/S2\* D4 ; SHIFT 3 PLACES  
+ /S0\*/S1\* S2\* D5 ; SHIFT 4 PLACES  
+ S0\*/S1\* S2\* D6 ; SHIFT 5 PLACES  
+ /S0\* S1\* S2\* D7 ; SHIFT 6 PLACES  
+ S0\* S1\* S2\* D0 ; SHIFT 7 PLACES

O2 = /S0\*/S1\*/S2\* D2 ; SHIFT 0 PLACES  
+ S0\*/S1\*/S2\* D3 ; SHIFT 1 PLACES  
+ /S0\* S1\*/S2\* D4 ; SHIFT 2 PLACES  
+ S0\* S1\*/S2\* D5 ; SHIFT 3 PLACES  
+ /S0\*/S1\* S2\* D6 ; SHIFT 4 PLACES  
+ S0\*/S1\* S2\* D7 ; SHIFT 5 PLACES  
+ /S0\* S1\* S2\* D0 ; SHIFT 6 PLACES  
+ S0\* S1\* S2\* D1 ; SHIFT 7 PLACES

O3 = /S0\*/S1\*/S2\* D3 ; SHIFT 0 PLACES  
+ S0\*/S1\*/S2\* D4 ; SHIFT 1 PLACES  
+ /S0\* S1\*/S2\* D5 ; SHIFT 2 PLACES  
+ S0\* S1\*/S2\* D6 ; SHIFT 3 PLACES  
+ /S0\*/S1\* S2\* D7 ; SHIFT 4 PLACES  
+ S0\*/S1\* S2\* D0 ; SHIFT 5 PLACES  
+ /S0\* S1\* S2\* D1 ; SHIFT 6 PLACES  
+ S0\* S1\* S2\* D2 ; SHIFT 7 PLACES

O4 = /S0\*/S1\*/S2\* D4 ; SHIFT 0 PLACES  
+ S0\*/S1\*/S2\* D5 ; SHIFT 1 PLACES  
+ /S0\* S1\*/S2\* D6 ; SHIFT 2 PLACES  
+ S0\* S1\*/S2\* D7 ; SHIFT 3 PLACES  
+ /S0\*/S1\* S2\* D0 ; SHIFT 4 PLACES  
+ S0\*/S1\* S2\* D1 ; SHIFT 5 PLACES  
+ /S0\* S1\* S2\* D2 ; SHIFT 6 PLACES  
+ S0\* S1\* S2\* D3 ; SHIFT 7 PLACES

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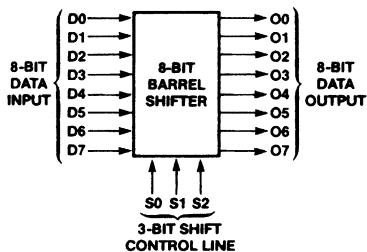
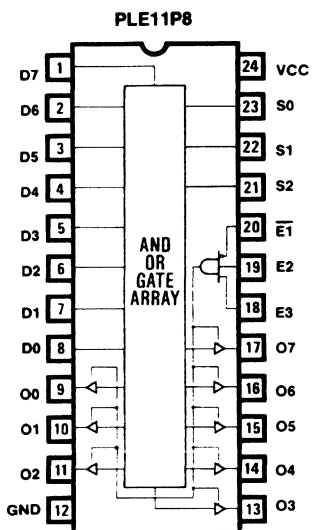
## Random Logic

### DESCRIPTION

THE 8-BIT BARREL SHIFTER, IMPLEMENTED IN A PLE11P8, ROTATES EIGHT BITS OF DATA (D7-D0) A NUMBER OF LOCATIONS INTO THE OUTPUTS (O7-O0) AS SPECIFIED BY THE 3-BIT BINARY ENCODED SHIFT CONTROL LINE (S2-S0). THE THREE-STATE OUTPUTS ARE IN A HIGH-Z STATE WHEN ANY ONE OF THE TWO OUTPUT ENABLE PINS (/E1 OR /E1) ARE HIGH.

A POSSIBLE UPGRADE VERSION OF THIS DESIGN IMPLEMENTED IN A PLE12P8 COULD INCLUDE A DIRECTION CONTROL LINE. THIS CONTROL LINE PERMITS THE 8-BIT BARREL SHIFTER TO ROTATE DATA IN EITHER DIRECTION (LEFT OR RIGHT).

### 8-BIT BARREL SHIFTER



TB01320M

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## Random Logic

```

O5 = /S0*/S1*/S2* D5      ; SHIFT 0 PLACES
    + S0*/S1*/S2* D6      ; SHIFT 1 PLACES
    + /S0* S1*/S2* D7      ; SHIFT 2 PLACES
    + S0* S1*/S2* D0      ; SHIFT 3 PLACES
    + /S0*/S1* S2* D1      ; SHIFT 4 PLACES
    + S0*/S1* S2* D2      ; SHIFT 5 PLACES
    + /S0* S1* S2* D3      ; SHIFT 6 PLACES
    + S0* S1* S2* D4      ; SHIFT 7 PLACES

O6 = /S0*/S1*/S2* D6      ; SHIFT 0 PLACES
    + S0*/S1*/S2* D7      ; SHIFT 1 PLACES
    + /S0* S1*/S2* D0      ; SHIFT 2 PLACES
    + S0* S1*/S2* D1      ; SHIFT 3 PLACES
    + /S0*/S1* S2* D2      ; SHIFT 4 PLACES
    + S0*/S1* S2* D3      ; SHIFT 5 PLACES
    + /S0* S1* S2* D4      ; SHIFT 6 PLACES
    + S0* S1* S2* D5      ; SHIFT 7 PLACES

O7 = /S0*/S1*/S2* D7      ; SHIFT 0 PLACES
    + S0*/S1*/S2* D0      ; SHIFT 1 PLACES
    + /S0* S1*/S2* D1      ; SHIFT 2 PLACES
    + S0* S1*/S2* D2      ; SHIFT 3 PLACES
    + /S0*/S1* S2* D3      ; SHIFT 4 PLACES
    + S0*/S1* S2* D4      ; SHIFT 5 PLACES
    + /S0* S1* S2* D5      ; SHIFT 6 PLACES
    + S0* S1* S2* D6      ; SHIFT 7 PLACES
    
```

### FUNCTION TABLE

S2 S1 S0 D7 D6 D5 D4 D3 D2 D1 D0 O7 O6 O5 O4 O3 O2 O1 O0

| ;SHIFT | INPUT DATA | OUTPUT DATA |                                |
|--------|------------|-------------|--------------------------------|
| ; SSS  | DDDDDDDD   | OOOOOOOO    |                                |
| ; 210  | 76543210   | 76543210    | COMMENTS                       |
| LLL    | HLLLLLLL   | HLLLLLLL    | BARREL SHIFT ONE HIGH 0 PLACES |
| LLH    | HLLLLLLL   | LHLLLLLL    | BARREL SHIFT ONE HIGH 1 PLACES |
| LHL    | HLLLLLLL   | LLHLLLLL    | BARREL SHIFT ONE HIGH 2 PLACES |
| LHH    | HLLLLLLL   | LLLHLLLL    | BARREL SHIFT ONE HIGH 3 PLACES |
| HLL    | HLLLLLLL   | LLLLHLLL    | BARREL SHIFT ONE HIGH 4 PLACES |
| H LH   | HLLLLLLL   | LLLLLHLL    | BARREL SHIFT ONE HIGH 5 PLACES |
| HHL    | HLLLLLLL   | LLLLLHL     | BARREL SHIFT ONE HIGH 6 PLACES |
| HHH    | HLLLLLLL   | LLLLLLLH    | BARREL SHIFT ONE HIGH 7 PLACES |
| LLL    | LHHHHHHH   | LHHHHHHH    | BARREL SHIFT ONE LOW 0 PLACES  |
| LLH    | LHHHHHHH   | HLHHHHHH    | BARREL SHIFT ONE LOW 1 PLACES  |
| LHL    | LHHHHHHH   | HHLHHHHH    | BARREL SHIFT ONE LOW 2 PLACES  |
| LHH    | LHHHHHHH   | HHHLHHHH    | BARREL SHIFT ONE LOW 3 PLACES  |
| HLL    | LHHHHHHH   | HHHHLHHH    | BARREL SHIFT ONE LOW 4 PLACES  |
| H LH   | LHHHHHHH   | HHHHLHHL    | BARREL SHIFT ONE LOW 5 PLACES  |
| HHL    | LHHHHHHH   | HHHHLHL     | BARREL SHIFT ONE LOW 6 PLACES  |
| HHH    | LHHHHHHH   | HHHHHHL     | BARREL SHIFT ONE LOW 7 PLACES  |

TB01300A

## Random Logic

PLE11P4

PLE CIRCUIT DESIGN SPECIFICATION

P5014

CHRIS JAY 05/30/84

4-BIT RIGHT SHIFTER WITH PROGRAMMABLE OUTPUT POLARITY

MMI LTD., FARNBOROUGH, U.K.

.ADD S0 S1 INV D0 D1 D2 D3 D4 D5 D6 /EN

.DAT O0 O1 O2 O3

O0 = D0\*/S0\*/S1\*/INV\* EN ; SELECT INPUT D0  
+ /D0\*/S0\*/S1\* INV\* EN ; SELECT INPUT /D0  
+ D1\* S0\*/S1\*/INV\* EN ; SELECT INPUT D1  
+ /D1\* S0\*/S1\* INV\* EN ; SELECT INPUT /D1  
+ D2\*/S0\* S1\*/INV\* EN ; SELECT INPUT D2  
+ /D2\*/S0\* S1\* INV\* EN ; SELECT INPUT /D2  
+ D3\* S0\* S1\*/INV\* EN ; SELECT INPUT D3  
+ /D3\* S0\* S1\* INV\* EN ; SELECT INPUT /D3

O1 = D1\*/S0\*/S1\*/INV\* EN ; SELECT INPUT D1  
+ /D1\*/S0\*/S1\* INV\* EN ; SELECT INPUT /D1  
+ D2\* S0\*/S1\*/INV\* EN ; SELECT INPUT D2  
+ /D2\* S0\*/S1\* INV\* EN ; SELECT INPUT /D2  
+ D3\*/S0\* S1\*/INV\* EN ; SELECT INPUT D3  
+ /D3\*/S0\* S1\* INV\* EN ; SELECT INPUT /D3  
+ D4\* S0\* S1\*/INV\* EN ; SELECT INPUT D4  
+ /D4\* S0\* S1\* INV\* EN ; SELECT INPUT /D4

O2 = D2\*/S0\*/S1\*/INV\* EN ; SELECT INPUT D2  
+ /D2\*/S0\*/S1\* INV\* EN ; SELECT INPUT /D2  
+ D3\* S0\*/S1\*/INV\* EN ; SELECT INPUT D3  
+ /D3\* S0\*/S1\* INV\* EN ; SELECT INPUT /D3  
+ D4\*/S0\* S1\*/INV\* EN ; SELECT INPUT D4  
+ /D4\*/S0\* S1\* INV\* EN ; SELECT INPUT /D4  
+ D5\* S0\* S1\*/INV\* EN ; SELECT INPUT D5  
+ /D5\* S0\* S1\* INV\* EN ; SELECT INPUT /D5

O3 = D3\*/S0\*/S1\*/INV\* EN ; SELECT INPUT D3  
+ /D3\*/S0\*/S1\* INV\* EN ; SELECT INPUT /D3  
+ D4\* S0\*/S1\*/INV\* EN ; SELECT INPUT D4  
+ /D4\* S0\*/S1\* INV\* EN ; SELECT INPUT /D4  
+ D5\*/S0\* S1\*/INV\* EN ; SELECT INPUT D5  
+ /D5\*/S0\* S1\* INV\* EN ; SELECT INPUT /D5  
+ D6\* S0\* S1\*/INV\* EN ; SELECT INPUT D6  
+ /D6\* S0\* S1\* INV\* EN ; SELECT INPUT /D6

TB01340M

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## Random Logic

### FUNCTION TABLE

/EN S1 S0 INV D6 D5 D4 D3 D2 D1 D0 O3 O2 O1 O0

| ;-CONTROL- |       |               |  |  |  |  |         |         |  |  |  |                                |
|------------|-------|---------------|--|--|--|--|---------|---------|--|--|--|--------------------------------|
| ;/         | I     | -INPUT DATA-  |  |  |  |  |         | OUTPUTS |  |  |  |                                |
| ;E         | S S N | D D D D D D D |  |  |  |  | O O O O |         |  |  |  |                                |
| ;N         | 1 0 V | 6 5 4 3 2 1 0 |  |  |  |  | 3 2 1 0 |         |  |  |  | COMMENTS                       |
| H          | X X X | X X X X X X X |  |  |  |  | L L L L |         |  |  |  | TEST ENABLE, OUTPUTS GO LOW    |
| L          | L L L | L L L H H H H |  |  |  |  | H H H H |         |  |  |  | SHIFT COUNT = 0, TRUE POLARITY |
| L          | L H L | L L L H H H H |  |  |  |  | L H H H |         |  |  |  | SHIFT COUNT = 1, TRUE POLARITY |
| L          | H L L | L L L H H H H |  |  |  |  | L L H H |         |  |  |  | SHIFT COUNT = 2, TRUE POLARITY |
| L          | H H L | L L L H H H H |  |  |  |  | L L L H |         |  |  |  | SHIFT COUNT = 3, TRUE POLARITY |
| L          | L L H | L L L H H H H |  |  |  |  | L L L L |         |  |  |  | SHIFT COUNT = 0, COMP POLARITY |
| L          | L H H | L L L H H H H |  |  |  |  | H L L L |         |  |  |  | SHIFT COUNT = 1, COMP POLARITY |
| L          | H L H | L L L H H H H |  |  |  |  | H H L L |         |  |  |  | SHIFT COUNT = 2, COMP POLARITY |
| L          | H H H | L L L H H H H |  |  |  |  | H H H L |         |  |  |  | SHIFT COUNT = 3, COMP POLARITY |

TB01350M



## Random Logic

### DESCRIPTION

THIS PLE11P4 IMPLEMENTS A 4-BIT RIGHT SHIFTER WITH PROGRAMMABLE OUTPUT POLARITY. THE SHIFTER CAN RIGHT SHIFT SEVEN BITS OF DATA, FOUR BITS AT A TIME. THE SEVEN DATA INPUTS (D6-D0) ARE SHIFTED 0, 1, 2, OR 3 LOCATIONS AS DETERMINED BY THE 2-BIT SHIFT CONTROL LINE (S1-S0). THE SHIFTED DATA IS THEN DIRECTED TO THE FOUR OUTPUTS (O3-O0).

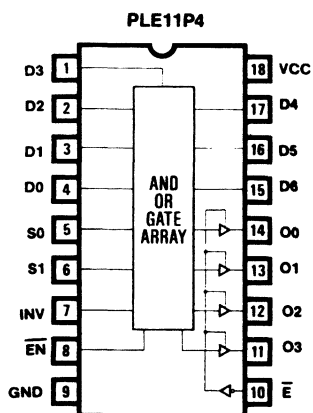
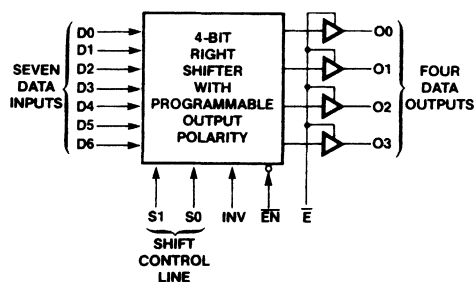
THE OUTPUT DATA IS NONINVERTED (O=D) WHEN INV=L AND INVERTED (O=/D) WHEN INV=H. THE OUTPUTS ARE FORCED LOW (O=L) WHEN /EN=H REGARDLESS OF OTHER INPUTS. THE PLE11P4 ALSO FEATURES THREE-STATE OUTPUTS WITH ONE ACTIVE LOW OUTPUT ENABLE (/E).

A POSSIBLE UPGRADE VERSION OF THIS DESIGN IMPLEMENTED IN A PLE12P4 COULD INCLUDE A DIRECTION CONTROL LINE. THIS CONTROL LINE PERMITS THE 4-BIT RIGHT SHIFTER TO SHIFT DATA IN EITHER DIRECTION (LEFT OR RIGHT).

### OPERATIONS TABLE:

| /EN | INV | S1-S0 | D6-D0 | O3-O0     | OPERATION                         |
|-----|-----|-------|-------|-----------|-----------------------------------|
| H   | X   | X     | X     | L         | DISABLE OUTPUTS LOW               |
| L   | L   | N     | D     | SHIFT(D)  | SHIFT NONINVERTED DATA "N" PLACES |
| L   | H   | N     | D     | SHIFT(/D) | SHIFT INVERTED DATA "N" PLACES    |

### 4-BIT RIGHT SHIFTER WITH PROGRAMMABLE OUTPUT POLARITY



T801360M

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## Random Logic

PLE8P8

PLE CIRCUIT DESIGN SPECIFICATION

P5015

MIKE VOGEL 11/28/83

8-BIT TWO'S COMPLEMENT CONVERSION

MMI BREA, CALIFORNIA

.ADD D0 D1 D2 D3 D4 D5 D6 D7

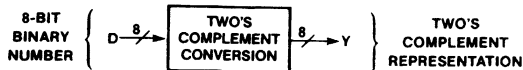
.DAT Y0 Y1 Y2 Y3 Y4 Y5 Y6 Y7

```

Y0 = D0                ; CONVERT 1ST BIT (LSB)
Y1 = D1 :+: D0         ; CONVERT 2ND BIT
Y2 = D2 :+: D0 + D1    ; CONVERT 3RD BIT
Y3 = D3 :+: D0 + D1 + D2 ; CONVERT 4TH BIT
Y4 = D4 :+: D0 + D1 + D2 + D3 ; CONVERT 5TH BIT
Y5 = D5 :+: D0 + D1 + D2 + D3 + D4 ; CONVERT 6TH BIT
Y6 = D6 :+: D0 + D1 + D2 + D3 + D4 + D5 ; CONVERT 7TH BIT
Y7 = D7 :+: D0 + D1 + D2 + D3 + D4 + D5 + D6 ; CONVERT 8TH BIT (MSB)
    
```

FUNCTION TABLE

| D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Y7 | Y6 | Y5 | Y4 | Y3 | Y2 | Y1 | Y0 | DECIMAL |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---------|
| L  | L  | L  | L  | L  | L  | L  | L  | L  | L  | L  | L  | L  | L  | L  | L  | 0       |
| L  | L  | L  | L  | L  | L  | L  | H  | H  | H  | H  | H  | H  | H  | H  | H  | 1       |
| L  | L  | L  | L  | L  | L  | H  | H  | H  | H  | H  | H  | H  | H  | H  | L  | 3       |
| L  | L  | L  | L  | L  | H  | H  | H  | H  | H  | H  | H  | H  | L  | L  | H  | 7       |
| L  | L  | L  | L  | H  | H  | H  | H  | H  | H  | H  | H  | L  | L  | L  | H  | 15      |
| L  | L  | L  | H  | H  | H  | H  | H  | H  | H  | H  | L  | L  | L  | L  | H  | 31      |
| L  | L  | H  | H  | H  | H  | H  | H  | H  | H  | L  | L  | L  | L  | L  | H  | 63      |
| L  | H  | H  | H  | H  | H  | H  | H  | H  | L  | L  | L  | L  | L  | L  | H  | 127     |
| H  | H  | H  | H  | H  | H  | H  | H  | L  | L  | L  | L  | L  | L  | L  | L  | 255     |
| H  | H  | H  | H  | H  | H  | H  | L  | L  | L  | L  | L  | L  | L  | H  | L  | 254     |
| H  | H  | H  | H  | H  | H  | L  | L  | L  | L  | L  | L  | L  | H  | L  | L  | 252     |
| H  | H  | H  | H  | H  | L  | L  | L  | L  | L  | L  | L  | H  | L  | L  | L  | 248     |
| H  | H  | H  | H  | L  | L  | L  | L  | L  | L  | L  | H  | L  | L  | L  | L  | 240     |
| H  | H  | H  | L  | L  | L  | L  | L  | L  | L  | H  | L  | L  | L  | L  | L  | 224     |
| H  | H  | L  | L  | L  | L  | L  | L  | L  | H  | L  | L  | L  | L  | L  | L  | 192     |
| H  | L  | L  | L  | L  | L  | L  | L  | H  | L  | L  | L  | L  | L  | L  | L  | 128     |



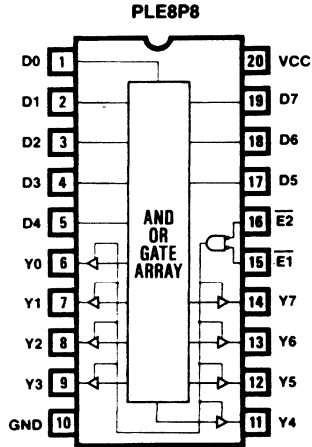
T801370M

## Random Logic

### DESCRIPTION

THIS PLE8P8 CONVERTS AN 8-BIT BINARY NUMBER (D7-D0) INTO TWO'S COMPLEMENT REPRESENTATION (Y7-Y0) WHERE D7 AND Y7 ARE THE MSB AND D0 AND Y0 ARE THE LSB. TWO'S COMPLEMENT REPRESENTATION IS USED IN SIGNED ARITHMETIC SYSTEMS.

### 8-BIT TWO'S COMPLEMENT CONVERSION



T801380M

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## Random Logic

PLE5P8 PLE CIRCUIT DESIGN SPECIFICATION  
P5027 S. HORIKO 11/29/83

A PORTION OF TIMING GENERATOR FOR PAL ARRAY PROGRAMMING  
MMI JAPAN

.ADD A0 A1 A2 A3 A4

.DAT NAO NA1 NA2 NA3 NA4 TIALR TVCC TO

; NEXT ADDRESS GENERATOR

NA0 = /A0 ; INCREMENTER (LSB)  
NA1 = A0 ; INCREMENTER (BIT1)  
:+: A1  
NA2 = A2 ; INCREMENTER (BIT2)  
:+: A0\* A1  
NA3 = A3 ; INCREMENTER (BIT3)  
:+: A0\* A1\* A2  
NA4 = A4 ; INCREMENTER (MSB)  
:+: A0\* A1\* A2\* A3

; TIMING WAVEFORMS

TIALR = /A4\*/A3 ; TIMING FOR I, A AND L/R  
+ /A4\* /A2\*/A1  
TVCC = /A4\*/A3\* A2 ; TIMING FOR VCC  
+ /A4\* A3\*/A2\*/A1  
TO = /A4\* A3\*/A2\*/A1\*/A0 ; TIMING FOR O  
+ /A4\*/A3\* A2\* A1  
+ /A4\*/A3\* A2\* A0

T801390M

## Random Logic

### FUNCTION TABLE

A4 A3 A2 A1 A0 NA4 NA3 NA2 NA1 NA0 TIALR TVCC TO

| ; NNNNN |       | TIMING WAVEFORMS |      |    |  |  | ; ## ; | COMMENTS           |
|---------|-------|------------------|------|----|--|--|--------|--------------------|
| ;AAAA   | AAAAA | TIALR            | TVCC | TO |  |  |        |                    |
| ;43210  | 43210 |                  |      |    |  |  |        |                    |
| LLLLL   | LLLLH | H                | L    | L  |  |  | ; 01 ; | ASSERT TIALR       |
| LLLLH   | LLLHL | H                | L    | L  |  |  | ; 02 ; |                    |
| LLLHL   | LLLHH | H                | L    | L  |  |  | ; 03 ; |                    |
| LLLHH   | LLHLL | H                | L    | L  |  |  | ; 04 ; |                    |
| LLHLL   | LLHLH | H                | H    | L  |  |  | ; 05 ; | ASSERT TVCC        |
| LLHLH   | LLHHL | H                | H    | H  |  |  | ; 06 ; | ASSERT TO          |
| LLHHL   | LLHHH | H                | H    | H  |  |  | ; 07 ; |                    |
| LLHHH   | LHLLL | H                | H    | H  |  |  | ; 08 ; |                    |
| LHLLL   | LHLLH | H                | H    | H  |  |  | ; 09 ; |                    |
| LHLLH   | LHHLH | H                | H    | L  |  |  | ; 10 ; | CLEAR TO           |
| LHHLH   | LHLHH | L                | L    | L  |  |  | ; 11 ; | CLEAR TIALR & TVCC |
| LHLHH   | LHLLL | L                | L    | L  |  |  | ; 12 ; |                    |
| LHLLL   | LHHLH | L                | L    | L  |  |  | ; 13 ; |                    |
| LHLLH   | LHHLH | L                | L    | L  |  |  | ; 14 ; |                    |
| LHHLH   | LHHLH | L                | L    | L  |  |  | ; 15 ; |                    |
| LHHLH   | HLLLL | L                | L    | L  |  |  | ; 16 ; |                    |
| HLLLL   | HLLLH | L                | L    | L  |  |  | ; 17 ; |                    |
| HLLLH   | HLLHL | L                | L    | L  |  |  | ; 18 ; |                    |
| HLLHL   | HLLHH | L                | L    | L  |  |  | ; 19 ; |                    |
| HLLHH   | HLHLL | L                | L    | L  |  |  | ; 20 ; |                    |
| HLHLL   | HLHLH | L                | L    | L  |  |  | ; 21 ; |                    |
| HLHLH   | HLHHL | L                | L    | L  |  |  | ; 22 ; |                    |
| HLHHL   | HLHHH | L                | L    | L  |  |  | ; 23 ; |                    |
| HLHHH   | HLLLL | L                | L    | L  |  |  | ; 24 ; |                    |
| HLLLL   | HLLLH | L                | L    | L  |  |  | ; 25 ; |                    |
| HLLLH   | HLLHL | L                | L    | L  |  |  | ; 26 ; |                    |
| HLLHL   | HLLHH | L                | L    | L  |  |  | ; 27 ; |                    |
| HLLHH   | HHLLL | L                | L    | L  |  |  | ; 28 ; |                    |
| HHLLL   | HHHLH | L                | L    | L  |  |  | ; 29 ; |                    |
| HHHLH   | HHHHL | L                | L    | L  |  |  | ; 30 ; |                    |
| HHHHL   | HHHHH | L                | L    | L  |  |  | ; 31 ; |                    |
| HHHHH   | LLLLL | L                | L    | L  |  |  | ; 32 ; |                    |

TBD1400M

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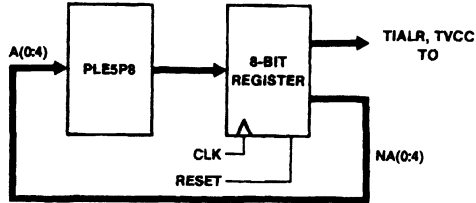
## Random Logic

### DESCRIPTION

THIS LOGIC SPECIFICATION IS A TIMING SIGNAL GENERATOR TO BE USED FOR ARRAY PROGRAMMING OF PAL DEVICES. A PLE5P8 FOLLOWED BY AN 8-BIT REGISTER ARE USED TO IMPLEMENT THIS FUNCTION.

THE PLE CONTAINS BOTH 5-BIT NEXT ADDRESS AND 3-BIT WAVEFORMS. TIALR OUTPUT IS A TIMING WAVEFORM FOR I, A, AND L/R SIGNALS, AND TVCC AND TO OUTPUTS ARE USED FOR VCC AND O SIGNALS, RESPECTIVELY.

THE SCHEMATIC IS AS FOLLOWS:

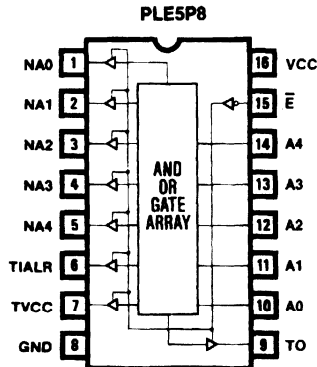


APPLYING 200KHz CLOCK SIGNAL TO THE CLK INPUT OF THE REGISTER GENERATES THE FOLLOWING TIMINGS:

1. I, A, AND L/R WIDTH : 50 usec
2. tD2 : 20 usec
3. tD : 5 usec
4. tVCCP : 30 usec
5. Tp : 20 usec

BECAUSE THE TIMING PATTERNS ARE STORED IN THE PROM, WE CAN EASILY CALIBRATE THE RELATIONS AND THE PERIOD AMONG THOSE SIGNALS TO MAKE AN OPTIMUM CONDITION.

### A PORTION OF A TIMING GENERATOR FOR PAL LOGIC CIRCUIT ARRAY PROGRAMMING



TB01410M



## Random Logic

### FUNCTION TABLE

A4 A3 A2 A1 A0 NA4 NA3 NA2 NA1 NA0 TVCC TP01 TP11

|        |       | NNNNN |   |   |  |        |      |           |        |                         |          |
|--------|-------|-------|---|---|--|--------|------|-----------|--------|-------------------------|----------|
| ;AAAAA |       | AAAAA |   |   |  | TIMING |      | WAVEFORMS |        |                         |          |
| ;43210 |       | 43210 |   |   |  | TVCCP  | TP01 | TP11      | ; ## ; |                         | COMMENTS |
| LLLLL  | LLLLH | H     | L | L |  |        |      |           | ; 01 ; | ASSERT TVCC, START HERE |          |
| LLLLH  | LLLHL | H     | H | L |  |        |      |           | ; 02 ; | ASSERT TP01             |          |
| LLLHL  | LLLHH | H     | H | L |  |        |      |           | ; 03 ; |                         |          |
| LLLHH  | LLHLL | H     | H | L |  |        |      |           | ; 04 ; |                         |          |
| LLHLL  | LLHLH | H     | H | L |  |        |      |           | ; 05 ; |                         |          |
| LLHLH  | LLHHL | H     | H | L |  |        |      |           | ; 06 ; |                         |          |
| LLHHL  | LLHHH | H     | H | L |  |        |      |           | ; 07 ; |                         |          |
| LLHHH  | LHLLL | H     | H | L |  |        |      |           | ; 08 ; |                         |          |
| LHLLL  | LHLLH | H     | H | L |  |        |      |           | ; 09 ; | CLEAR TP01              |          |
| LHLLH  | LHLHL | H     | L | L |  |        |      |           | ; 10 ; | ASSERT TP11             |          |
| LHLHL  | LHLHH | H     | L | H |  |        |      |           | ; 11 ; |                         |          |
| LHLHH  | LHLLL | H     | L | H |  |        |      |           | ; 12 ; |                         |          |
| LHLLL  | LHHLH | H     | L | H |  |        |      |           | ; 13 ; |                         |          |
| LHHLH  | LHHHL | H     | L | H |  |        |      |           | ; 14 ; |                         |          |
| LHHHL  | LHHHH | H     | L | H |  |        |      |           | ; 15 ; |                         |          |
| LHHHH  | HLLLL | H     | L | H |  |        |      |           | ; 16 ; |                         |          |
| HLLLL  | HLLLH | H     | L | H |  |        |      |           | ; 17 ; |                         |          |
| HLLLH  | HLLHL | H     | L | H |  |        |      |           | ; 18 ; |                         |          |
| HLLHL  | HLLHH | H     | L | L |  |        |      |           | ; 19 ; | CLEAR TP11              |          |
| HLLHH  | HLHLL | L     | L | L |  |        |      |           | ; 20 ; | CLEAR TVCC              |          |
| HLHLL  | HLHLH | L     | L | L |  |        |      |           | ; 21 ; |                         |          |
| HLHLH  | HLHLH | L     | L | L |  |        |      |           | ; 22 ; | LOOP HERE UNTIL RESET   |          |

TS01430M



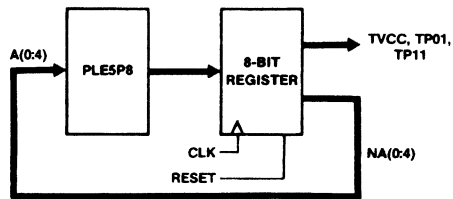
## Random Logic

### DESCRIPTION

THIS LOGIC SPECIFICATION IS A TIMING SIGNAL GENERATOR TO BE USED FOR SECURITY FUSE PROGRAMMING OF PAL DEVICES. A PLE5P8 FOLLOWED BY AN 8-BIT REGISTER ARE USED TO IMPLEMENT THIS FUNCTION.

THE PLE LOGIC CIRCUIT CONTAINS TWO FUNCTIONS IN THE SINGLE CHIP. THE FIRST FUNCTION IS A UNIQUE COUNTER USED FOR NEXT ADDRESS GENERATION. THE COUNTER INCREMENTS UP TO COUNT-21 AND THEN LOCKS UP THE INCREMENTAL OPERATION AT COUNT-22. THE SECOND FUNCTION IS A TIMING GENERATOR USED FOR DEFINING TIMING RELATIONSHIP AMONG VCC, P01, AND P11 SIGNALS.

THE SCHEMATIC IS AS FOLLOWS:



THIS LOGIC OUTPUTS A SEQUENCE OF TIMING PATTERNS DURING THE INCREMENTAL OPERATION AND THEN HOLDS ALL OUTPUTS LOW UNTIL A RESET SIGNAL FOR THE 8-BIT REGISTER IS APPLIED.

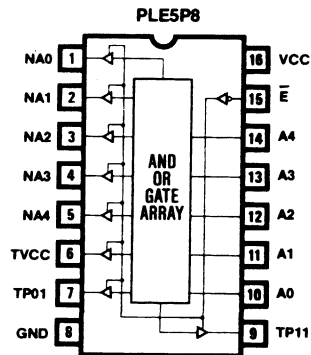
APPLYING 200 KHz CLOCK SIGNAL TO THE CLK INPUT OF THE REGISTER, THE FOLLOWING TIMINGS ARE GENERATED:

1. VCC WIDTH : 95 usec
2. TPP : 40 usec
3. tD : 5 usec

BY APPLYING THIS DESIGN METHOD, WE CAN EASILY GENERATE A SEQUENCE OF UNIQUELY DEFINED PATTERNS EACH TIME THE RESET PULSE IS APPLIED.

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### TIMING GENERATOR FOR PAL SECURITY FUSE PROGRAMMING



T001440M

### Fast Arithmetic Look-up

In performing arithmetic operations like trigonometric functions, multiplications and division, in order to reduce the delay, look-up tables are often used.

#### Sine Look-up

For trigonometric functions like sine function, it is very time-consuming to generate the function using the polynomial which represents the function. PLE devices can provide a very good alternative for sine look-up. An example is to use a 2Kx8 PLE device to do a sine look-up of an 11-bit input to 8-bit sine outputs.

Since sine function has the following property:  $\sin(x) = \sin(\pi - x) = -\sin(\pi + x) = -\sin(2\pi - x) = \sin(2\pi + x)$ , what is needed is just the sine function for  $0 < x < \pi/2$ ; the rest can be easily calculated using the above relations. In order to fully utilize the dynamic range, the inputs of the sine look-up PLE device should be normalized to  $(\pi/2)/(2^n) = \pi[2^n + 1]$  where  $n$  is the number of address lines to the device.

Since  $n$  is fixed for the PLE device chosen, and  $\pi$  is a constant, for the look-up table  $\pi/[2^n + 1]$  is a constant. Therefore, if the sine function of a given  $x$  is to be found,  $x$  will first be multiplied by the constant  $[2^n + 1]/\pi$  and sent to the address of the PLE device to get the final result.

$\cos(x)$  is related to sine function as  $\sin(\pi/2 - x)$ . Thus the cosine function can also be found in the same manner by using  $\pi/2 - x$  instead of just  $x$ . Other functions like tangent, secant etc., can also be found as a function of sine.

To increase the dynamic range of outputs, we can just use another PLE device to generate the less-significant bits of the sine function.

If a larger dynamic range is needed for the inputs, the result may be approximated using the Taylor series:

$$f(x) = f(x_0) + f'(x_0)(x - x_0) + 1/2f''(x_0)(x - x_0)^2 + \dots$$

Where  $f'$  and  $f''$  are the first and second derivations of  $f$ . Since  $x_0$  by itself represents a resolution of  $2^{-n}$ , and  $X$  is  $x_0$  concatenated with the rest of the bits,  $X - x_0$  must lie between 0 and  $1/2^{-n}$ . For  $f(x) = \sin(x)$ ,

$$f(x_0) = \sin(x_0)$$

$$f'(x_0) = \cos(x_0)$$

$$\text{and } f''(x_0) = -\sin(x_0)$$

So  $f''(x_0)$  is between  $-1$  and  $0$  for  $x_0$  lies between  $0$  and  $\pi/2$  and  $X - x_0 < 2^{-n}$ . Therefore, the last term will be between  $1/2^n$  and  $0$ , and as long as we do not want to expand the dynamic range of  $X$  beyond  $2n$ -bits, it should be sufficient to approximate  $\sin(x)$  in the first two terms:

$$\sin(x) \approx \sin(x_0) + \cos(x_0)(x - x_0)$$

Since  $x - x_0$  is represented by only the bits after the more significant  $n$ -bits, and  $\cos(x_0) = \sin(\pi/2 - x_0)$ , the implementation will be very simple.

#### Division

Division will normally be much slower than multiplication. There are several ways to perform division. Bit-by-bit division restoring and nonrestoring algorithms are generally very slow. Another way is to use several bits at a time division which is faster than the previous methods. A third way is to multiply the dividend by the inverse of the divisor. The inverse of the divisor can be found by getting an approximation followed by iterations.

The approximation is again given by the Taylor series:

$$f(x) = f(x_0) + f'(x_0)(x - x_0) + 1/2f''(x_0)(x - x_0)^2 + \dots$$

$$\text{and } f(x_0) = 1/x_0$$

$$f'(x_0) = -1/x_0^2$$

$$f''(x_0) = 2/x_0^3$$

Say  $x_0$  is 8-bits long and the first approximation of the inverse is found using a 256x8 PLE device. The first approximation can be obtained by subtracting  $(x - x_0)/(x_0^2)$ . Since the first approximation is limited by an error of approximately  $(x - x_0)^2/x_0^2$ , and if  $x_0$  at least 1, the error is limited by approximately  $(x - x_0)^2$ . Since  $x_0$  has an 8-bit resolution,  $x - x_0$  is represented by the rest of the bits. The resolution of the second approximation will be about 16 bits. The third approximation is similarly deduced and has a resolution of about 32 bits, and the fourth has a resolution of about 64 bits.

The inverse thus obtained is then multiplied by the dividend to give the quotient.

#### Scaling

In arithmetic operations, scaling is sometimes needed. Scaling normally involves multiplication or division by a constant. If this constant can be expressed in  $2^n$  where  $n$  is an integer, then scaling is simply shifting. Scaling with other constants may need a multiplier. A multiplier is more expensive and has a higher pin count than using a PLE device because the constant that the operand is to be scaled by is not required as an input as in the case of a multiplier. This will tremendously reduce the overhead for data scaling.

#### Other Applications

Arithmetic look-up are also very useful for arithmetic operations where conventional binary integral arithmetic is not applicable — like residue arithmetic, and distributed arithmetic.

## Fast Arithmetic Look-up

PLE8P8  
P5018

PLE CIRCUIT DESIGN SPECIFICATION  
VINCENT COLI 12/08/82

4-BIT MULTIPLIER LOOK-UP TABLE  
MMI SANTA CLARA, CALIFORNIA  
.ADD X0 X1 X2 X3 Y0 Y1 Y2 Y3  
.DAT S0 S1 S2 S3 S4 S5 S6 S7

$S7, S6, S5, S4, S3, S2, S1, S0 = X3, X2, X1, X0 \cdot Y3, Y2, Y1, Y0$  ;  $S = X * Y$

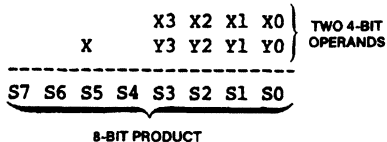
### FUNCTION TABLE

X3 X2 X1 X0 Y3 Y2 Y1 Y0 S7 S6 S5 S4 S3 S2 S1 S0

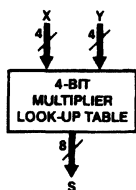
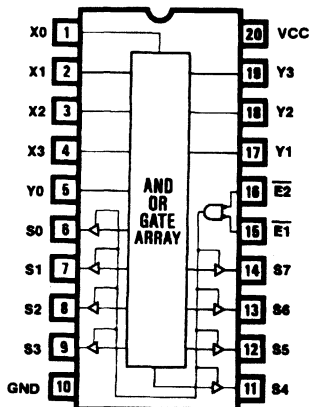
| ;-OPERANDS- |      | PRODUCTS | COMMENTS      |
|-------------|------|----------|---------------|
| ;XXXX       | YYYY | SSSSSSSS |               |
| ;3210       | 3210 | 76543210 |               |
| LLLL        | LLLL | LLLLLLLL | 0 * 0 = 0     |
| LLLH        | HHHH | LLLLHHHH | 1 * 15 = 15   |
| HHHH        | LLLH | LLLLHHHH | 15 * 1 = 15   |
| HHHH        | HHHH | HHLLLLLH | 15 * 15 = 225 |

### DESCRIPTION

THIS PLE8P8 PERFORMS 4-BIT LOOK-UP TABLE MULTIPLICATION. THE DEVICE ACCEPTS TWO 4-BIT OPERANDS (X3-X0 AND Y3-Y0) TO PRODUCE THE 8-BIT PRODUCT (S7-S0). THE PLE8P8 ALSO HAS THREE-STATE OUTPUTS WITH TWO ACTIVE-LOW OUTPUT ENABLE CONTROL PINS (/E1 AND /E2).



**4-BIT MULTIPLIER  
LOOK-UP TABLE  
PLE8P8**



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T801400M

## Fast Arithmetic Look-up

PLE5P8  
P5023  
ARC TANGENT LOOK-UP TABLE  
MMI GMBH MUNICH  
.ADD A0 A1 A2 A3 A4  
.DAT F0 F1 F2 F3 F4 F5 F6 F7

PLE CIRCUIT DESIGN SPECIFICATION  
PETER ZECHERLE 03/06/84

F0 = A1\* /A3\*/A4 ; COMPUTE DIGIT FOR 2EXP-7 (0.00078125) (LSB)  
+ A2\*/A3  
+ A0\*/A1\* A3\*/A4  
+ /A0\* A1\* /A4  
+ /A0\*/A1\* /A3\* A4  
+ A0\* A2  
+ A1\* A2

F1 = /A1\* A3\*/A4 ; COMPUTE DIGIT FOR 2EXP-6 (0.015625)  
+ A0\* /A3\* A4  
+ A1\* /A3\* A4  
+ A2\*/A3\* A4  
+ A0\* A1\* /A3  
+ A0\* A2\*/A3  
+ /A0\* A1\* A2\* /A4  
+ A0\* /A2\* A3\*/A4

F2 = A0\* /A3\*/A4 ; COMPUTE DIGIT FOR 2EXP-5 (0.03125)  
+ A1\*/A2\* /A4  
+ A3\* A4  
+ /A0\* A2\* A3\*/A4  
+ /A1\* A2\* A3\*/A4

F3 = A1\*/A2\* /A4 ; COMPUTE DIGIT FOR 2EXP-4 (0.0625)  
+ /A1\* A2\* /A4  
+ /A0\* A3\*/A4  
+ /A1\* A3\*/A4

F4 = /A1\* A3\*/A4 ; COMPUTE DIGIT FOR 2EXP-3 (0.125)  
+ A0\* A1\*/A2\* /A4  
+ A1\* A2\*/A3\*/A4  
+ /A0\* A3\*/A4

F5 = A0\*/A1\* /A4 ; COMPUTE DIGIT FOR 2EXP-2 (0.25)  
+ A2\*/A3\*/A4  
+ /A2\* A3\*/A4  
+ /A0\* A3\*/A4

F6 = A0\*/A1\*/A2\*/A3 ; COMPUTE DIGIT FOR 2EXP-1 (0.5)  
+ A0\* A1\* A2\* A3  
+ A4

F7 = A1 ; COMPUTE DIGIT FOR 2EXP0 (1) (MSB)  
+ A2  
+ A3  
+ A4

TB01450M

## Fast Arithmetic Look-up

### FUNCTION TABLE

| ;---ANGLE--- |    |    |    |    | -----F = ARCTAN(A)----- |    |           |    |    |    |    |    | ---F = ARCTAN(A)--- |        |        |         |            |
|--------------|----|----|----|----|-------------------------|----|-----------|----|----|----|----|----|---------------------|--------|--------|---------|------------|
| ; INTEGER    |    |    |    |    | INTEGER                 |    | FRACTIONS |    |    |    |    |    | ;ANGLE              |        |        | LOOK-UP | CALCULATED |
| A4           | A3 | A2 | A1 | A0 | F7                      | F6 | F5        | F4 | F3 | F2 | F1 | F0 |                     |        |        |         |            |
| L            | L  | L  | L  | L  | L                       | L  | L         | L  | L  | L  | L  | L  | 0                   | 0.0000 | 0.0000 |         |            |
| L            | L  | L  | L  | H  | L                       | H  | H         | L  | L  | H  | L  | L  | 1                   | 0.7813 | 0.7854 |         |            |
| L            | L  | L  | H  | L  | H                       | L  | L         | L  | H  | H  | L  | H  | 2                   | 1.1016 | 1.1071 |         |            |
| L            | L  | H  | L  | L  | H                       | L  | H         | L  | H  | L  | L  | H  | 4                   | 1.3203 | 1.3258 |         |            |
| L            | L  | H  | L  | H  | H                       | L  | H         | L  | H  | H  | H  | H  | 5                   | 1.3672 | 1.3734 |         |            |
| L            | H  | L  | L  | L  | H                       | L  | H         | H  | H  | L  | H  | L  | 8                   | 1.4531 | 1.4464 |         |            |
| H            | L  | L  | L  | L  | H                       | H  | L         | L  | L  | L  | L  | H  | 16                  | 1.5078 | 1.5084 |         |            |
| H            | H  | H  | H  | H  | H                       | H  | L         | L  | L  | H  | L  | H  | 31                  | 1.5391 | 1.5385 |         |            |

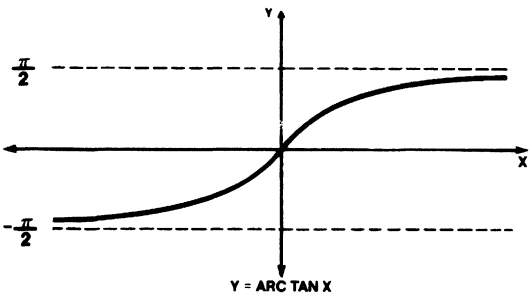
### DESCRIPTION

THIS APPLICATION ILLUSTRATES THE CALCULATION OF THE ARC TANGENT FUNCTION USING A PLE5P8 AS A LOOK-UP TABLE. OTHER TRIGONOMETRIC FUNCTIONS (SUCH AS SINE, COSINE, COTANGENT, SECANT, COSECANT AND THEIR ARC INVERSE EQUIVALENT FUNCTIONS) OR HYPERBOLIC FUNCTIONS CAN ALSO BE CONSTRUCTED USING PLE DEVICES AS LOOK-UP TABLES.

$F = \text{ARCTAN}(A)$       WHERE  $F = \text{ARC TANGENT OF } A$   
 $A = \text{ANGLE IN RADIANS}$

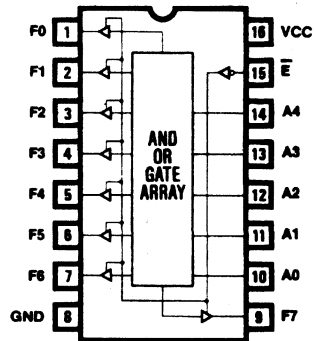
EXAMPLE: FOR  $A = 5$ ,  $F = \text{ARCTAN}(5) = 1.3672$

A PLE DEVICE WITH MORE INPUTS, SUCH AS THE PLE11P8, SHOULD BE USED TO CONSTRUCT A LOOK-UP TABLE WHEN ADDITIONAL ACCURACY IS REQUIRED.



### ARC TANGENT LOOK-UP TABLE

PLE5P8



TD01470M

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## Fast Arithmetic Look-up

PLE5P8

PLE CIRCUIT DESIGN SPECIFICATION

P5024

WILLY VOLDAN 06/02/84

HYPOTENUSE OF A RIGHT TRIANGLE LOOK-UP TABLE

MMI GMBH MUNICH

.ADD A0 A1 B0 B1 B2

.DAT C0 C1 C2 C3 C4 C5 C6 C7

C0 =       A0\*/B2\* B1                   ; COMPUTE DIGIT FOR 2EXP-5 (0.03125) (LSB)  
+ /A1\* A0\* B2\*/B1  
+ A1\*       /B2\*       B0  
+ A1\*       /B2\* B1  
+ A1\*/A0\* B2\*/B1\*/B0  
+ A1\* A0\*       B1\* B0  
+       A0\*/B2\*       B0

C1 =       A0\*       B1\*/B0               ; COMPUTE DIGIT FOR 2EXP-4 (0.0625)  
+ /A1\* A0\* B2  
+ A1\*/A0\*/B2\*       B0  
+ A1\*/A0\* B2\*       /B0  
+       A0\* B2\*       B0  
+ A1\* A0\*       B1

C2 =       A0\*/B2\*       B0               ; COMPUTE DIGIT FOR 2EXP-3 (0.125)  
+ /A1\* A0\*/B2\* B1  
+ A1\*/A0\* B2\*/B1  
+ A1\* A0\* B2\* B1  
+ A1\*       /B2\*/B1\* B0

C3 = /A1\* A0\*/B2\*/B1\* B0               ; COMPUTE DIGIT FOR 2EXP-2 (0.25)  
+ A1\*/A0\*       B1\*/B0  
+ A1\*/A0\* B2  
+ A1\*       B2\*       B0

C4 = A1\*/A0\*/B2\* B1                   ; COMPUTE DIGIT FOR 2EXP-1 (0.5)  
+ A1\* A0\* B2\*/B1\* B0  
+ A1\* A0\*       B1\*/B0

C5 = /A1\*               B0               ; COMPUTE DIGIT FOR 2EXP0 (1)  
+       A0\*/B2\*/B1  
+       /A0\*       B1\* B0  
+       B2\*       B0  
+ A1\* A0\*/B2\*       /B0  
+ A1\* A0\*       /B1

C6 = /A1\*               B1               ; COMPUTE DIGIT FOR 2EXP1 (2)  
+ A1\*       /B2\*/B1  
+       B2\* B1  
+       /A0\*       B1  
+       B1\*/B0

C7 =       B2                           ; COMPUTE DIGIT FOR 2EXP2 (4) (MSB)  
+ A1\* A0\*       B1\* B0

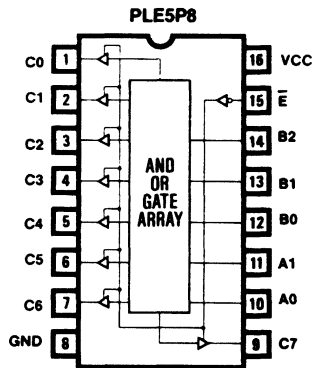
TDC1490M

## Fast Arithmetic Look-up

### FUNCTION TABLE

| ;-LENGTH OF SIDES- |    |          | LENGTH OF THE HYPOTENUSE |    |    |          |    | SIDES<br>;A B | LENGTH OF HYPOTENUSE |            |     |      |      |
|--------------------|----|----------|--------------------------|----|----|----------|----|---------------|----------------------|------------|-----|------|------|
| ;SIDE A            |    | SIDE B   | INTEGER                  |    |    | FRACTION |    |               | LOOK-UP              | CALCULATED |     |      |      |
| A1                 | A0 | B2 B1 B0 | C7                       | C6 | C5 | C4       | C3 | C2            | C1                   | C0         |     |      |      |
| L                  | L  | L L L    | L                        | L  | L  | L        | L  | L             | L                    | L          | 0 0 | 0.00 | 0.00 |
| L                  | L  | L L H    | L                        | L  | H  | L        | L  | L             | L                    | L          | 0 1 | 1.00 | 1.00 |
| L                  | L  | L H L    | L                        | H  | L  | L        | L  | L             | L                    | L          | 0 2 | 2.00 | 2.00 |
| L                  | L  | H L L    | H                        | L  | L  | L        | L  | L             | L                    | L          | 0 4 | 4.00 | 4.00 |
| L                  | H  | L L L    | L                        | L  | H  | L        | L  | L             | L                    | L          | 1 0 | 1.00 | 1.00 |
| H                  | L  | L L L    | L                        | H  | L  | L        | L  | L             | L                    | L          | 2 0 | 1.00 | 1.00 |
| H                  | L  | L H L    | L                        | H  | L  | H        | H  | L             | L                    | H          | 2 2 | 2.78 | 2.83 |
| H                  | L  | H L L    | H                        | L  | L  | L        | H  | H             | H                    | H          | 2 4 | 4.47 | 4.47 |
| H                  | H  | L H L    | L                        | H  | H  | H        | L  | L             | H                    | H          | 3 2 | 3.59 | 3.61 |
| H                  | H  | H H H    | H                        | H  | H  | L        | H  | H             | H                    | H          | 3 7 | 7.47 | 7.62 |

### HYPOTENUSE OF A RIGHT TRIANGLE LOOK-UP TABLE



T801490M

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## Fast Arithmetic Look-up

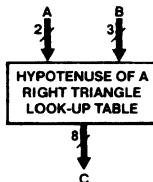
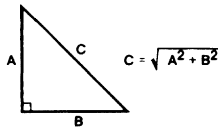
### DESCRIPTION

THE GENERATION OF COMPLEX ARITHMETIC FUNCTIONS SUCH AS THE PYTHAGOREAN THEOREM IS GENERALLY VERY DIFFICULT TO IMPLEMENT DIRECTLY IN HARDWARE. HOWEVER, IMPLEMENTING THE FUNCTION AS A LOOK-UP TABLE USING A PLE GREATLY SIMPLIFIES THE PROBLEM.

THIS EXAMPLE ILLUSTRATES HOW TO IMPLEMENT A LOOK-UP TABLE IN A PLE5P8 WHICH CALCULATES THE LENGTH OF THE HYPOTENUSE OF A RIGHT TRIANGLE AS A FUNCTION OF THE LENGTH OF THE TWO REMAINING SIDES OF THE TRIANGLE. THE THEOREM OF PATHAGOREAN STATES THAT THE LENGTH OF THE HYPOTENUSE OF A RIGHT TRIANGLE IS EQUAL TO THE SQUARE ROOT OF THE SUM OF THE SQUARE OF THE OTHER TWO SIDES OR  $C = \text{SQRT}(A^{**2} + B^{**2})$ . THE INPUTS, "A" AND "B", CORRESPOND TO THE SIDES ADJACENT TO THE RIGHT ANGLE (I.E. 90 DEGREE ANGLE), WHILE THE OUTPUT, "C", CORRESPONDS TO THE SIDE OPPOSITE TO THE RIGHT ANGLE WHICH IS CALLED THE HYPOTENUSE.

$C = \text{SQRT}(A^{**2} + B^{**2})$       WHERE C = LENGTH OF SIDE C (THE HYPOTENUSE)  
A = LENGTH OF SIDE A  
B = LENGTH OF SIDE B

EXAMPLE: FOR A = 2 AND B = 4,  $C = \text{SQRT}(2^{**2} + 4^{**2}) = 4.47$



T8015004



## Fast Arithmetic Look-up

PLE5P8  
P5025

PLE CIRCUIT DESIGN SPECIFICATION  
PETER WITTFOTH 06/02/84

PERIMETER OF A CIRCLE LOOK-UP TABLE

MMI GMBH MUNICH

.ADD R0 R1 R2 R3 R4

.DAT P0 P1 P2 P3 P4 P5 P6 P7

P0 =  $\frac{R1}{R0} \cdot \frac{R2}{R1} \cdot \frac{R3}{R2} \cdot \frac{R4}{R3}$  ; COMPUTE DIGIT FOR 2EXP0 (1) (LSB)

+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2}$   
+  $\frac{R1}{R2} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2}$   
+  $\frac{R3}{R4}$

P1 =  $R0 \cdot \frac{R2}{R1} \cdot \frac{R3}{R2}$  ; COMPUTE DIGIT FOR 2EXP1 (2)

+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R2}{R3}$   
+  $\frac{R0}{R1} \cdot \frac{R2}{R3}$   
+  $R0 \cdot \frac{R2}{R3}$   
+  $\frac{R0}{R1} \cdot \frac{R2}{R3} \cdot \frac{R4}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R2}{R3}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $R0 \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$

P2 =  $R0 \cdot \frac{R1}{R1} \cdot \frac{R3}{R2} \cdot \frac{R4}{R3}$  ; COMPUTE DIGIT FOR 2EXP2 (4)

+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $R0 \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $R0 \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$

P3 =  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R4}{R4}$  ; COMPUTE DIGIT FOR 2EXP3 (8)

+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R2}{R3}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R2}{R3}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$

P4 =  $R0 \cdot \frac{R1}{R2} \cdot \frac{R2}{R3}$  ; COMPUTE DIGIT FOR 2EXP4 (16)

+  $\frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R2}{R3}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3}$   
+  $\frac{R0}{R1} \cdot \frac{R1}{R2} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$   
+  $\frac{R1}{R2} \cdot \frac{R2}{R3}$   
+  $\frac{R0}{R1} \cdot \frac{R2}{R3} \cdot \frac{R3}{R4}$

T801510M

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## Fast Arithmetic Look-up

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P5 =      R1* R2*/R3*/R4      ; COMPUTE DIGIT FOR 2EXP5 (32)
+      /R1*/R2* R3*/R4
+      /R2*/R3* R4
+      R1*/R2* R4
+      /R1* R2* R3* R4
+ /R0* R1*/R2* R3
+ /R0*/R1* R2* R4
+ /R0* R2* R3* R4

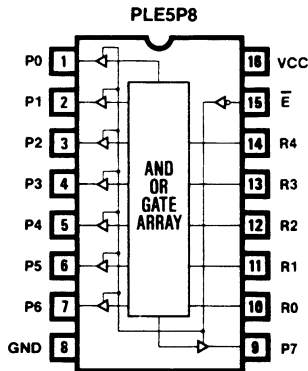
P6 = R0* R1* R3*/R4      ; COMPUTE DIGIT FOR 2EXP6 (64)
+ /R0*/R1* /R3* R4
+      R2* R3*/R4
+      /R2*/R3* R4
+ R0* R1* R2* R3

P7 = R0* R2* R4      ; COMPUTE DIGIT FOR 2EXP7 (128) (MSB)
+      R1* R2* R4
+      R3* R4
    
```

### FUNCTION TABLE

| ;---RADIUS--- |    |    |    |    | -----PERIMETER----- |    |    |    |    |    |    |    |                       |    |         |         |            |
|---------------|----|----|----|----|---------------------|----|----|----|----|----|----|----|-----------------------|----|---------|---------|------------|
| ; INTEGER     |    |    |    |    | INTEGER             |    |    |    |    |    |    |    | PERIMETER OF A CIRCLE |    |         |         |            |
| R4            | R3 | R2 | R1 | R0 | MSB                 | P7 | P6 | P5 | P4 | P3 | P2 | P1 | LSB                   | P0 | ;RADIUS | LOOK-UP | CALCULATED |
| L             | L  | L  | L  | L  | L                   | L  | L  | L  | L  | L  | L  | L  | L                     | 0  | 0       | 0.0     |            |
| L             | L  | L  | L  | H  | L                   | L  | L  | L  | L  | H  | H  | L  | L                     | 1  | 6       | 6.3     |            |
| L             | L  | L  | H  | L  | L                   | L  | L  | L  | H  | H  | L  | H  | L                     | 2  | 13      | 12.6    |            |
| L             | L  | L  | H  | H  | L                   | L  | L  | H  | L  | L  | H  | H  | H                     | 3  | 19      | 18.8    |            |
| L             | L  | H  | L  | L  | L                   | L  | L  | H  | H  | L  | L  | H  | H                     | 4  | 25      | 25.1    |            |
| L             | H  | L  | L  | L  | L                   | L  | H  | H  | L  | L  | H  | L  | L                     | 8  | 50      | 50.3    |            |
| H             | L  | L  | L  | L  | L                   | H  | H  | L  | L  | H  | L  | H  | H                     | 16 | 101     | 100.5   |            |
| H             | H  | H  | H  | H  | H                   | H  | L  | L  | L  | L  | H  | H  | H                     | 31 | 195     | 194.8   |            |

**PERIMETER OF A CIRCLE  
LOOK-UP TABLE**



TB015204



## Fast Arithmetic Look-up

PLE5P8  
P5026

PLE CIRCUIT DESIGN SPECIFICATION  
WILLY VOLDAN 06/03/84

PERIOD OF OSCILLATION FOR A MATHEMATICAL PENDULUM LOOK-UP TABLE  
MMI GMBH MUNICH

.ADD L0 L1 L2 L3 L4  
.DAT T0 T1 T2 T3 T4 T5 T6 T7

T0 = /L4\* /L2\*/L1\* L0 ; COMPUTE DIGIT FOR 2EXP-5 (0.03125) (LSB)  
+ /L3\*/L2\* L1\*/L0  
+ L3\*/L2\* L0  
+ /L4\* L2\*/L1\*/L0  
+ L4\* L3\* L0  
+ L4\*/L3\* L1  
+ L4\*/L3\* L2\* /L0

T1 = /L2\* L1\*/L0 ; COMPUTE DIGIT FOR 2EXP-4 (0.0625)  
+ /L4\*/L3\* L2\* L0  
+ /L4\* L3\*/L2\* L1  
+ /L4\* L2\*/L1\*/L0  
+ L4\*/L3\*/L2\* L1  
+ /L3\* L2\*/L1  
+ L4\* L3\* /L1\* L0  
+ L4\* L3\* L1\*/L0

T2 = /L4\*/L3\* L1\*/L0 ; COMPUTE DIGIT FOR 2EXP-3 (0.125)  
+ /L4\* L3\*/L2\* L0  
+ L4\*/L3\*/L2\*/L1\*/L0  
+ L4\*/L3\* L1\* L0  
+ L4\* L3\*/L2\* L1\*/L0  
+ L4\* L3\* L2\*/L1  
+ L4\* L2\* L0  
+ /L4\*/L3\* /L1\* L0  
+ /L4\*/L3\* L2\* /L0

T3 = /L4\* L3\* L1\* L0 ; COMPUTE DIGIT FOR 2EXP-2 (0.25)  
+ L4\*/L3\* L1  
+ L4\* L3\* L2\*/L1  
+ /L3\*/L2\*/L1\* L0  
+ /L3\* L2\* L1\* L0  
+ L3\*/L2\* L1\* L0  
+ L3\* L2\*/L1\* L0  
+ /L4\* L2\*/L1\* L0

T4 = /L4\*/L3\* L1\*/L0 ; COMPUTE DIGIT FOR 2EXP-1 (0.5)  
+ /L3\* L2\* L1  
+ /L4\* L3\* L2\*/L1  
+ L4\*/L3\* L2  
+ L4\* L2\* L1  
+ L2\* L1\*/L0

TB01540M

## Fast Arithmetic Look-up

T5 = /L4\*      /L2\*      /L0                    ; COMPUTE DIGIT FOR 2EXP0 (1)  
 + /L4\*      /L2\*/L1  
 +      L3\*                    /L0  
 +      L3\*/L2  
 +      L3\*      /L1  
 + L4\* L3

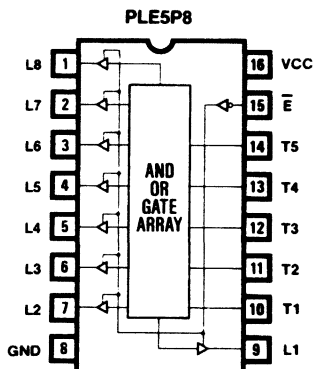
T6 = /L4\*      /L2\* L1\* L0                    ; COMPUTE DIGIT FOR 2EXP1 (2)  
 + /L4\* L3\*                    /L0  
 + /L4\*/L3\* L2  
 + /L4\*/L3\*      /L1

T7 =      L3\* L2\* L1\* L0                    ; COMPUTE DIGIT FOR 2EXP2 (4) (MSB)  
 + L4

### FUNCTION TABLE

| ;--AMPLITUDE-- |    |    |    |    | --PERIOD OF OSCILLATION-- |    |    |    |          |    |    |    | PERIOD OF OSCILLATION |         |            |
|----------------|----|----|----|----|---------------------------|----|----|----|----------|----|----|----|-----------------------|---------|------------|
| ; INTEGER      |    |    |    |    | INTEGER                   |    |    |    | FRACTION |    |    |    |                       |         |            |
| L4             | L3 | L2 | L1 | L0 | T7                        | T6 | T5 | T4 | T3       | T2 | T1 | T0 | ; AMPLITUDE           | LOOK-UP | CALCULATED |
| L              | L  | L  | L  | L  | L                         | L  | H  | L  | L        | L  | L  | L  | 1                     | 2.0000  | 2.0050     |
| L              | L  | L  | L  | H  | L                         | L  | H  | L  | H        | H  | L  | H  | 2                     | 2.8125  | 2.8356     |
| L              | L  | L  | H  | L  | L                         | L  | H  | H  | L        | H  | H  | H  | 3                     | 3.4375  | 3.4728     |
| L              | L  | H  | L  | L  | L                         | H  | L  | L  | L        | H  | H  | H  | 5                     | 4.4375  | 4.4834     |
| L              | H  | L  | L  | L  | L                         | H  | H  | L  | L        | L  | L  | L  | 9                     | 6.0000  | 6.0151     |
| H              | L  | L  | L  | L  | H                         | L  | L  | L  | L        | H  | L  | L  | 17                    | 8.2500  | 8.2670     |
| H              | H  | H  | H  | H  | H                         | L  | H  | H  | L        | H  | L  | H  | 32                    | 11.3125 | 11.3423    |

### PERIOD OF OSCILLATION FOR A MATHEMATICAL PENDULUM LOOK-UP TABLE



TB01550M

## Fast Arithmetic Look-up

### DESCRIPTION

THIS PLE5P8 IS USED TO IMPLEMENT A LOOK-UP TABLE FOR THE PERIOD OF OSCILLATION OF A MATHEMATICAL PENDULUM. THE PERIOD OF OSCILLATION FOR MATHEMATICAL PENDULUM (T) IS DEPENDENT UPON ITS AMPLITUDE OF SWING (L) AND THE ACCELERATION DUE TO GRAVITY (G). THE PERIOD OF OSCILLATION IS CALCULATED USING THE FOLLOWING EQUATION:

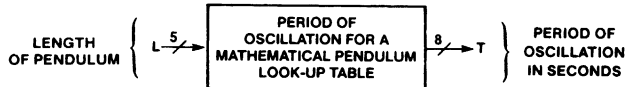
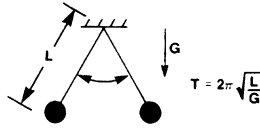
$$T = 2\pi\sqrt{L/G}$$

WHERE T = PERIOD OF OSCILLATION IN SECONDS  
PI = 3.14  
L = AMPLITUDE OF SWING IN METERS  
G = ACCELERATION DUE TO GRAVITY IN M/S/S  
(9.81 M/S/S)

EXAMPLE: FOR L = 5, T = 2\*PI\*SQRT(5/G) = 4.4375

A PLE DEVICE WITH 5 INPUTS CAN BE USED TO CALCULATE THE PERIOD OF OSCILLATION FOR AMPLITUDES UP TO L = 32 METERS. PLE DEVICE WITH MORE INPUTS SHOULD BE USED TO CALCULATE LARGER PERIODS OF OSCILLATION.

THIS EXAMPLE DEMONSTRATES HOW EASY IT IS TO CONSTRUCT LOOK-UP TABLES FOR COMPLEX ARITHMETIC FUNCTIONS USING PLE DEVICES



TS01500M

## Fast Arithmetic Look-up

PLE12P8  
P5017

PLE CIRCUIT DESIGN SPECIFICATION  
FRANK LEE 10/14/83

ARITHMETIC LOGIC UNIT

MMI SANTA CLARA, CALIFORNIA

.ADD A3 A2 A1 A0 B3 B2 B1 B0 CIN I2 I1 I0  
.DAT C3 C2 C1 C0 Z V C

\*\*\*\*\*  
\* THIS DESIGN IS NOT YET SUPPORTED BY PLEASM \*  
\*\*\*\*\*

```
C,C3,C2,C1,C0 = /S2*/S1* S0*/A3,/A2,/A1,/A0           ;B - A - 1 + CIN
                .+. B3, B2, B1, B0.+ CIN
                + /S2* S1*/S0* A3, A2, A1, A0         ;A - B - 1 + CIN
                .+./B3,/B2,/B1,/B0.+ CIN
                + /S2* S1* S0* A3, A2, A1, A0         ;A + B + CIN
                .+. B3, B2, B1, B0.+ CIN
                + S2*/S1*/S0*/A3,/A2,/A1,/A0         ;A XOR B
                :*: B3, B2, B1, B0
                + S2*/S1* S0* A3, A2, A1, A0         ;A + B
                + S2*/S1* S0* B3, B2, B1, B0
                + S2* S1*/S0* A3, A2, A1, A0         ;A * B
                * B3, B2, B1, B0
                + S2* S1* S0                           ;PRESET

V               = C+: C3                               ;OVERFLOW

Z               = /C3*/C2*/C1*/C0                     ;ZERO
```

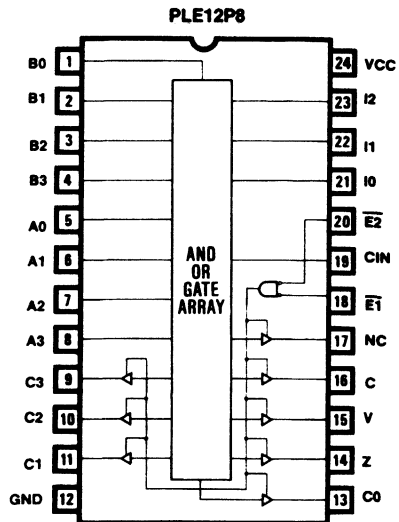
**DESCRIPTION**

THIS ALU CAN PERFORM 8 FUNCTIONS ON TWO 4-BIT OPERANDS A (A3-A0) AND B (B3-B0) WITH CARRYIN (CIN) AND GIVES A 4-BIT RESULT C (C3-C0) WITH CARRYOUT (C). IT WILL ALSO GIVE STATUS AS OVERFLOW (V) AND ZERO (Z).

THE FUNCTION IS DETERMINED BY A 3-BIT FUNCTION SELECT CODE (S2-S0):

| MODE | S2 | S1 | S0 | FUNCTION        |
|------|----|----|----|-----------------|
| 0    | 0  | 0  | 0  | CLEAR           |
| 1    | 0  | 0  | 1  | B - A - 1 + CIN |
| 2    | 0  | 1  | 0  | A - B - 1 + CIN |
| 3    | 0  | 1  | 1  | A + B + CIN     |
| 4    | 1  | 0  | 0  | A XOR B         |
| 5    | 1  | 0  | 1  | A + B           |
| 6    | 1  | 1  | 0  | A * B           |
| 7    | 1  | 1  | 1  | PRESET          |

**ARITHMETIC LOGIC UNIT**



T801570M

10

## Wallace Tree Compression

### Wallace Tree Compression

In performing arithmetic calculations, it may happen that more than two numbers are to be added together. Adding two numbers can be achieved by using a simple adder. If there are more than two numbers to be summed, several levels of adders may be needed. This often causes too much delay.

An alternative is to use Wallace Tree Compression. Suppose there are  $m$  numbers each of  $n$ -bits wide. Summation over these numbers will range from 0 to  $m \times (2^n - 1)$  which will take  $\log_2[m(2^n - 1) + 1]$  bits (rounded UP to the nearest integer). For example, if there are five 2-bit numbers, i.e.,  $m = 5$ , and  $n = 2$ , the sum will be bounded by  $5 \times (2^2 - 1) = 15$  which will need a total of 4 bits.

One Wallace Tree Compression by itself will not be very useful. But consider if five 8-bit integers are added together. This technique enables vertical compression of these numbers in four groups. This type of vertical compression also eliminates the need of carry propagation. The five numbers are represented by:

- A = (a7, a6, a5, a4, a3, a2, a1, a0)
- B = (b7, b6, b5, b4, b3, b2, b1, b0)
- C = (c7, c6, c5, c4, c3, c2, c1, c0)
- D = (d7, d6, d5, d4, d3, d2, d1, d0)
- E = (e7, e6, e5, e4, e3, e2, e1, e0)

where the 7<sup>th</sup> bits are the most significant; the calculation is as follows:

The groups are assigned as follows:

- G1:(a0, a1, b0, b1, c0, c1, d0, d1, e0, e1)
- G2:(a2, a3, b2, b3, c2, c3, d2, d3, e2, e3)
- G3:(a4, a5, b4, b5, c4, c5, d4, d5, e4, e5)
- G4:(a6, a7, b6, b7, c6, c7, d6, d7, e6, e7)

The above groups of bits can be compressed to:

- H1:(h1<sub>3</sub>, h1<sub>2</sub>, h1<sub>1</sub>, h1<sub>0</sub>)
- H2:(h2<sub>3</sub>, h2<sub>2</sub>, h2<sub>1</sub>, h2<sub>0</sub>)
- H3:(h3<sub>3</sub>, h3<sub>2</sub>, h3<sub>1</sub>, h3<sub>0</sub>)
- H4:(h4<sub>3</sub>, h4<sub>2</sub>, h4<sub>1</sub>, h4<sub>0</sub>)

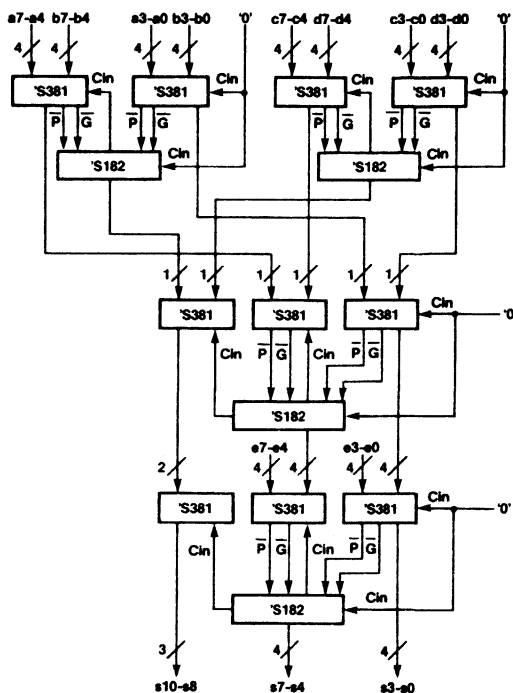
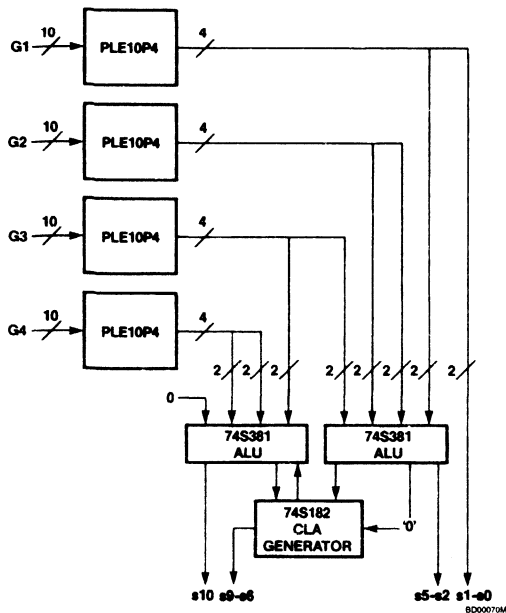
|     |                 | G4              |                 | G3              |                 | G2              |                 | G1              |                 |      |          |
|-----|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------|----------|
|     |                 | a7              | a6              | a5              | a4              | a3              | a2              | a1              | a0              | = A  |          |
|     |                 | b7              | b6              | b5              | b4              | b3              | b2              | b1              | b0              | = B  |          |
|     |                 | c7              | c6              | c5              | c4              | c3              | c2              | c1              | c0              | = C  |          |
|     |                 | d7              | d6              | d5              | d4              | d3              | d2              | d1              | d0              | = D  |          |
|     | +)              | e7              | e6              | e5              | e4              | e3              | e2              | e1              | e0              | = E  |          |
|     |                 |                 |                 |                 |                 | h1 <sub>3</sub> | h1 <sub>2</sub> | h1 <sub>1</sub> | h1 <sub>0</sub> | = H1 |          |
|     |                 |                 |                 | h2 <sub>3</sub> | h2 <sub>2</sub> | h2 <sub>1</sub> | h2 <sub>0</sub> |                 |                 | = H2 |          |
|     |                 | h3 <sub>3</sub> | h3 <sub>2</sub> | h3 <sub>1</sub> | h3 <sub>0</sub> |                 |                 |                 |                 | = H3 |          |
| +)  | h4 <sub>3</sub> | h4 <sub>2</sub> | h4 <sub>1</sub> | h4 <sub>0</sub> |                 |                 |                 |                 |                 | = H4 |          |
|     |                 | h3 <sub>3</sub> | h3 <sub>2</sub> | h3 <sub>1</sub> | h3 <sub>0</sub> | h1 <sub>3</sub> | h1 <sub>2</sub> | h1 <sub>1</sub> | h1 <sub>0</sub> |      |          |
| +)  | h4 <sub>3</sub> | h4 <sub>2</sub> | h4 <sub>1</sub> | h4 <sub>0</sub> | h2 <sub>3</sub> | h2 <sub>2</sub> | h2 <sub>1</sub> | h2 <sub>0</sub> |                 |      |          |
| S10 | S9              | S8              | S7              | S6              | S5              | S4              | S3              | S2              | S1              | S0   | = result |



## Wallace Tree Compression

S1 and S0 are just  $h_1$  and  $h_0$ . S10-S2 can be obtained through addition of other bits. The hardware implementation is as follows:

It needs four PLE10P4 devices, two 74S381 ALUs and one 74S182. An alternative is using ten 74S381 ALUs and four 74S182 Carry Lookahead Generators.



A comparison between the two architectures gives the following data:

|                                | USING WALLACE<br>TREE COMPRESSION | USING CONVENTIONAL<br>ARITHMETIC LOGIC |
|--------------------------------|-----------------------------------|--|
| Delay (ns)                     | 79                                | 115                                    |
| Number of components           | 7                                 | 14                                     |
| Total number pins on the parts | 128                               | 264                                    |

Since Wallace tree compression can be of any configuration, there is no predefined part available. A PLE device provides an excellent solution. The designer may define his own configuration as long as it can be put in a commercially available PLE device.

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# Wallace Tree Compression

PLE8P4

PLE CIRCUIT DESIGN SPECIFICATION

P5019

VINCENT COLI 04/06/83

SEVEN 1-BIT INTEGER ROW PARTIAL PRODUCTS ADDER

MMI SANTA CLARA, CALIFORNIA

.ADD A B C D E F G

.DAT P0 P1 P2

P2,P1,P0 = A .+. B .+. C .+. D .+. E .+. F .+. G ; P = A+B+C+D+E+F+G

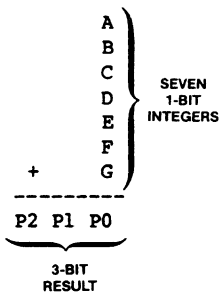
FUNCTION TABLE

A B C D E F G P2 P1 P0

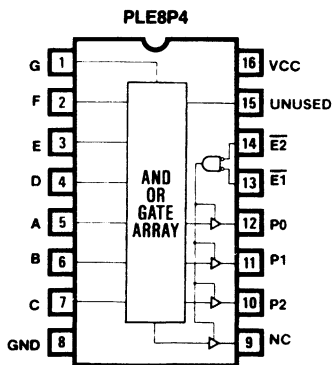
|   |   |   |   |   |   |   | PPP | COMMENTS |                               |
|---|---|---|---|---|---|---|-----|----------|-------------------------------|
| ; | A | B | C | D | E | F | G   | 210      | A + B + C + D + E + F + G = P |
| L | L | L | L | L | L | L | L   | LLL      | 0 + 0 + 0 + 0 + 0 + 0 + 0 = 0 |
| L | H | L | H | L | H | L | L   | LHH      | 0 + 1 + 0 + 1 + 0 + 1 + 0 = 3 |
| H | L | H | L | H | L | H | L   | HLL      | 1 + 0 + 1 + 0 + 1 + 0 + 1 = 4 |
| H | H | H | H | H | H | H | H   | HHH      | 1 + 1 + 1 + 1 + 1 + 1 + 1 = 7 |

DESCRIPTION

THIS PLE8P4 PERFORMS PARTIAL PRODUCTS REDUCTION FOR WALLACE TREE COMPRESSION. SEVEN ROWS OF 1-BIT NUMBERS (A, B, C, D, E, F, AND G) ARE NUMERICALLY SUMMED TO PRODUCE A 3-BIT RESULT (P2-P0).



SEVEN 1-BIT INTEGER ROW PARTIAL PRODUCTS ADDER



TBO1580M

## Wallace Tree Compression

PLE10P4  
P5020

PLE CIRCUIT DESIGN SPECIFICATION  
VINCENT COLI 08/22/83

FIVE 2-BIT INTEGER ROW PARTIAL PRODUCTS ADDER  
MMI SANTA CLARA, CALIFORNIA

.ADD A0 A1 B0 B1 C0 C1 D0 D1 E0 E1  
.DAT P0 P1 P2 P3

$P_3, P_2, P_1, P_0 = A_1, A_0 \text{ .+} . B_1, B_0 \text{ .+} . C_1, C_0 \text{ .+} . D_1, D_0 \text{ .+} . E_1, E_0$  ;  $P = A+B+C+D+E$

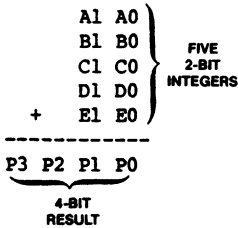
### FUNCTION TABLE

A1 A0 B1 B0 C1 C0 D1 D0 E1 E0 P3 P2 P1 P0

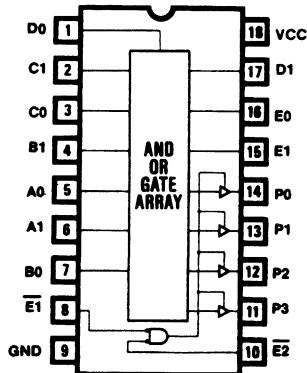
| AA | BB | CC | DD | EE | PPPP | COMMENTS                 |
|----|----|----|----|----|------|--------------------------|
| 10 | 10 | 10 | 10 | 10 | 3210 | $A + B + C + D + E = P$  |
| LL | LL | LL | LL | LL | LLLL | $0 + 0 + 0 + 0 + 0 = 0$  |
| LH | LH | LH | LH | LH | LHLH | $1 + 1 + 1 + 1 + 1 = 5$  |
| HL | HL | HL | HL | HL | HLHL | $2 + 2 + 2 + 2 + 2 = 10$ |
| HH | HH | HH | HH | HH | HHHH | $3 + 3 + 3 + 3 + 3 = 15$ |

### DESCRIPTION

THIS PLE10P4 PERFORMS PARTIAL PRODUCTS REDUCTION FOR WALLACE TREE COMPRESSION. FIVE ROWS OF 2-BIT NUMBERS (A1-A0, B1-B0, C1-C0, D1-D0, AND E1-E0) ARE NUMERICALLY SUMMED TO PRODUCE A 4-BIT RESULT (P3-P0).



**FIVE 2-BIT INTEGER ROW  
PARTIAL PRODUCTS ADDER  
PLE10P4**



TB01590M

10

# Wallace Tree Compression

**PLE12P8**  
**P5021**  
**FOUR 3-BIT INTEGER ROW PARTIAL PRODUCTS ADDER**  
**MMI SANTA CLARA, CALIFORNIA**  
**.ADD A0 A1 A2 B0 B1 B2 C0 C1 C2 D0 D1 D2**  
**.DAT P0 P1 P2 P3 P4**

**PLE CIRCUIT DESIGN SPECIFICATION**  
**VINCENT COLI 02/10/83**

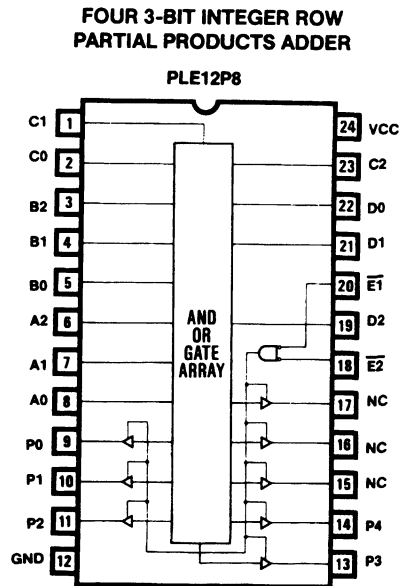
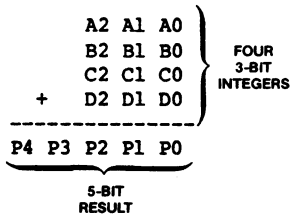
$P_4, P_3, P_2, P_1, P_0 = A_2, A_1, A_0 \cdot + \cdot B_2, B_1, B_0 \cdot + \cdot C_2, C_1, C_0 \cdot + \cdot D_2, D_1, D_0$  ;  $P = A+B+C+D$

**FUNCTION TABLE**

| A2  | A1  | A0  | B2  | B1  | B0  | C2  | C1  | C0  | D2  | D1  | D0  | P4 | P3 | P2 | P1 | P0 |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|----|----|----|----|
| ;AAA    BBB    CCC    DDD    PPPPP    COMMENTS          |     |     |     |     |     |     |     |     |     |     |     |    |    |    |    |    |
| ;210    210    210    210    43210    A + B + C + D = P |     |     |     |     |     |     |     |     |     |     |     |    |    |    |    |    |
| -----   |     |     |     |     |     |     |     |     |     |     |     |    |    |    |    |    |
| LLL   | LLL | LLL | LLL | LLL | LLL | LLL | LLL | LLL | LLL | LLL | LLL | 0  | 0  | 0  | 0  | 0  |
| LLH   | LLH | LLH | LLH | LLH | LLH | LLH | LLH | LLH | LLH | LLH | LLH | 1  | 1  | 1  | 1  | 4  |
| LHL   | LHL | LHL | LHL | LHL | LHL | LHL | LHL | LHL | LHL | LHL | LHL | 2  | 2  | 2  | 2  | 8  |
| LHH   | LHH | LHH | LHH | LHH | LHH | LHH | LHH | LHH | LHH | LHH | LHH | 3  | 3  | 3  | 3  | 12 |
| HLL   | HLL | HLL | HLL | HLL | HLL | HLL | HLL | HLL | HLL | HLL | HLL | 4  | 4  | 4  | 4  | 16 |
| HHH   | HHH | HHH | HHH | HHH | HHH | HHH | HHH | HHH | HHH | HHH | HHH | 7  | 7  | 7  | 7  | 28 |
| -----   |     |     |     |     |     |     |     |     |     |     |     |    |    |    |    |    |

**DESCRIPTION**

THIS PLE12P8 PERFORMS PARTIAL PRODUCTS REDUCTION FOR WALLACE TREE COMPRESSION. FOUR ROWS OF 3-BIT NUMBERS (A2-A0, B2-B0, C2-C0, AND D2-D0) ARE NUMERICALLY SUMMED TO PRODUCE A 5-BIT RESULT (P4-P0).



TS01000M

## Wallace Tree Compression

PLE12P8  
P5022

PLE CIRCUIT DESIGN SPECIFICATION  
VINCENT COLI 08/10/83

THREE 4-BIT INTEGER ROW PARTIAL PRODUCTS ADDER  
MMI SANTA CLARA, CALIFORNIA  
.ADD A0 A1 A2 A3 B0 B1 B2 B3 C0 C1 C2 C3  
.DAT P0 P1 P2 P3 P4 P5

$P_5, P_4, P_3, P_2, P_1, P_0 = A_3, A_2, A_1, A_0 \cdot +. B_3, B_2, B_1, B_0 \cdot +. C_3, C_2, C_1, C_0$  ;  $P = A+B+C$

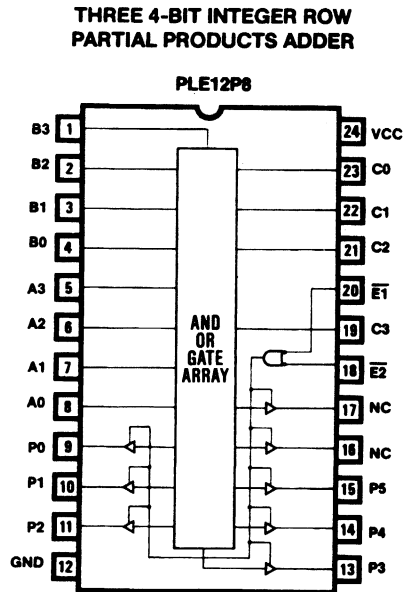
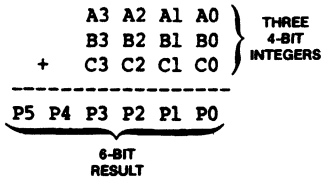
### FUNCTION TABLE

A3 A2 A1 A0 B3 B2 B1 B0 C3 C2 C1 C0 P5 P4 P3 P2 P1 P0

| ;AAAA | BBBB | CCCC | PPPPPP | COMMENTS          |
|-------|------|------|--------|-------------------|
| ;3210 | 3210 | 3210 | 543210 | A + B + C = P     |
| LLLL  | LLLL | LLLL | LLLLLL | 0 + 0 + 0 = 0     |
| LLLH  | LLLH | LLLH | LLLHHH | 1 + 1 + 1 = 3     |
| LLHL  | LLHL | LLHL | LLHLLH | 2 + 2 + 2 = 6     |
| LHLL  | LHLL | LHLL | LLHLLL | 4 + 4 + 4 = 12    |
| HLLL  | HLLL | HLLL | LHLLLL | 8 + 8 + 8 = 24    |
| HHHH  | HHHH | HHHH | HLHHLH | 15 + 15 + 15 = 45 |

### DESCRIPTION

THIS PLE12P8 PERFORMS PARTIAL PRODUCTS REDUCTION FOR WALLACE TREE COMPRESSION. THREE ROWS OF 4-BIT NUMBERS (A3-A0, B3-B0, AND C3-C0) ARE NUMERICALLY SUMMED TO PRODUCE A 6-BIT RESULT (P5-P0).



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T801610M

## Residue Arithmetic using PLE Devices

### Residue Arithmetic using PLE Devices

Conventional binary arithmetic can be replaced by another kind of computational methodology known as the Residue Number System. The use of this system allows integer arithmetic to be performed by arrays of PLE devices. The idea of PLE devices as arithmetic elements is simply to store pre-computed values of the arithmetic operation in the PLE memory cells and to use the input variables to the arithmetic as addresses to the PLE devices. Since we are computing the results of the arithmetic operations, the same PLE device organization may be used for many different functions. As an example, a 256x8-bit PLE device can be used as a 4 x 4-bit binary multiplier, or a 4 + 4-bit binary adder with the output multiplied by any 3-bit constant. It is this flexibility which holds so much appeal for the use of PLE devices as computational elements.

### Introduction

Arithmetic operations often involve carry propagation. This propagation causes too much delay for high-speed arithmetic. The Residue Number System (RNS) provides the required separation property needed for high-speed arithmetic. Each digit of the RNS representation is coded into a certain number of bits. In performing the basic operations of addition, subtraction, and multiplication, no information is required to be passed between the digits. Therefore, the number of bits required for representing each digit can be partitioned so that commercially available PLE devices can be used to implement the arithmetic.

### Basics of the Residue Number System

In this section, the elements of performing arithmetic using the RNS are introduced. The mechanism of coding numbers, the method of performing arithmetic using the RNS, and finally conversion between binary and RNS are presented.

### Coding of Residue Numbers

In principle, the coding of Residue Numbers is extremely simple. A residue digit is the remainder when the number to be coded is divided by another number (a modulus). As an example, the residue of 15 divided by a modulus 7 which yields 1 as the remainder can be represented by  $15|_7 = 1$ .

If operations are performed on an RNS where only one modulus is used, it will not be advantageous against a simple binary scheme at all since no information is encoded. Only the encoding of the binary numbers will provide the separation property which will speed up the arithmetic operation. The advantage of the RNS accrues when more digits are used.

Another example of encoding a number using 3 moduli to give a 3-digit RNS representation is as follows: let the moduli be

$m_1 = 3, m_2 = 4, m_3 = 5$ . The residues of  $X = 25$  will be shown as  $x_i$  where  $i = 1, 2, 3$ . Thus,

$$X_1 = \lfloor 25 \rfloor_{m_1} = \lfloor 25 \rfloor_3 = 1$$

$$X_2 = \lfloor 25 \rfloor_{m_2} = \lfloor 25 \rfloor_4 = 1$$

$$X_3 = \lfloor 25 \rfloor_{m_3} = \lfloor 25 \rfloor_5 = 0$$

In the RNS using the moduli 3, 4, 5, the number 25 is represented as (1, 1, 0).

The number of unique representations for a set of moduli is the Least Common Multiple (LCM) of the moduli. The most efficient set of moduli is one in which all moduli are pairwise relatively prime.

Table 1 illustrates an example of a set of moduli (3, 4) which can represent 12 integers. Note that the representations of 0 and 12 are the same, since the representation repeats itself after 12 integers.

| X  | (3)<br>x1 | (4)<br>x2 |
|----|-----------|-----------|
| 0  | 0         | 0         |
| 1  | 1         | 1         |
| 2  | 2         | 2         |
| 3  | 0         | 3         |
| 4  | 1         | 0         |
| 5  | 2         | 1         |
| 6  | 0         | 2         |
| 7  | 1         | 3         |
| 8  | 2         | 0         |
| 9  | 0         | 1         |
| 10 | 1         | 2         |
| 11 | 2         | 3         |
| 12 | 0         | 0         |

**Table 1. Representation of 0 to 12 in RNS Using Moduli 3 and 4. The Representation Repeats Itself After 12 Integers**

In table 2, (4, 6) is the set of moduli uses. Since 4 and 6 are not relatively prime, the number of integers that can be represented is not the product of 4 and 6, but instead is the LCM of 4 and 6 which is 12. The representation again repeats itself once every 12 integers.

## Residue Arithmetic using PLE Devices

| X  | (3)<br>x1 | (4)<br>x2 |
|----|-----------|-----------|
| 0  | 0         | 0         |
| 1  | 1         | 1         |
| 2  | 2         | 2         |
| 3  | 3         | 3         |
| 4  | 0         | 4         |
| 5  | 1         | 5         |
| 6  | 2         | 0         |
| 7  | 3         | 1         |
| 8  | 0         | 2         |
| 9  | 1         | 3         |
| 10 | 2         | 4         |
| 11 | 3         | 5         |
| 12 | 0         | 0         |
| 13 | 1         | 1         |
| 14 | 2         | 2         |
| 15 | 3         | 3         |
| 16 | 0         | 4         |
| 17 | 1         | 5         |
| 18 | 2         | 0         |
| 19 | 3         | 1         |
| 20 | 0         | 2         |
| 21 | 1         | 3         |
| 22 | 2         | 4         |
| 23 | 3         | 5         |
| 24 | 0         | 0         |

**Table 2. Representation of 0x24 for Moduli 4 and 6. Since 4 and 6 are Not Relatively Prime, and their LCM is Only 12, the Representation Again Repeats Itself Every 12 Integers**

Negative numbers are formed in the same way negative numbers are formed in binary (two's complement) system. To form the two's complement of a number in binary, we subtract the number  $2^B$  where B is the number of bits of the representation. In RNS, we subtract the RNS number from  $m_i$  to form the negative. Table 1 can be rewritten as in table 3 for encoding of negative numbers.

| X | (3)<br>x1 | (4)<br>x2 |
|---|-----------|-----------|
| 0 | 0         | 0         |
| 1 | 1         | 1         |
| 2 | 2         | 2         |
| 3 | 0         | 3         |
| 4 | 1         | 0         |
| 5 | 2         | 1         |
| 6 | 0         | 2         |
| 5 | 1         | 3         |
| 4 | 2         | 0         |
| 3 | 0         | 1         |
| 2 | 1         | 2         |
| 1 | 2         | 3         |

**Table 3. Representation of -6 to 5 in RNS using Moduli 3 and 4**

### Arithmetic Using the RNS

For two RNS numbers, X and Y, the result of the addition of the two numbers, Z, in RNS is given by:

$$|x_i + y_i|_{m_i} = z_i \text{ for all of the RNS digits.}$$

The same result is found of subtraction and multiplication. This means that arithmetic can be carried out between the same digits of the two numbers, X and Y, without interaction between adjacent digits. The arithmetic is therefore "carry-free". As an example, let us consider the following computation:

$$Z = (863 \times 3942) + (-862 \times 3942) = 3942$$

We only need sufficient dynamic range to represent the result; intermediate overflows can be ignored. Let us choose the following moduli for the RNS representation:

$$m_1 = 7, m_2 = 9, m_3 = 11, m_4 = 13$$

$$M = 9009$$

The above set can represent numbers in the range -4505 to 4504, and so this number range is sufficient for the calculation of this example. The computation is shown in table 4.

| X           | (7)<br>x1 | (9)<br>x2 | (11)<br>x3 | (13)<br>x4 |        |
|-------------|-----------|-----------|------------|------------|--------|
| 3942        | 1         | 0         | 4          | 3          |        |
| 863         | 2         | 8         | 5          | 5          |        |
| 862         | 1         | 7         | 4          | 4          |        |
| -862        | 6         | 2         | 7          | 9          |        |
| 863 x 3942  | 2         | 0         | 9          | 2          |        |
| -862 x 3942 | 6         | 0         | 6          | 1          |        |
| Z           | 1         | 0         | 4          | 3          | = 3942 |

**Table 4. Calculating  $Z = 863 \times 3942 + (-862 \times 3942) = 3942$**

10

## Division and Scaling

Division of residue numbers is more complicated than addition, subtraction, or multiplication. If the dividend is exactly divisible by the divisor, the operation is easier. In this case, a division by a number is the same as a multiplication by the inverse of that number. The multiplication inverse of an integer  $X$  in modulo arithmetic can be found by finding the vector  $(d_1, \dots, d_n)$  which satisfies the following:

$$|X \cdot d|_{m_i} = 1$$

For example, 95 divided by 5 in moduli 2, 7 and 9 can be done by first finding the vectors representing 95 and the inverse of 5.

$$|95|_2 = 1$$

$$|95|_7 = 4$$

$$|95|_9 = 5$$

So, for the multiplicative inverse of 5, we have:

$$|1/5|_2 = 1 \quad |5 \times 1|_2 = 1$$

$$|1/5|_7 = 3 \text{ since } |5 \times 3|_7 = 1$$

$$|1/5|_9 = 2 \quad |5 \times 2|_9 = 1$$

Therefore,

$$|95/5|_2 = |95|_2 \times |1/5|_2 = |1 \times 1|_2 = 1$$

$$|95/5|_7 = |95|_7 \times |1/5|_7 = |4 \times 3|_7 = 5$$

$$|95/5|_9 = |95|_9 \times |1/5|_9 = |5 \times 2|_9 = 1$$

and the answer is 19.

The operation becomes more complicated when the dividend is not exactly divisible by the divisor or one of the moduli of the multiplicative inverse does not exist, say, if the residue of the divisor for that modulus is 0. In this case, we need to obtain the remainder and then subtract the remainder from the dividend and then perform the division. The problem in finding the remainder seems to be the same as performing the division itself. However, this type of division can be done in a process called scaling, which will not be discussed in detail in this paper.

In spite of the improvements made in implementing scaling algorithms, scaling still represents a major effort in any calculation. It is advisable to use RNS only on systems where many arithmetic operations can be performed for each scaling operation.

## A System Using an RNS

An RNS is very useful in systems which have predefined operations and dynamic ranges. Moreover, it can only operate on integers, or at most, block floating-point numbers. Since the RNS involves conversions between integers and their RNS representations, and conversions by themselves are already time-consuming, the problem to be solved in the RNS system should be operation intensive.

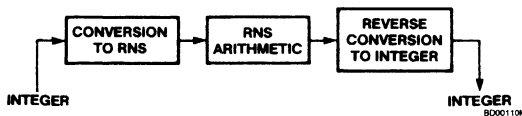


Figure 1. Architecture of an RNS

## Conversion to RNS Representation

The conversion of an integer to RNS can be viewed as a mapping process. PLE devices provide a natural implementation for mapping. For example, if an 8-bit integer is used to represent numbers ranging from 0 to 255, and the following moduli are arbitrarily chosen for conversion to RNS — 2, 11 and 15 (which can represent 330 integers), 8 bits of address are needed for the integer input and 9 outputs (1 for modulus 2, 4 for modulus 11 and 4 for modulus 15). In reality, only 8 outputs are needed because that bit of residue for modulus 2 is not required, since the least significant bit of the integer is also the residue of itself in modulus. In fact, a PLE8P8 will be sufficient.

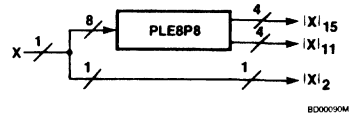


Figure 2. Mapping an 8-bit Integer,  $X$ , to Its Residues on Moduli 2, 11 and 15

Another example is a 14-bit integer which is to be converted to RNS. A 14-bit address needs 16K address spaces for the mapping. 16K is too deep for a PLE device. An alternative is to use 4K-deep PLE devices. PLE12P4 and PLE12P8 devices and a selector (e.g., a PLE5P8 to control the PLE devices (See Figure 3)). The PLE5P8 device will decode two of the address bits and will selectively enable one of the four sets of PLE devices as the mapping set, thus deepening the effective address to 16K.

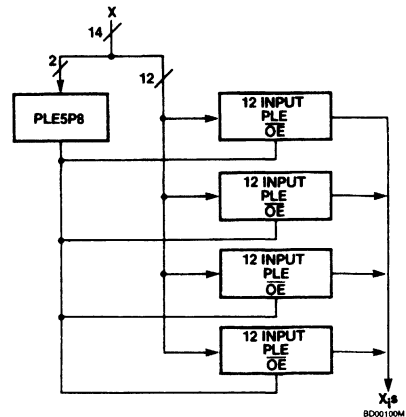


Figure 3. Mapping a 14-bit Integer,  $X$ , to Its Residues by Selectively Enabling the Outputs of One of the Four Sets of 12-input PLE Devices

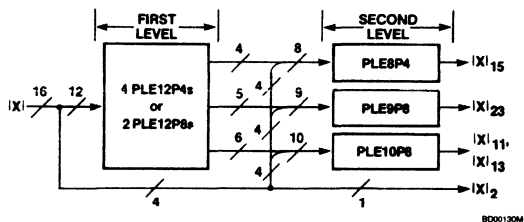
This method of expansion is not effective with bigger integers. If the integer is  $N$ -bit and the PLE address space available is  $M$ -bit, then  $2^{N-M}$  sets of PLE devices will be needed. Besides, as the dynamic range increases, the width of the outputs will



## Residue Arithmetic Using PLE Circuits

also increase about proportionally. An alternative method is to use two or more levels of PLE devices to generate the residues. The first level generates the remainders from the more significant bits of the integer and the products of some of the moduli. These remainders are in turns concatenated with the rest of the bits to become the inputs to the second level PLE devices.

For example, for a 16-bit integer 43689, and let us use (2, 11, 13, 15, 23) as the set of moduli. We may choose 23, 30 and 143 as the moduli for the first level. The first level consists of PLE12P4s and PLE12P8s which generate the remainders of the most significant 12 bits of 43689 which is 2730. We know that  $2730_{23}$  will be at most 22 and can therefore be represented by a 5-bit number;  $2730_{15}$  will be at most 14 and can be represented by another 4-bit number; and  $2730_{143}$  will be at most 142 and can be represented by a 6-bit number. The 5-bit number represented by  $2730_{23}$  will be concatenated with the least significant 4 bits of the integer and gives a 9-bit number which can perform another division by 23 to give the final  $43689_{23}$ ; the 4-bit number represented by  $2730_{15}$  will be concatenated with the least significant 4 bits of the integer and gives an 8-bit number which can perform another division by 15 to give the final  $43689_{15}$ ; the 6-bit number represented by  $2730_{143}$  will be concatenated with the least significant 4 bits of the integer and gives a 10-bit number which can perform another division by 11 and 13 to give the final  $43689_{11}$  and  $43689_{13}$ . As in the first example,  $43689_2$  is just the least significant bit of the integer.



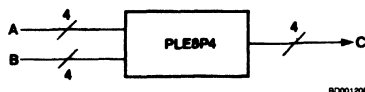
**Figure 4. Mapping a 16-Bit Integer X to Residues in Modulo 2, 11, 13, 15, and 23 Using Two-Level Mapping. The First Level Gives Remainders from the More Significant Twelve Bits, While the Second Level Finds the Final Residues**

In some circumstances, although an N-bit integer only has a dynamic range of  $2^N$ , the intermediate calculations may over-

flow. It is sometimes necessary to add some other moduli to boost up the dynamic range for the intermediate calculations.

### Arithmetic Operations in RNS

The arithmetic operations of the RNS is different from regular arithmetic in that even simple addition must be performed in modulo arithmetic. Simple ALU may not be able to handle this arithmetic. Again, PLE devices are proven to be most useful. A PLE8P4 device can perform addition, subtraction, or multiplication on two 4-bit residue numbers and give a 4-bit modulo result.



**Figure 5. Calculating  $C = A + B$ ,  $A - B$ ,  $B - A \times B$  Using PLE8P4**

If the modulus is large, say greater than 64, the combined number of bits for two residues will be greater than the number of address bits for the largest of the commercially available PLE device. Of course, more than one device can be used to deepen the effective address space. In this case, for every additional bit of a modulus, two more bits of address will be needed — one for each operand. In other words, for each additional bit of a modulus the address space of operation will be quadrupled. It is not very effective when the modulus grows too large. Fortunately, for both addition and multiplication, there are more efficient procedures.

### Large Modulus Addition

Table 5 shows the contents required for the addition operations in modulus 11. There is a lot of redundancy in the table which can be compressed by reducing what should be eight bits of inputs to five bits. What we need is just another level of mapping. There are a total of 121 combinations for a number of modulus 11 operating on another operand of the same modulus. In reality, only numbers ranging from 0 to 10 can be represented in modulus 11. The sum ranges from 0 to 20 (not in modulus 11). This range can be represented by a new set of submoduli (3, 7) which is five bits wide. In fact, any new set of submoduli which has a dynamic range of at least twenty-one can be used. The operands in modulus 11 will be converted to their representations in submoduli 3 and 7. The addition is done in the submoduli and the result is reconverted back to modulus 11 RNS (see Table 6).

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## Residue Arithmetic Using PLE Circuits

$x_{11} \begin{array}{c} \downarrow \\ \text{---} \\ \downarrow \\ 4 \end{array}$

|    |    |    |    |    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|----|----|
|    | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
| 0  | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
| 1  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 0  |
| 2  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 0  | 1  |
| 3  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 0  | 1  | 2  |
| 4  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 0  | 1  | 2  | 3  |
| 5  | 5  | 6  | 7  | 8  | 9  | 10 | 0  | 1  | 2  | 3  | 4  |
| 6  | 6  | 7  | 8  | 9  | 10 | 0  | 1  | 2  | 3  | 4  | 5  |
| 7  | 7  | 8  | 9  | 10 | 0  | 1  | 2  | 3  | 4  | 5  | 6  |
| 8  | 8  | 9  | 10 | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
| 9  | 9  | 10 | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
| 10 | 10 | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |

$y_{11} \begin{array}{c} \nearrow \\ \text{---} \\ \nearrow \\ 4 \end{array}$

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Table 5. Addition Table in Modulo 11 Arithmetic

|                              |   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |
|------------------------------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| $x + y$                      | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| $\lfloor x + y \rfloor_{11}$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
| $\lfloor x + y \rfloor_7$    | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 0 | 1 | 2 | 3  | 4  | 5  | 6  | 0  | 1  | 2  | 3  | 4  | 5  | 6  |
| $\lfloor x + y \rfloor_3$    | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1  | 2  | 0  | 1  | 2  | 0  | 1  | 2  | 0  | 1  | 2  |

Table 6. Conversion Table Between Modulo 11 Arithmetic and Modulo 3 and 7 Arithmetic

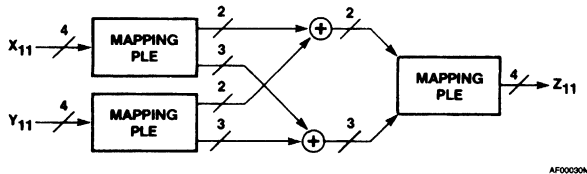


Figure 6. Calculating Addition of Two Numbers in Modulo 11 Using Submoduli Operations

### Large Modulus Multiplication

The solution to this problem in multiplication is similar. For example, if two RNS digits in modulus 91 is to be multiplied, (7, 13) may be chosen as a set of submoduli. The representation of an RNS digit in modulus 91 needs 7-bits. These 7-bits are first mapped to two RNS digits — in modulo 7 which needs 3-bits; and in modulo 13 which needs 4-bits. The representations of the two operands in the two moduli can then be multiplied and give the result in modulo 7 and modulo 13. The result is then converted back to modulo 91. Unfortunately, this scheme can be used only when the modulus can be expressed as a product of two integers which are relatively prime. But, in this case, the RNS digit may simply be repre-

sented as the residue of the two smaller integers instead of using them as submoduli.

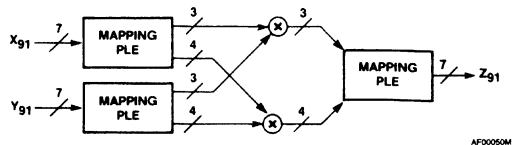


Figure 7. Calculating Multiplication of Two Numbers in Modulo 91 Using Submoduli Operations

## Residue Arithmetic Using PLE Circuits

Suppose another modulus 101 is used. 101 is a prime number and RNS in modulus 101 ranges from 0 to 100. The real dynamic range of the product of two numbers in modulus 101 is 0 to 10000, which is already too large for a PLE address space. For this modulus, we may use three 4K-deep PLE devices to deepen the address space. For a modulus like 1001, it may not be too efficient to use this scheme. Instead, since:

$$xy = [(x + y)^2 - (x - y)^2]/4$$

$$\text{or } = [x + y]^2/4 - [(x - y)^2]/4.$$

we may do  $x + y$  and  $x - y$  first and then do the squaring of the sum and the difference scaled by a factor of 4. Since the final product of two integers must be an integer, the squaring and scaling may be performed in one operation with the fractional part discarded. The way to obtain  $x + y$  and  $x - y$  is the same as what was discussed earlier in the "Large Modulo Addition" session.

In any event, operations on residues of large moduli are slower and involve more hardware and are not recommended.

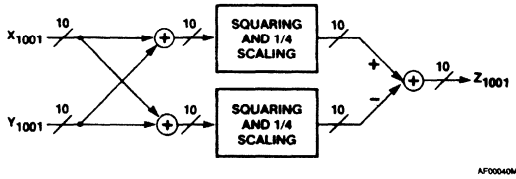


Figure 8. Performing Modulo 1001 Multiplication

### The Reverse Conversion

The reverse mapping from RNS to integer is not as straightforward as the other way. For an RNS system which has a total of twelve bits for all the residues, we can still use 12-input PLE devices to convert. We may also use several sets of 12-input PLE devices to reverse map the RNS if the integer is not much longer. But for very long integers, we may need to use the general algorithm for the reverse map:

1. Find  $M = m_1 \times m_2 \times \dots \times m_{n-1}$  (where  $n$  is the number of moduli)
2. Find  $t_i = M/m_i$

3. Find  $X = |x_1t_1 + x_2t_2 + \dots + x_n - 1n - 1|/M$

In hardware implementation,  $t_i$ 's are all known beforehand. We can map  $x_i$ 's to get the  $x_i t_i$ 's. Then we may perform Wallace Tree Compression (see the session on this subject in this handbook for more information) on the  $x_i t_i$ 's to give two-level operands which add to the final sum and divide it by  $M$  to get  $X$ . Again, PLE devices provide the best solution for Wallace Tree Compression.

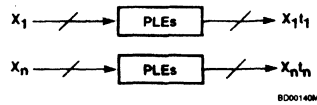


Figure 9a. Reverse Mapping to Get  $X_i t_i$

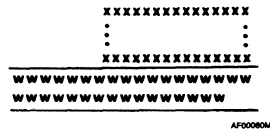


Figure 9b. Modulo  $M$  Wallace Tree Compression to Reduce the Number of Levels for Summation to 2 Followed by an Addition and Division to get  $X = |x_1t_1 + \dots + x_{n-1}t_{n-1}|/M$

### Conclusion

Memory elements provide excellent solutions to mapping functions — for control purposes, for arithmetic operations and general logic replacements. This paper investigates the possibility of using PLE devices as arithmetic units. In fact, for logic like residue number arithmetic, there is no better solution than to use these devices.

### Acknowledgement

Portions of this article were extracted from "Integer Arithmetic Using PROMs" by Dr. G.A. Jullien of the University of Windsor, Canada.

**Distributed Arithmetic Using PLE Devices**

In digital signal processing, sum-of-product type of operations are often necessary. These operations take the form of:

$$y = \sum_{i=0}^M a_i x_i \quad \text{where } a_i\text{'s are some constants}$$

If real multiplications are to be performed on every product term, it will need a total of M multiplications and M-1 additions. Multiplication operations normally take much longer than simple addition. An alternative to calculate equations of the above form is by using distributed arithmetic.

Suppose there is an N-bit integer X given by:

$$x = [x(N-1), x(N-2), \dots, x(1), x(0)]$$

or equivalently:

$$x = \sum_{j=0}^{N-1} x(j) 2^j$$

where x(N-1) is the most significant bit. The equation:

$$y = \sum_{i=0}^M a_i x_i$$

can be expressed as:

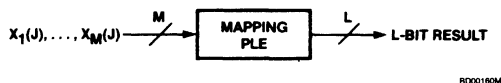
$$y = \sum_{j=0}^{N-1} a_j \left( \sum_{i=0}^{M-1} x_i(j) 2^j \right)$$

$$= \sum_{j=0}^{N-1} 2^j \left( \sum_{i=0}^{M-1} a_i x_i(j) \right)$$

Now, let:

$$H(j) = \sum_{i=0}^{M-1} a_i x_i(j)$$

Since H(j) is independent of i and since a<sub>i</sub>'s are all constants, we precompute for every x(j) = [x<sub>1</sub>(j), x<sub>2</sub>(j), ..., x<sub>M</sub>(j)] the values [x<sub>1</sub>(j), x<sub>2</sub>(j), ..., x<sub>M</sub>(j)] the values of H(j). Then x(j) can be used as the address of PLE devices whose outputs are the pre-computed result H(j).



**Figure 1. Mapping the j<sup>th</sup> Bit from Each of the x<sub>i</sub>'s to An L-bit Result**

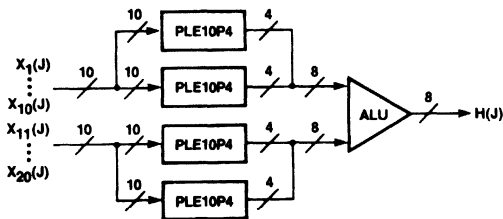
If there are M bits of data and the result is L-bit wide, and if M is very large, say 20, and L is 8, then we need 20 bits of

address lines if we want to use only PLE mapping. Since 20 bits of address translate to 1M words, and there is no available 1M-deep PLE device on the market, it is not realistic to use PLE mapping. Instead, H(j) can be partitioned as follows:

$$H(j) = \sum_{i=1}^{20} a_i x_i(j) \quad \text{for } M = 20$$

$$= \sum_{i=1}^{10} a_i x_i(j) + \sum_{i=11}^{20} a_i x_i(j)$$

the 20-bit address can be separated to two 10-bit addresses and each of them is individually mapped. The two outputs will then be added together to give H(j). An implementation of this mapping is shown in figure 2.



**Figure 2. Mapping the j<sup>th</sup> Bit of Each of x<sub>i</sub>'s to an L-bit Result When There Are Too Many x's (20 in This Case)**

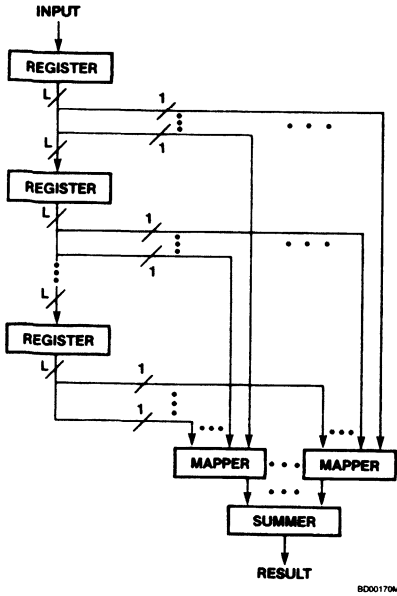
There is another alternative for implementing a sum-of-product operation: by using a multiplier accumulator (MAC).

The main constraint on distributed arithmetic is that one set of the multiplicands must be fixed, i.e. a<sub>i</sub>'s in this case, for the sum-of-product mapping while a MAC will allow flexibility.

There are normally some constraints on the width for the data bus from which the operands are loaded. If all the operands are new, it will need M cycles to load in the operands anyway, distributed arithmetic offers no advantages over MAC since distributed arithmetic needs to wait for all the operands to be loaded in before any operation can start while MAC can perform a multiplication and an addition every cycle. M cycles will be needed anyway for the complete operation using a MAC while distributed arithmetic may take even longer.

On the other hand, for operations like convolutions where one set of operands are fixed and only one new variable operand is needed for every result, distributed arithmetic will be a better solution since it can give a result in every clock-cycle while a MAC will need M-cycles (because recalculations of all the product terms are necessary). An implementation for convolution is shown in Figure 3.

## Distributed Arithmetic Using PLE™ Devices



**Figure 3. An Implementation of a Distributed Arithmetic System for Convolution**

There is another way to implement distributed arithmetic through bit-serialization:

From  $H(j)$ , the sum-of-product of  $y$  can be obtained as:

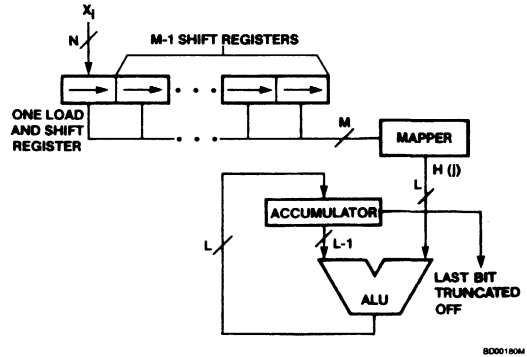
$$y = \sum_{j=0}^{N-1} 2^j J(j)$$

To implement this equation, consider that the least significant bit of the result is to be used only for rounding purposes only. Only the more significant bits will be retained. The computation can be performed in the following way:

- 1) For  $j = 0$ ,  
 $y_0 = 2^0 H(0) = H(0)$
- 2) For  $j = 1$  to  $N - 1$   
 $y_j = H(j) + 1/2 H(j - 1)$

Note that the second term of the last equation means that the previous result ( $y_{j-1}$ ) is shifted right one-bit; the last bit of  $y_{j-1}$  is truncated.

The implementation of such a system is shown in Figure 4. The system consists of a shift register, a mapper (PLE circuits, or PLE circuits with adders), an accumulator, and an ALU.



**Figure 4. A Bit-Serialization Implementation for a Distributed Arithmetic System**

The operations are as follows:

- 1) Load  $x_i$  onto the load and shift register at clock 0.
- 2) Load  $H(0)$  onto accumulator and shift all registers at clock 1.
- 3) From clock  $k$  (between clock 2 to clock  $N - 1$ ), the content of the accumulator will be replaced by the sum of  $H(k-1)$  and the more significant  $N - 1$  bits of the current accumulator value.
- 4) For clock  $N$ , the following are performed:
  - a) Repeat step 3. At the end of the operation, the accumulator contains the value of the result (scaled by the number of shifts)
  - b)  $x_{i+1}$  is loaded onto the load and shift register. The shifting frequency is equal to  $N$  times the basic rate.

Due to the fact that there are a number of shift operations necessary for each data load, this method is recommended for the following conditions:

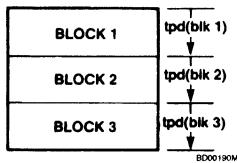
- 1) This design is under cost, power dissipation, and board space constraints.
- 2) This design is for high  $M$ -to- $N$ -ratio array multiplications.

10

## Registered PLE Devices in Pipelined Arithmetic

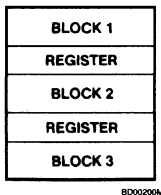
PLE devices are useful as logic elements, and registered PLEs are excellent media for pipelined arithmetic. Monolithic Memories supplies a number of registered PLE devices which provide effective solutions to pipelined systems.

A data processing system may have fall-through architecture. Since many of these operations may take a long time, it happens that the devices are not often tied up in operations. For example, in a system as in figure 1, the operations can be divided into three functional blocks. When the operands are loaded in, block 1 will operate first, followed by block 2 and then by block 3. When the data is in block 2, block 1 is not doing anything. We cannot at this time put in the next set of operands because changes in operands may disturb the operation in block 2.



**Figure 1. An Example of the Fall-Through Approach to Arithmetic Operation**

A solution to this is by registering the operands and signal paths when the operations is switched to block 2; and by registering the operands and signal paths again when the operations is carried out in block 3. The result is stated in figure 2. This architecture is called the pipelined structure. It makes the loading of the second set of operands possible even before the first result is out, thus increasing the throughput.



**Figure 2. Pipelined Arithmetic Operation**

The introduction of the registers for the pipeline increases the operation time of every block due to the addition of the setup times and the clock to output delays. The result is as follows:

- 1) Overall delay. The architecture in Figure 2 will need at least an additional 2 setup time and 2 clock to output delays of a register. In real, it will be more, because the minimum clock period will be determined by the sum of (i) the maximum of the operation times of individual blocks, and (ii) the setup time of the pipelined registers and (iii) the clock to output delay of the pipelined registers. Symbolically, the overall delays for the architectures in Figures 1 and 2 are:

$$t_{pd}(\text{Fig.1}) = t_{pd}(\text{blk 1}) + t_{pd}(\text{blk 2}) + t_{pd}(\text{blk 3})$$

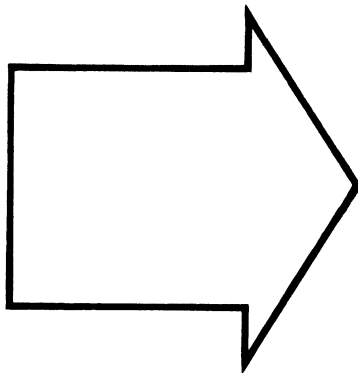
$$t_{pd}(\text{Fig.2}) = 2 \times \{ \max[t_{pd}(\text{blk 1}), t_{pd}(\text{blk 2}), t_{pd}(\text{blk 3})] + t_{su} + t_{clk} \} + t_{pd}(\text{blk 3})$$

Where  $t_{pd}(\text{Fig.1})$  and  $t_{pd}(\text{Fig. 2})$  are the propagation delays of the architectures in figure 1 and figure 2 respectively;  $t_{pd}(\text{blk 1})$ ,  $t_{pd}(\text{blk 2})$ ,  $t_{pd}(\text{blk 3})$  are the propagation delays of block 1, block 2, and block 3 respectively; and  $t_{su}$  and  $t_{clk}$  are the setup time and clock-to-output delay of the registers respectively.

- 2) Throughputs of clock rate. The architecture in figure 1 has a throughput period of  $(t_{pd}(\text{blk 1}) + t_{pd}(\text{blk 2}) + t_{pd}(\text{blk 3}) + t_{su} + t_{clk})$ , assuming that the operands are coming from and the result is going to some registers; the architecture in Figure 2 has a throughput period of  $(\max[t_{pd}(\text{blk 1}), t_{pd}(\text{blk 2}), t_{pd}(\text{blk 3})] + t_{su} + t_{clk})$  which is faster.

PLE devices are useful as logic elements, and registered PLE devices are excellent media for pipelined arithmetic. Monolithic Memories supplies a number of registered PLE devices which provide effective solutions to pipelined systems.

Applications for pipeline arithmetic include array and digital signal processing.



|   |           |
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# Testing Your PAL Devices

Manouchehr Vafai

## Introduction

The advantage of Programmable Array Logic (PAL®) circuits as a basic building block of digital system is now well established.

PAL circuits are a unified group of devices which combine programmable flexibility with high speed and extensive selection of interface options.

The architecture of PAL circuits consists of programmable-AND-OR gate arrays, output-registers and I/O feedback as shown in Figure 1.

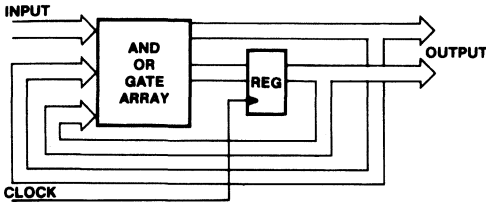


Figure 1. PAL Circuit Architecture

The increased system speed, reduced chip count and availability of a CAD tool called PALASM™ software should leave no doubt for design engineers that they have made a right choice in choosing PAL circuits.

The HAL circuit family is the masked program version of a PAL circuit. HAL® circuits will provide the users a cost-effective solution for large quantities and is unique in that it is a gate array with a programmable prototype.

The following steps are required when designing with PAL circuits.

- Familiarity with Demorgan's law.
- Familiarity with the Karnaugh maps.
- Ability to express logic equation in Sum-of-Product form.
- Ability to write simple seed vector for function table.
- Familiarity with different PAL circuits.

## Programming PAL Circuits

PAL circuits will be programmed using PALASM software.

PALASM software is the CAD tool developed by Monolithic Memories to facilitate the process of programming. PALASM software is a Fortran IV program which assembles and simulates PAL circuits design specifications. It generates PAL circuit fuse patterns in formats compatible with PAL circuits or PROM programmers.

Besides generating PAL circuit fuse pattern in different pro-

gramming formats, PALASM software does the following:

- Assembles PAL circuit design specification and reports error messages.
- Simulates the Function Table.
- Tests each product term for Stuck at zero (SA0) and stuck at one (SA1) faults.

The purpose of writing vectors is to prove that a device is capable of performing its function before it is put in a system. PALASM software will exercise the vectors and will report any discrepancy. Writing vectors will raise confidence that a device will function properly at least in the design level. The simulator also transfers the function table vectors to a set of universal test vectors which may be used for functional testing after the device is programmed.

When a new system is transferred to production, the system designer hands over the responsibility for the system to the test engineering department, who now determines how and what test should be performed to ensure proper operation of the system. At this point the system designer transmits the necessary information for understanding the system operation. Unfortunately, much information is lost at this point. Test engineers usually have a hard time understanding how the system works with insufficient information. It is the design engineer who best knows the operation of his PAL circuit design, and it is the design engineer who can quickly specify a few seed vectors to give the test a starting point in solving the future problem.

## Design for Testability

In short the only way to control a digital circuit is to apply a known value to its input. Fault simulation has been the best technique of yielding a quantitative measure of test effectiveness. Fault simulation will test stuck-at-0 (SA0) and stuck-at-1 (SA1) of input and output lines. By generating test vectors that will test for each product term for (SA0) and (SA1) faults, then by observing the corresponding output and comparing it with the fault-free output, one can conclude whether a fault can be detected or not.

Consider the following example:

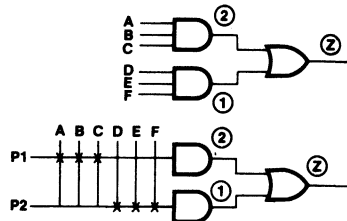


Figure 2. Logic Diagram and its PAL Circuit Implementation

## Testing Your PAL Devices

A B C D E F Z (vector-1)  
1 1 1 0 X X 1

The (vector-1) selects a product term P1. Under a fault-free condition, the output (2) will be high (we can observe this); however, under a fault condition the output will be low. In other words, one can conclude that either product term (P1) is (SA0) or outputs Z (Figure 2.) are (SA0).

Now consider vector 2.

A B C D E F G (vector-2)  
0 0 0 0 0 0

As it can be seen that both of the product terms are low, if the observed output is high, one can conclude that either product terms or outputs are Stuck-at-one.

Fault simulation grading is used by Monolithic Memories to evaluate candidates design for transferring from a PAL circuit to a HAL circuit.

In designing with PAL circuits, four different cases should be considered.

1. A purely combinational circuit where output is function of input.
2. A purely combinational circuit where output is function of input and feedback from output.
3. A purely sequential logic where output is function of input and feedback from output.
4. A combinational-sequential logic where output is function of input, feedback from combinational output and feedback from sequential output.

In cases 1 and 2 we can define a structured way of writing function table. Cases 3 and 4, on the other hand, because of dependency of the device on the previous state of the device, impose a relatively more sophisticated scheme of testing strategy.

In the following examples the various techniques which might be helpful in testability of PALs, will be discussed.

### Example 1: Glitch-free and Testable

Suppose we want to implement (EQ-1) using any of the combinational PAL.

$$F = X'A + \bar{X}'B \quad (\text{eq-1})$$

The K-MAP and logic diagram are shown in (Figure 3.)

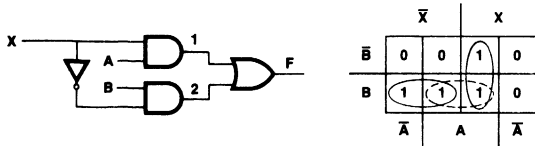


Figure 3. Logic Diagram and its K-Map

The above logic is testable because we have full control over each node for (SA0) and (SA1) test.

The implementation using PAL circuits is as follows:

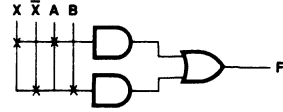


Figure 4. PAL Circuit Implementation of the Logic

Ideally the output should always be high if both inputs are high. The circuit is not glitch-free, the output might momentarily drop to low if we change the state of X, due to propagation delay between X and X-bar.

The problem will be solved by including a redundant (AB) term to (eq-2).

The equation will look like this.

$$F = XA + \bar{X}B + AB \quad (\text{eq-2})$$

The output is glitch-free, but untestable!

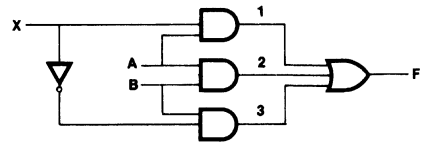


Figure 5. A Glitch-free Circuit

Node (2) is not Observable for (SA0). One can not force node (2) to one and keep node (1) and (3) in the low state. So the redundant product term is untestable.

This circuit can be made testable by the addition of control signal (Y) as follows:

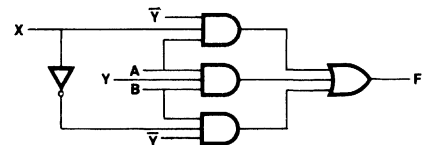


Figure 6. Glitch-free and Testable Logic

Now the logic is glitch-free and testable.

### Example 2: Untestable Logic — A Simple Example

The logic  $F := \bar{F}$  is untestable

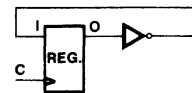
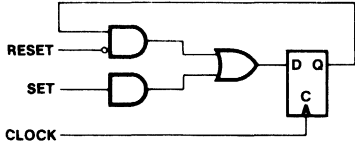


Figure 7. Implementation of  $F := \bar{F}$

## Testing Your PAL Devices

The initial state of the oscillator is unknown; this system can be made testable as follows:



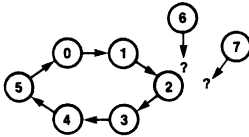
**Figure 8. Implementation of  $F := \bar{F}$  with SET and RESET**

It has been done by addition of two control signals (RESET and SET) and one extra product term.

### Illegal States

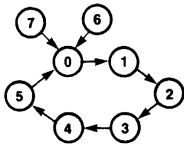
Upon power-up the initial state of output registers are unknown; this might force the device into one of the "illegal states".

The design engineer should be worried about the illegal state at design time. For example let's look at modulo-6 state machine



**Figure 9. State Transition Diagram for a Modulo-6 Counter**

The design engineer might ignore the other possible state (6, 7) but his ignorance might be costly at test time. If upon power-up the machine starts at either of (6) or (7) state, there is no way to control the state-machine. The best solution is to force both of the illegal states into one of the known states.

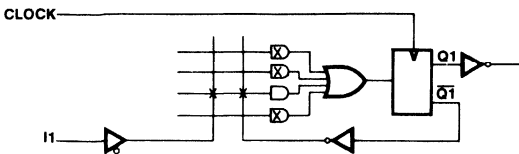


**Figure 10. A Modulo 5 Counter with No Illegal State**

### Example 3: Design "pitfall" Case One

Consider the implementation of the following example

$$Q1 := I1 * Q1$$



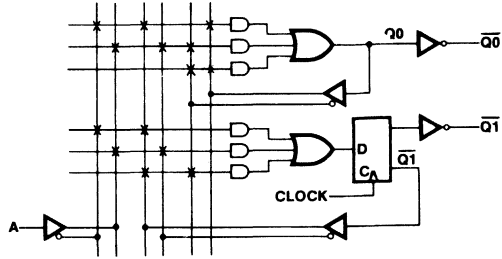
**Figure 11. Implementation of  $Q1 := I1 * Q1$  Using a PAL**

If Q1 falls to zero, it will stay there forever. The logic needs a control signal for output reset.

### Example 4: Design "Pitfall" Case Two

Consider the implementation of the following equation:

$$\bar{Q0} = \bar{A} * \bar{Q1} * Q0 + A * Q1 * \bar{Q0} + \bar{Q0}$$



**Figure 12. Implementation of  $\bar{Q0} = \bar{A} * \bar{Q1} * Q0 + A * Q1 * \bar{Q0} + \bar{Q0}$**

If  $\bar{Q0}$  goes to one it will stay there forever, the logic needs a control signal to clear it's output.

### Hard Array Logic (HAL) Devices

The HAL device is the Hard Array version of a PAL device.

HAL logic circuits are the best choice for designs that are firm and volumes are large enough to justify the initial cost. Besides having Boolean equation in PAL DESIGN SPECIFICATION format the user should provide the following.

1. A FUNCTION TABLE which gives enough information about the operation of the device. Normally this FUNCTION TABLE shall test a minimum of 50% "Stuck at fault" grading using PALASM or TEGAS fault grading test.
2. The FUNCTION TABLE shall be constructed such that the device may be initialized to a known state within a specified number of steps (or clocks).

The HAL CIRCUIT SPECIFICATION is the input file used with PALASM software for the HAL's. The input format as shown in example 5 is as follow:

- Line 1 HAL circuit part number
- Line 2 user's part number followed by originator's name and the date
- Line 3 device application name
- Line 4 user's company name, city, state
- Line 5 pin list which is a sequence of symbolic names separated by one or more spaces. All pins including VCC and GND must be named
- Line M the logic equation which are used to generate metal masks from the provided equations

## Testing Your PAL Devices

```

HALL2H6                      PAL DESIGN SPECIFICATION
EXAMPLE 5                    MANO VAFAI 04/20/83
BASIC GATES
MMI SANTA CLARA, CALIFORNIA
C D F G M N P Q I QND J K L R O H E B A VCC
    
```

```

B = /A      ;      INVERTER GATE (EQ - 1)
              ;      ONE PRODUCT TERM: #1 (/A)

E = C*D     ;      AND GATE (EQ - 2)
              ;      ONE PRODUCT TERM: #1 (C*D)

H = F + G   ;      OR GATE (EQ - 3)
              ;      TWO PRODUCT TERMS: #1 (F), #2 (G)

L = /I + /J + /K ;      NAND GATE (EQ -4)
              ;      THREE PRODUCT TERMS: #1(/I), #2(/J), #3(/K)

O = /M*/N   ;      NOR GATE (EQ-5)
              ;      ONE PRODUCT TERM: #1 (/M*/N)

R = P*/Q + /P*Q ;      XOR GATE (EQ-6)
              ;      TWO PRODUCT TERMS: #1(P*/Q), #2(/P*Q)
    
```

```

_____| LINE 1
_____| LINE 2
_____| LINE 3
_____| LINE 4
_____| LINE 5
    
```

} LINE M

### FUNCTION TABLE

| A                        | B   | C   | D    | E   | F   | G | H | I | J | K | L | M | N | O | P | Q | R |                          |
|--------------------------|-----|-----|------|-----|-----|---|---|---|---|---|---|---|---|---|---|---|---|--------------------------|
| ;AB CDE FGH IJKL MNO PQR |     |     |      |     |     |   |   |   |   |   |   |   |   |   |   |   |   | OPTIONAL COMMENTS FIELD  |
| LH                       | XXX | XXX | XXXX | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-1,PT-1) SA0 TEST     |
| HL                       | XXX | XXX | XXXX | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-1,PT-1) SA1 TEST     |
| XX                       | BBH | XXX | XXXX | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-2,PT-1) SA0 TEST     |
| XX                       | LLL | XXX | XXXX | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-2,PT-1) SA1 TEST     |
| XX                       | XXX | HLH | XXXX | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-3,PT-1) SA0 TEST     |
| XX                       | XXX | LHH | XXXX | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-3,PT-2) SA0 TEST     |
| XX                       | XXX | LLL | XXXX | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-3,PT-1,2) SA1 TEST   |
| XX                       | XXX | XXX | LBBH | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-4,PT-1) SA0 TEST     |
| XX                       | XXX | XXX | HLHH | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-4,PT-2) SA0 TEST     |
| XX                       | XXX | XXX | BBHL | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-4,PT-3) SA0 TEST     |
| XX                       | XXX | XXX | BBHL | XXX | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-4,PT-1,2,3) SA1 TEST |
| XX                       | XXX | XXX | XXXX | LLH | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-5,PT-1) SA0 TEST     |
| XX                       | XXX | XXX | XXXX | HHL | XXX |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-5,PT-1,2) SA1 TEST   |
| XX                       | XXX | XXX | XXXX | XXX | HLH |   |   |   |   |   |   |   |   |   |   |   |   | (EQ-6,PT-1) SA0 TEST     |

} LINE N

### DESCRIPTION

THE MAIN PURPOSE OF THIS EXAMPLE IS TO FAMILIARIZE THE USER WITH WHAT WE MEAN BY "FUNCTION TABLE", PRODUCT TERM (PT) COVERAGE, STUCK-AT-0 (SA0) AND STUCK-AT-ONE (SA1) TESTS.

### EXAMPLE 5

- Line N the function table which begins with the key word "FUNCTION TABLE." It's followed by a pin list which may be in a different order and polarity from the pin list in line 5. VCC and GND cannot be listed. The pin list is followed by dashed line; e.g., - - - - which in turn is followed by a list of vectors, one vector per line. One state must be specified for each pin name and optionally separated by spaces. A vector is a sequence of states listed in the same order as the pin list and followed by an optional comment.

The allowable states are H (HIGH LEVEL), L (LOW LEVEL), X (IRRELEVANT), C (TRANSITION FROM HIGH TO LOW OR CLOCK PULSE) and Z (HIGH IMPEDENCE). After preparing the PAL DESIGN SPECIFICATION in the above format, PALASM software can be used to simulate and perform fault testing.

## Testing Your PAL Devices

### BASIC GATES

```

1 XXXXXXXXXXXXXXXXXXXX01
2 XXXXXXXXXXXXXXXXXXXX11
3 1XXXXXXXXXXXXXXXXXXXX1
4 0XXXXXXXXXXXXXXXXXXXX1
5 XX10XXXXXXXXXXXXXXXX1
6 XX01XXXXXXXXXXXXXXXX1
7 XX00XXXXXXXXXXXXXXXX1
8 XXXXXXXX011XXXXXXXX1
9 XXXXXXXX101XXXXXXXX1
10 XXXXXXXX1010XXXXXXXX1
11 XXXXXXXX1111XXXXXXXX1
12 XXXX00XXXXXXXXXXXX1
13 XXXX11XXXXXXXXXXXX1
14 XXXXX10XXXXX0XXXX1
    
```

### PASS SIMULATION

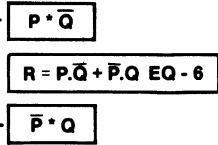
```

PRODUCT: 1 OF EQUATION. 6 UNTESTED (SA1) FAULT
PRODUCT: 2 OF EQUATION. 6 UNTESTED (SA1) FAULT
PRODUCT: 2 OF EQUATION. 6 UNTESTED (SA0) FAULT
    
```

NUMBER OF STUCK AT ONE (SA1) FAULTS ARE = 8

NUMBER OF STUCK AT ZERO (SA0) FAULTS ARE = 9

PRODUCT TERM COVERAGE = 85%



### FAULT-TESTING

The following information is reported to the user

- Total number of SA1 Faults. (8 in example 5)
- Total number of detected SA0 faults. (9 in example 5)

SA1 faults + SA0 faults

-----

2 \* total number of product terms

$$* 100 \% \left( \frac{8+9}{2*10} \right) * 100\% = 85\% \text{ ex-5}$$

- One vector may detect more than one SA0 OR SA1 FAULTS (vector # 11 in example 5)
- The user is reported with a message which tells him the product term for which it was not tested. (PRODUCT TERM 1 & 2-EQ 6, in example 5)

The following vectors can be added to the function table in example 5 in order to achieve 100% fault coverage.

| AB CDE FGH IJKL MNO PQR | COMMENTS (EXAMPLE 5)   |
|-------------------------|------------------------|
| XX XXX XXX XXXX XXX LHH | (EQ-6,PT2) SA0 TEST    |
| XX XXX XXX XXXX XXX HHL | (EQ-6,PT-1,2) SA1 TEST |

PALASM™ software has tested the above function table for example 5, the result is as follows:

### BASIC GATES

```

1 XXXXXXXXXXXXXXXXXXXX01
2 XXXXXXXXXXXXXXXXXXXX11
3 1XXXXXXXXXXXXXXXXXXXX1
4 0XXXXXXXXXXXXXXXXXXXX1
5 XX10XXXXXXXXXXXXXXXX1
6 XX01XXXXXXXXXXXXXXXX1
7 XX00XXXXXXXXXXXXXXXX1
8 XXXXXXXX011XXXXXXXX1
9 XXXXXXXX101XXXXXXXX1
10 XXXXXXXX1010XXXXXXXX1
11 XXXXXXXX1111XXXXXXXX1
12 XXXX00XXXXXXXXXXXX1
13 XXXX11XXXXXXXXXXXX1
14 XXXXX10XXXXX0XXXX1
15 XXXXX01XXXXX0XXXX1
16 XXXXXX1XXXXX0XXXX1
    
```

### PASS SIMULATION

NUMBER OF STUCK AT ONE (SA1) FAULTS ARE = 10

NUMBER OF STUCK AT ZERO (SA0) FAULTS ARE = 10

PRODUCT TERM COVERAGE = 100%

PALASM™ is a trademark of Monolithic Memories.

# PAL<sup>®</sup> 20RA10 Design for Testability

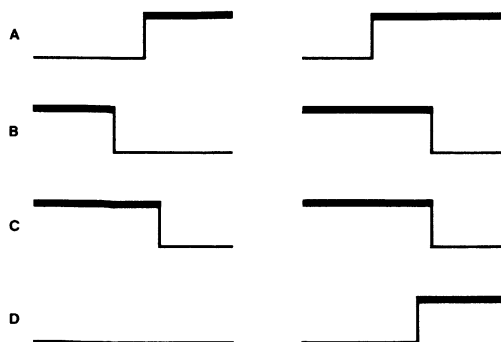
Edwin Young

This article is written to help customers of the PAL20RA1 recognize some fundamental design-for-testability issues which may arise due to the part's unique architecture. Customers should understand that these issues represent design criteria which Monolithic Memories will use to accept PAL20RA10 patterns for test generation/fault grading and for estimating the resource cost to test engineering if accepted. This article does not address the BUSINESS REQUIREMENTS such as the need for acceptable test vectors and the acceptability of a particular pattern for processing as a HAL<sup>®</sup> device.

The designer who wishes to use a 20RA10 in his/her design must bear in mind that although the part has preloadability, certain designs could diminish the effectiveness of this feature. The following rules are presented to help establish Test Engineering acceptance standards for the 20RA10. Additional general guidelines applicable are available in the PAL Handbook article reprint "Testing Your PAL Devices" by M. Vafai.

## Avoid False Latching Situations

The equation  $D = (A \cdot B) + (C + D)$  and its variants are susceptible to latching hazards since ATE may have considerable input skew. Of course, from a testing viewpoint, such implementations should be avoided. But if they must be implemented, care must be exercised in developing the function table so as to account for the possibility of latching. The designer must adopt and stick to some guideline such as "no more than one input undergoes a change in logic value per vector" when specifying the function table.

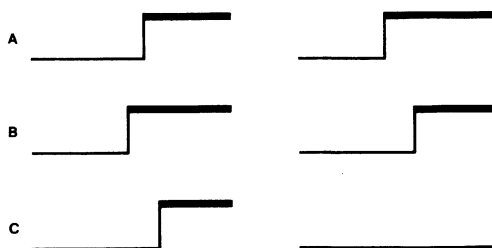


Assume A, B and C are primary inputs while D is a fed-back output. The waveforms to the left show two possible outcomes for output D depending on the skew of inputs A and B, which is a function of tester calibration.

The latch problem described is not unique to the 20RA10 but is clearly applicable to any PAL with asynchronous outputs with feedback (e.g., 16R4). The designer should realize, however, that false latching may occur on a 20RA10 even if all outputs are registered. Consider the equation set  $D := C$  and  $D.CLKF = A \cdot B$  for a simple registered 20RA10 output. The resulting waveforms would look similar to those of the previous asynchronous example. The important distinction here is that a 20RA10 has programmable asynchronous clocks rather than a single 'master clock' pin which can cause difficulties in testing.

## Allow Data to Setup Prior to Clocking

The previous two pitfalls were examples of flaky latching due to glitches during testing. Consider the equation set  $C := B$  and  $C.CLKF = A$  for a registered output. The following example shows a definite positive latching...but of flaky (skewed) data.



Assume B is a primary input. Then the timing for situations at far left and right may be with A as feedback and as primary input respectively.

This example illustrates another aspect of the programmable asynchronous clock feature of the 20RA20: Clock pulses can have critical minimal or no delay relative to data setup time. Note that all other registered PAL devices have dedicated common clock pins to which delayed pulses are applied by the ATE to allow sufficient data setup time and ATE input skew.

## Avoid Unreachable States

The 20RA10 may be preloaded to any state desired for testing purposes. Unfortunately, the desired state may not exist long enough for the simulator or ATE to use it. With all other pre-loadable PALs, any arbitrary state may be preloaded into the registers on a given test vector and the state will persist into the next vector providing the required conditions to detect some fault/s. This means all stuck-at-type faults *possibly* detectable can be detected. With the 20RA10, the preloaded state may feed back to assert state dependent resets or presets on one or more

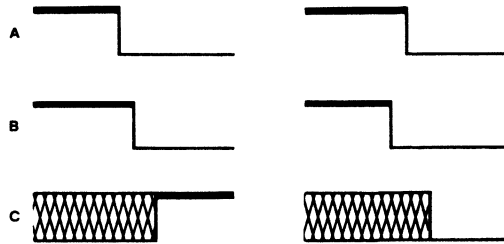
## PAL20RA10 Design for Testability

registers. Consequently, the desired state may last only a few nanoseconds after the preload vector is complete before changing to some new state. Since the desired state is not stable going into the vector immediately following the preload vector, the faults expected to be detected become non-detectable.

Another problem arises whenever output control logic is a function of state. In this case, assume the desired state for detecting faults is preload and is stable in the next vector. If this state provides the conditions necessary to detect faults and also disables the outputs, then the faults will be effectively masked from detection.

### Caution on Individual Register Bypass Mode

The 20RA10 allows the designer to permanently and independently bypass any register. Those registers not permanently bypassed may be bypassed under program control by setting both SET and RESET nodes to logic high. In this 'bypass mode', the register's D node is multiplexed to the output rather than its Q node. There is generally no test problem in going into bypass mode. The pitfall is in returning to 'register mode' operation, which only the 20RA10 can do. Consider the equation set  $C.RSTF = A$  and  $C.SETF = B$  of a simple registered output and



An indeterminate state on the output can occur if both primary inputs A and B go to logic low on the same vector.

the following possible waveforms. A race condition will occur to see whether set or reset operation prevails in going from bypass to register mode. There are two methods by which to get known states for testing purposes:

- 1) Clock a known value into the register on the next vector or;
- 2) Set RESET to logic low on one vector and then SET to low on the next or vice versa.

# PAL® Design Function and Test Vectors

E. Young

## Introduction

This article was written to help customers understand the purpose of seed vectors and provide some general guidelines as to what elements are important in developing them. It is assumed that the reader has read the "PALASM" Manual and the "PAL Handbook" article reprint *Testing Your PAL Devices*.

In general, PAL®/HAL® devices are required to provide a function table or "Seed Vectors" to Monolithic Memories in order to ensure that parts shipped have a high degree of reliability for the application intended. Ideally, these vectors should accomplish three objectives:

- 1) Initialize the PAL device preferably in the same way as in the actual system;
- 2) Exercise the customer's functions thoroughly, emulating actual system operation as closely as possible;
- 3) Provide a high degree of fault coverage.

## Initialization

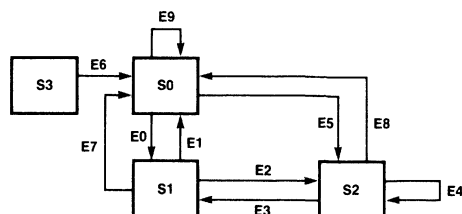
Seed vectors which initialize the PAL logic circuit consist of one or more vectors placed at the very beginning which will bring both combinatorial and registered outputs to a stable and known logic state (1 or 0). This is necessary in the system also so that its operation upon power-up is predictable. Furthermore, care should be taken to ensure that the initialization state is a legal state of the state machine for which the PAL device is intended.

## Exercise Functions

The essential functions for which the PAL device was originally designed must be exercised fully. This will assure that the tested parts work the way they were intended to. In addition to essential "designed-for" functions, it is prudent to include general test exercises such as verifying that outputs don't change in the absence of clock pulses and checking to see that inputs in the "don't care" (X) state don't produce adverse responses. General test exercises help to reinforce the validity of a design and can uncover overlooked design errors. After a set of exercises has been decided upon, the next step is to write them in a format suitable for simulation purposes.

The designer may have originally defined the functions in terms of equations, state diagrams, truth tables, etc. Truth tables are readily reformatted to PALASM1 syntax "Function Tables" and exercises with the simulation option (code=S). State diagrams can be converted by expressing each state and input edge in binary vector format and sequencing them according to the diagram's flow. The customer should become thoroughly familiar with the syntax of the function table description (see the PALASM Manual for a detailed treatment of syntax) before attempting to translate truth tables, etc.

The following simple example demonstrates how exercising seed vectors might be derived from a designer's state diagram:



Assume the following state and edge definitions accompany the diagram:

|                        |             |
|------------------------|-------------|
| STATE 0 = LL           | EDGE 0 = LL |
| STATE 1 = LH           | EDGE 1 = LH |
| STATE 2 = HL           | EDGE 2 = LL |
| (ILLEGAL) STATE 3 = HH | EDGE 3 = LH |
|                        | EDGE 4 = LL |
|                        | EDGE 5 = HH |
| (INITIALIZING)         | EDGE 6 = HL |
| (INITIALIZING)         | EDGE 7 = HL |
| (INITIALIZING)         | EDGE 8 = HL |
| (INITIALIZING)         | EDGE 9 = HL |

From the above information, it is possible to create the truth table for the diagram and then the function table representation:

| EDGE | PRESENT STATE | NEXT STATE |
|------|---------------|------------|
| AB   | CD            | CD         |
| HL   | XX            | LL         |
| HH   | LL            | HL         |
| LL   | HL            | HL         |
| LH   | HL            | LH         |
| LH   | LH            | LL         |
| LL   | LL            | LH         |
| LL   | LH            | HL         |



## PAL Function and Test Vectors

| FUNCTION TABLE REPRESENTATION |    |                   |
|-------------------------------|----|-------------------|
| FUNCTION TABLE                |    |                   |
| AB                            | CD |                   |
| HL                            | LL | INITIALIZE DEVICE |
| HH                            | HL | TEST EDGE 5       |
| LL                            | HL | TEST EDGE 4       |
| LH                            | LH | TEST EDGE 3       |
| LH                            | LL | TEST EDGE 1       |
| LL                            | LH | TEST EDGE 0       |
| LL                            | HL | TEST EDGE 2       |

### Fault Coverage

Another criterion for seed vector completeness is "fault coverage". Fault coverage is an empirical method and is more quantitative than functional exercising — indeed, no knowledge of the circuit's intended function is necessary or assumed (although it could help) while developing fault coverage vectors.

Fault coverage, being an empirical approach to determining a logic circuit's reliability, uses the concept of "failure models" to grade the effectiveness of a given set of test vectors. This is called "fault grading". In fault grading a set of vectors, a fault coverage value is calculated that is simply the ratio of detected faults to total faults expressed as a percentage.

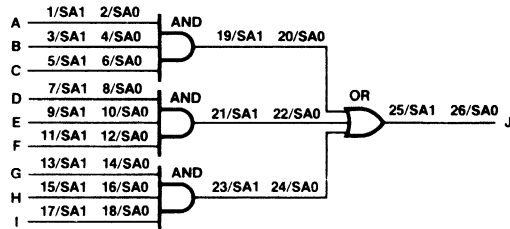
Test vectors may be graded against one or more failure models. Some well-known models include single stuck-at-1/stuck-at-0, pattern sensitivities, shorts and opens and multiple stuck-at models. Selection of a failure model (or models) for fault grading fundamentally depends on the model's empirical effectiveness for screening bad parts and will be affected by a number of factors including circuit technology and fault simulator capabilities.

The most common and primary fault coverage failure model considered by "TGEN" at Monolithic Memories is the classic single stuck-at-1/stuck-at-0 failure model. "TGEN" automatically appends test vectors which test for the following additional failure models where applicable: 1) Adjacencies, 2) Clock, 3) Tri-state.

"TGEN" has a specified minimum value of fault coverage for PAL and HAL devices based on the single stuck-at failure model. The minimum values are determined by current "TGEN" policy (see your FAE) and reflect the economic trade-off between acceptable levels of reliability and the cost of test generation for maximum coverage. PAL and HAL devices for which the specified minimum values cannot be attained will require the customer's written waiver for low coverage prior to production release of the pattern.

The fault coverage percentage determined by "TGEN" is different from the percentage determined by selecting the fault testing option (code=F) of PALASM1 software. In PALASM1 software fault coverage is based on product term coverage (PTC). PTC is still the ratio of detected to total faults except that "detected" and "total" fault sums refer to stuck-at faults on product term outputs only. PTC ignores stuck-at faults which occur anywhere else. A more accurate procedure is to calculate the coverage based on all the circuit nodes where a stuck-at condition may occur. When every node (fault site or wire) is considered, the coverage calculated correlates to the design's testability better and will generally be a much lower value than PTC. "TGEN" goes one step further in conservatism by calculating fault coverage on a "collapsed" fault basis. Fault collapsing simply divides all the stuck-at faults into groups such that, within a group, if one fault is detected, then all the others in the group are detected too. The advantage of collapsing it that only one representative fault in a group needs to be selected for test generation and if it is detected, then the other "equivalent" faults are detected by definition. This saves time and effort on test generation for equivalent faults. Calculations on a collapsed fault basis treat each group as one fault.

The following simplified example demonstrates the difference in fault coverage calculations using a collapsed fault list:



Note: This example is a simplified one for illustrative purposes only and does not show the effects of faults normally associated with input or output buffers. Also, some partial collapsing has already been done (i.e., input faults of "OR" gate are collapsed into output faults of "AND" gates).

Assume the above circuit is to be realized as a PAL or HAL device. Suppose some seed vectors are provided also, as shown here:

|          | A | B | C | D | E | F | G | H | I |
|----------|---|---|---|---|---|---|---|---|---|
| VECTOR 1 | H | H | H | L | L | L | L | L | L |
| VECTOR 2 | L | L | L | H | H | H | L | L | L |
| VECTOR 3 | L | L | L | L | L | L | H | H | H |
| VECTOR 4 | L | L | L | L | L | L | L | L | L |

## PAL Function and Test Vectors

The seed vectors on the previous page yield various values for fault coverages corresponding to the method of calculation as shown in the table below.

|   | PTC               | EVERY NODE   | COLLAPSED                       |          |
|---|-------------------|--|---------------------------------|----------|
| <b>SUBSET OF TOTAL FAULTS CONSIDERED FOR CALCULATIONS THAT ARE DETECTED BY EACH VECTOR (SHOWN AT FAR RIGHT)</b> | 20                | 2,4,6,20,26  | 2                               | Vector 1 |
|   | 22                | 8,10,12,22   | 8                               | Vector 2 |
|   | 24                | 14,16,18,24  | 14                              | Vector 3 |
|   | 19,21,23          | 19,21,23,25  | 19                              | Vector 4 |
| <b>TOTAL FAULTS CONSIDERED FOR CALCULATIONS</b>   | 19,20,21,22,23,24 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26 | 1,2,3,5,7,8,9,11,13,14,15,17,19 |          |
| <b>PERCENT COVERAGE</b>   | 6/6 = 100%        | 17/26 = 65%  | 4/13 = 31%                      |          |

As can be seen from the above example, given the same seed vectors, PALASM1 software would show 100% coverage whereas "TGEN" would show 31% coverage. Notice that the poor coverage by "TGEN" is due to none of the input nodes being tested for stuck-at-1. In most instances, a better set of test vectors

can improve the coverage significantly. For the above example, the reader can verify that the following slight modification of the seed vectors would yield 100% coverage for all calculation methods:

|          | A | B | C | D | E | F | G | H | I |
|----------|---|---|---|---|---|---|---|---|---|
| VECTOR 1 | H | H | H | L | L | L | L | L | L |
| VECTOR 2 | L | L | L | H | H | H | L | L | L |
| VECTOR 3 | L | L | L | L | L | L | H | H | H |
| VECTOR 4 | L | H | H | L | H | H | L | H | H |
| VECTOR 5 | H | L | H | H | L | H | H | L | H |
| VECTOR 6 | H | H | L | H | H | L | H | H | L |

### Testability

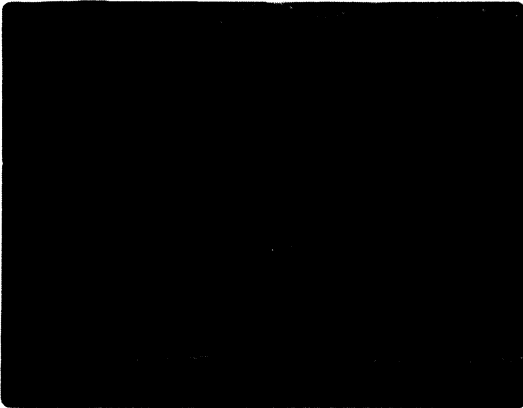
The previous sections described some essentials for comprehensive seed vector set. Variations on how fault coverage is calculated was covered also. However, no matter how it is calculated, fault coverage is only as good as the testability of the circuit permits. Using the stuck-at failure model, the customer must consider both absolute and practical fault coverages achievable for his PAL/HAL logic circuit design. Certain testa-

bility factors, such as redundancy, number of test points (outputs) or reconvergence, affect absolute (i.e., theoretical maximum) coverage. Other factors, including pre-loadable state machines, the amount of feedback and overall controllability, will affect practical coverage since many faults may be potentially detectable but uneconomical to detect due to excessive vectors or difficult to reach states. As testability is improved, absolute and practical fault coverage will usually increase.

# METASTABILITY

## A Study of the anomalous behavior of synchronizer circuits

Danesh M. Tavara



### INTRODUCTION

This article will summarize the results of the studies performed on synchronizer circuits. The information presented may be used by system designers to gain insight into the anomalous behavior of edge-triggered flip-flops. Understanding flip-flop behavior and applying some simple design practices can result in an increased reliability of any system.

### METASTABILITY

In the digital world a bit represents the fundamental unit of measure. The output state of any digital device is either "HIGH" (a voltage level above  $V_{IH}$ ) or "LOW" (a voltage level below  $V_{IL}$ ) as shown in figure 2. Under the proper operating conditions the register in figure 1 outputs a HIGH or a LOW on the rising edge of the clock within a nominal delay called the "clock to out" delay. If the setup and hold times are violated the register has a small probability of entering a third region of operation called the "metastable" state. Metastable is a Greek word meaning "in between" and it is a state between HIGH and LOW. Even though most synchronizers snap out of metastability in a short period of time, theoretically this state can persist indefinitely. Some of the registers built from older technologies had metastable states which lasted as long as a few microseconds. When the output of a device goes into metastability the clock to out delay will be grossly affected. This may alter the system's worst case propagation delay and potentially lead to a system crash!

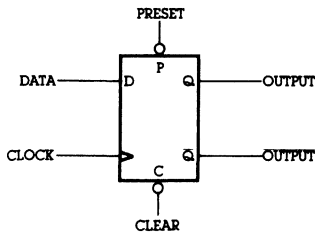


Figure 1

### SYNCHRONIZERS

The design of a synchronous digital system is based on the assumption that the maximum propagation delay of a flip-flop and any other gates are known. A digital system is free of hazardous race conditions and timing anomalies if the maximum propagation delay in the system does not exceed the clock's period. In systems where an asynchronous input is interfaced with a clocked device such as a flip-flop, the maximum specified propagation delay of this device may no longer be valid if certain electrical parameters are violated. Computer peripherals, an operator's keyboard, or two independently clocked subsystems are instances where there is a possibility of interfacing an asynchronous input which will violate the synchronizer's electrical parameters.

A popular device typically used in synchronized systems is the edge-triggered register shown in figure 1. The edge-triggered register will properly synchronize the incoming data to the system's clock as long as its operating conditions are satisfied. Table 1 summarizes these specifications for Monolithic Memories Inc's (MMI) 74LS374 register. It is difficult to guarantee setup and hold time requirements when the data is asynchronously interfaced to a register. The violation of setup or hold time in a register has a probability of initiating a misbehavior termed "Metastability."

| SYMBOL   | PARAMETER                | COMMERCIAL |      |      | UNIT               |
|----------|--------------------------|------------|------|------|--------------------|
|          |                          | MIN.       | TYP. | MAX. |                    |
| $V_{CC}$ | Supply Voltage           | 4.5        | 5    | 5.5  | V                  |
| $T_A$    | Operating free air temp. | 0          |      | 75   | $^{\circ}\text{C}$ |
| $t_w$    | Width of clock           | 15         |      |      | ns                 |
| $t_{su}$ | Setup time               | 20         |      |      | ns                 |
| $t_h$    | Hold time                | 0          |      |      | ns                 |

Table 1

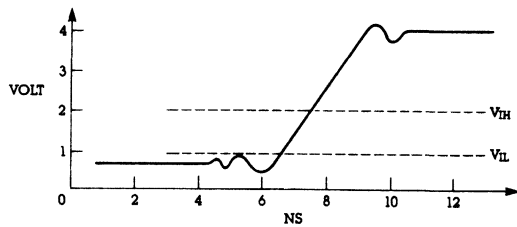


Figure 2

The diagrams in figure 3 illustrate some examples of waveforms in the metastable condition. From the waveforms it is evident that the outputs are distorted under metastable conditions. Figure 3d shows the output of a typical 74LS374 register manufactured by Monolithic Memories. Monolithic Memories family of bipolar devices exhibit superior metastable hardened performance due to their high speed bipolar technology and advanced Schottky TTL circuit design techniques. Most of these devices typically snap out of metastability in a flashing 15 nanoseconds.

### WHY THE SYNCHRONIZER FAILS

Before attempting to explain how the synchronizer's internal circuitry fails let's take a look at an interesting problem.

**PROBLEM:** In the SR type latch shown in figure 4 what happens if the set (S) and the reset (R) inputs are simultaneously raised from a LOW voltage level to a HIGH level?

# Metastability

ANSWER: The outputs will be in a stable state of HIGH prior to the RS transition and will quickly oscillate to a final steady state of either HIGH or LOW (see figure 3a). To demonstrate this result the reader is encouraged to do this exercise either mentally or to actually build the circuit and view the output on the oscilloscope.

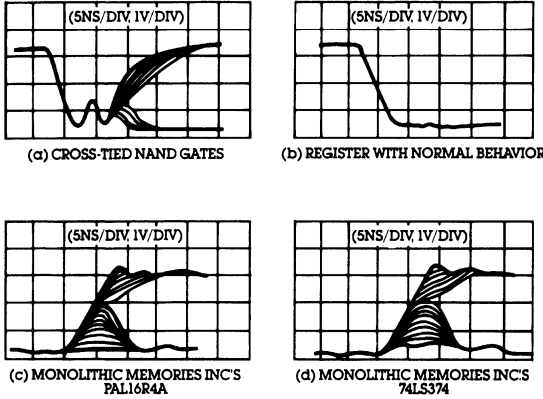


Figure 3

Clock driven master-slave flip-flops contain the same type of cross tied RS latch within their internal circuitry. The NAND gate equivalent of the master-slave D type flip-flop is shown in figure 5. The gates circled in this figure can potentially behave similar to the above problem. If the clock and data are triggered within a specific window of one another the output may have an oscillatory behavior before settling down.

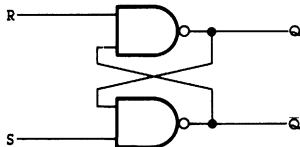
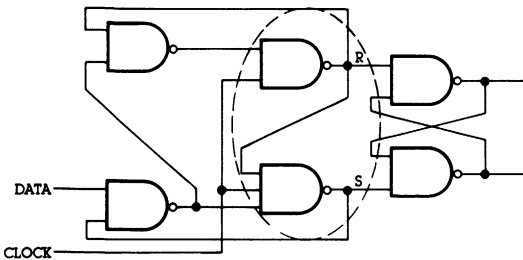


Figure 4



Cross tied RS latch structure is seen in the master-slave edge triggered flip-flop.

Figure 5

## METASTABLE DETECTOR

This section will show how to characterize the behavior of an edge triggered flip-flop with an asynchronous data interface. If the setup and hold times of the flip-flop are satisfied the output behaves properly (figure 6a). One of the four possible events below can take place if the flip-flop goes metastable:

- 1) The output starts to make a transition but snaps back to its original state (figure 6b).
- 2) The output makes a complete transition but the maximum propagation delay of the device is exceeded (figure 6c).
- 3) The output starts oscillating and retains its present state (figure 6d).
- 4) The output oscillates to a new state (figure 6e).

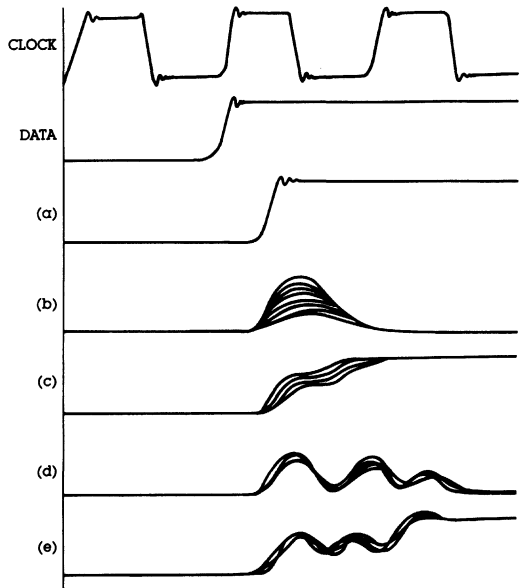
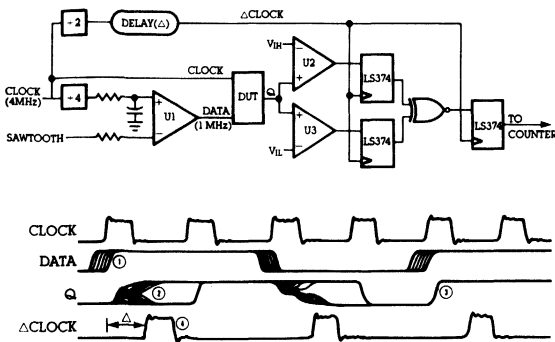


Figure 6

The circuit shown in figure 7 is used to obtain experimental results of a metastable device. The circuit can detect and count the number of events of metastability. The device under test (DUT) is forced into metastability by repeatedly sweeping the edges of the data past the rising edges of the clock. The modulation of the data is possible by using a comparator device (U1) along with an external sawtooth waveform. Thousands of transitions are created within the setup and hold time window of the DUT. Sweeping the data edges past the low to high clock transitions simulates an asynchronous input and increases the probability of getting a metastable failure on the output (Q) of the DUT.

# Metastability



- ① JITTER BAND SIMULATES AN ASYNCHRONOUS BEHAVIOR
- ② METASTABLE OUTPUT
- ③ PROPER OUTPUT WAVEFORM
- ④ ΔCLOCK SAMPLES THE OUTPUT (Q) AFTER A DELAY Δ

Figure 7

If the output of the device goes into metastability it will be detected by the comparator pair (U2) and (U3). The comparators will have complementary outputs if the output (Q) of DUT is anywhere between VIH and VIL. The outputs of the comparators are latched by a delayed version of the clock (ΔClock). The EXCLUSIVE-NOR gate followed by the register signal the event of metastability to an external counter.

The variable delay (Δ) between the two clocks will sample the output at various locations on the time axis. As this delay is varied the event of metastability is sampled and counted at these locations by our circuit. Therefore the output of our circuit measures the rate of metastability versus time delay. The real behavior of a metastable output can thus be effectively characterized with this scheme, that is, we can determine the length of time a metastable condition will persist and the density distribution of the metastable event.

Three 74374 devices and four PAL devices are used in this experiment. The plots of metastable failure versus time are shown in figures 8a,b. The next section will discuss in detail the characteristics of these plots.

## EXPERIMENTAL RESULTS

Various graphs of metastability failure rate versus delay time are illustrated in figure 8. We can conclude from these graphs that the rate of metastability failure decreases as the sample clock (ΔCLOCK) moves farther and farther away from the DUT clock. The pictures shown in figure 9 have captured repeated events of metastability on the oscilloscope.

Let's take a closer look at one of the graphs to examine the behavior of the device. The PAL16R4A-4 device exhibits one count per second if the delay (Δ) is 60 nanoseconds. As the delay (Δ) is decreased, the rate increases exponentially until the delay equals 32 ns at which point the rate flattens out and remains fixed. The 32 ns forms the knee of our graph and will be referred to as Δo. The rate will remain constant if the delay (Δ) is decreased past the knee of our graph. Further reduction in the delay will place the sampling clock's rising edge prior to data transitions and thus the error rate vanishes to zero. The time at which the rate goes to zero is marked with an (X) on the graphs. By using this time (X), and another location on the graph such as the time where only one error per second occurs, we can associate an approximate range of metastability for different devices. This range of metastability is referred to as the "mean time to snap out of metastability". From the graph it is evident that the mean time to snap out of metastability for the PAL16R4A-4 logic circuit is the difference between 60 ns and 25 ns which is 35 ns.

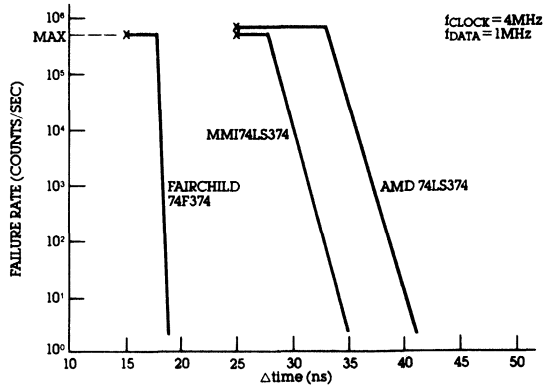


Figure 8a

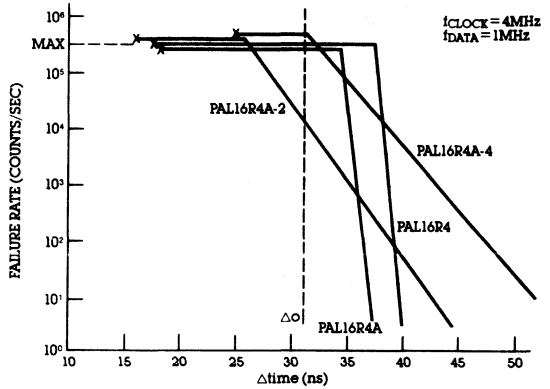


Figure 8b

All of the graphs illustrated can be quantified by an equation of the form:

$$\log \text{FAILURE} = \log \text{MAX} - b(\Delta - \Delta_o)$$

Since a natural logarithm is a constant multiple of base 10 logarithm we can rewrite the above equation as:

$$\alpha \cdot \ln \text{FAILURE} = \alpha \cdot \ln \text{MAX} - b(\Delta - \Delta_o)$$

In the above equation the MAX value is representative of the maximum metastability failure rate in our device. This MAX value is closely related to the frequency at which a metastable condition may occur in our device. The frequency at which metastability occurs is simply a constant multiple of the product of CLOCK and DATA frequency.

$$\text{MAX} = K1 \cdot f_{\text{CLOCK}} \cdot f_{\text{DATA}}$$

Substituting this in our original equation we get:

$$\alpha \cdot \ln \text{FAILURE} = \alpha \cdot \ln (K1 \cdot f_{\text{CLOCK}} \cdot f_{\text{DATA}}) - b(\Delta - \Delta_o)$$

$$\ln \text{FAILURE} = \ln (K1 \cdot f_{\text{CLOCK}} \cdot f_{\text{DATA}}) - b/\alpha(\Delta - \Delta_o)$$

$$\text{FAILURE} = (K1 \cdot f_{\text{CLOCK}} \cdot f_{\text{DATA}}) e^{-k2(\Delta - \Delta_o)}$$

# Metastability

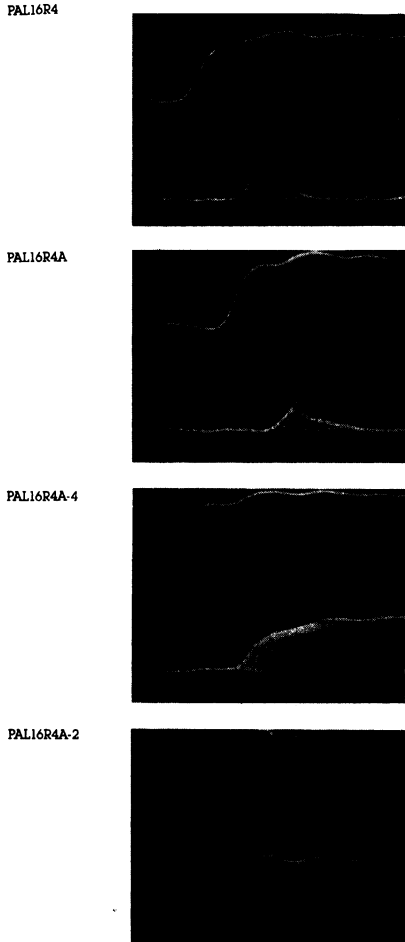


Figure 9 (2v/DIV, 5ns/DIV)

Table 2 gives the three important parameters which can be used by system designers to fully characterize the metastable behavior of the mentioned devices. These parameters can be obtained for different devices by duplicating this experiment. An example is given below to show how the information on table 2 may help the designer in the design of asynchronous systems.

| MANUFACTURER | DEVICE     | $K_1$ (Sec)        | $K_2$ (ns <sup>-2</sup> ) | $\Delta O$ (ns) |
|--------------|------------|--------------------|---------------------------|-----------------|
| MMI          | PAL16R4    | $1 \times 10^{-7}$ | 4.3                       | 37              |
|              | PAL16R4A   | $1 \times 10^{-7}$ | 4.3                       | 34.5            |
|              | PAL16R4A-2 | $1 \times 10^{-7}$ | .64                       | 25              |
|              | PAL16R4A-4 | $1 \times 10^{-7}$ | .5                        | 31              |
| AMD          | 74LS374    | $2 \times 10^{-7}$ | 1.8                       | 27.5            |
| AMD          | 74LS374    | $2 \times 10^{-7}$ | 2.0                       | 34.5            |
| FAIRCHILD    | 74F374     | $2 \times 10^{-7}$ | 11.5                      | 17.5            |

Table 2

## EXAMPLE

For the hardware implementation in figure 10 determine the maximum clock frequency to give a typical error rate of one failure per year. We must choose the minimum period to give an error rate of less than

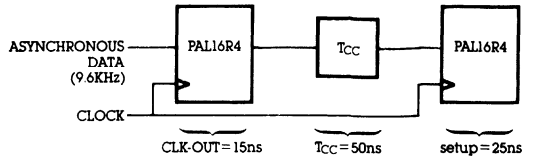


Figure 10

one failure per year. From this result we can determine the maximum clock frequency. The time  $\Delta$  in the equation below will determine the distance between clock edges. We must determine  $\Delta$  from the equation by numerical extrapolation. The system clock's period can be represented as  $(\Delta + T_{cc} + \text{setup})$ , or plugging in the numbers it is  $\Delta + 75$ .

$$\text{FAILURE} = (K_1 \cdot f_{\text{CLOCK}} \cdot f_{\text{DATA}}) e^{-K_2(\Delta - \Delta_0)}$$

and plugging in the appropriate values we have:

$$3.2 \text{EE} - 8 = [(1 \text{EE} - 7) (1/(\Delta + 75 \text{ns})) (9600)] e^{-[(4.3)(\Delta - 37)]}$$

Solving for  $\Delta$ , we see that it is approximately 43 nanoseconds. The system period is thus seen to be the sum of 43ns and 75ns or 118ns. The maximum clock frequency is the inverse of the period or approximately 8 MHz.

## CONCLUSION

Synchronization of two independent pulse trains is possible through the use of edge triggered registers. The electrical characteristics of the flip-flop are affected when the setup and hold times of the device are violated. This misbehavior is termed "metastability" and its probability of occurrence can be derived for a given system. The factors which affect this probability and the length of time which a metastable condition persists are influenced by the technology of the device as well as by the circuit design techniques.

An important fact which needs to be stressed is that even if a register's output goes metastable, the system may not necessarily fail if the register snaps out in time to satisfy the system's worst case timing requirement. The following design practices are suggested when using synchronizers.

Try to minimize the number of locations where asynchronous signals enter your system.

Clocking the asynchronous inputs through two pipelined registers can greatly reduce the error rate.

Use a single clock within your local system environment. For multiple system clocks, derive all the clock signals from a single source to assure synchronization between different devices within the system.

When analyzing the worst case timing of your system, add the time to snap out of metastability to any register in an asynchronous data path.

A single PAL\* with registers can be your best choice for state machine analysis of asynchronous events. As the registers have virtually identical setup times, the simultaneous observation of a metastable event by different register states are likely to be the same. Contrasted to a distributed system of observing register states with different setup times, the PAL system of register states with identical setup times is a superior synchronizer.

Avoid edge sensitive devices on the output paths of the registers which have asynchronous inputs. The glitch created when the synchronizer goes metastable is enough to trigger the edge sensitive device. The use of level sensitive devices is generally a better design practice.

PAL devices can be effective synchronizers where various registering schemes are easily implemented.

# High-Speed Bipolar PROMs Find New Applications As Programmable Logic Elements\*

Vincent J. Coli and Frank Lee

Classic applications for bipolar PROMs include instruction storage for microprogram control store and software for microprocessor programs. However, due to a new design methodology and state-of-the-art performance, PROMs are finding increasing

numbers of applications as Programmable Logic Element (or PLE) devices. This paper will cover the architecture, applications, and software support for PLE devices.

\* This paper is a slightly modified version of the paper by the same name which appeared in the Conference Proceedings of the 9th West Coast Computer Faire, pages 40-47; April 1984.

# High-Speed Bipolar PROMs Find New Applications As Programmable Logic Elements

Vincent J. Coli and Frank Lee

Classic applications for bipolar PROMs include instruction storage for microprogram control store and software for micro-processor programs. However, due to a new design methodology and state-of-the-art performance, PROMs are finding increasing numbers of applications as Programmable Logic Element (or PLE) devices. This paper will cover the architecture, applications, and software support for PLE devices.

## Fuse-Programmable Logic Families

A typical combinatorial Boolean equation can be written in sum-of-product form, which consists of several AND gates summed at an OR gate. In general, a set of combinatorial Boolean equations with  $n$  inputs ( $I_0, I_1, \dots, I_{n-1}$ ) and  $m$  outputs ( $O_0, O_1, \dots, O_{m-1}$ ) can be generated through one level of AND gates followed by one level of OR gates. Custom logic functions can be defined using programmable logic.

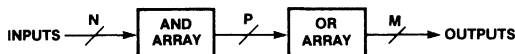


Figure 1. Structure of Programmable Logic Devices

Fuse-programmable devices normally consist of two levels of logic — AND-array and OR-array — as suggested above. There are three basic types of fuse-programmable devices — PROM (Programmable Read Only Memory), PLA (Programmable Logic Array), and PAL® (Programmable Array Logic) devices. Which arrays are fuse-programmable distinguish these three types of devices.

PLAs offer the greatest flexibility since both the AND and OR arrays are programmable. This flexibility comes with the cost of lower performance, higher power dissipation, and generally higher price.

A PAL device has only the AND-array programmable; the OR-array is fixed. Each output has an OR gate associated with it which sums a fixed number of product terms (AND combinations). Statistically there is only a limited number of product terms in any equation. So the flexibility of a PLA is normally not needed. This is a compromise between flexibility and cost and performance.

The OR-array is programmable in a PROM, but the fixed AND-array consists of all combinations of literals for each of the input variables. For example, there are 32 product terms available in a PROM with 5 inputs  $a, b, c, d, e$  (corresponding to words 0 through 31 in the PROM memory):

- $/a^*b^*c^*d^*e$  (Word 0)
- $/a^*b^*c^*d^*e$  (Word 1)
- $/a^*b^*c^*d^*e$  (Word 2)
- ...
- $a^*b^*c^*d^*e$  (Word 29)
- $a^*b^*c^*d^*e$  (Word 30)
- $a^*b^*c^*d^*e$  (Word 31)

where '\*' represents the Boolean AND operator and '/' represents the Boolean NOT or inverter operator. The fuses in the OR-array are programmed to select the desired AND combinations.

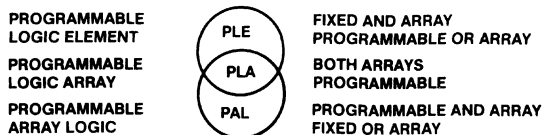


Figure 2. Structural Difference Between PLE (PROM), PLA and PAL Devices. Note that the PAL and PLE Logic Circuits Complement Each Other. The PAL Device has Many Input Terms While the PLE Device is Rich in Product Terms

The existence of all combinations of literals for all inputs makes it possible to define functions which cannot be implemented in a PLA or a PAL device. For example, a 5-input Exclusive-OR (XOR) function can be implemented using sixteen product terms. This may exceed the number of product terms available in a PAL device and will consume too many product terms in a PLA, but can be constructed quite efficiently in a PROM. It is important to realize that any combination of inputs can be decoded in a PROM as long as sufficient input pins are provided since a PROM provides  $2^n$  product terms (where  $n$  is the number of inputs). Another way of looking at this is that PROMs store the logic transfer function in a memory. The fixed AND-array (or AND-plane) consists of the row and column decoders while the fuses in the OR-array (or OR-plane) are the bits in the memory. In a memory, a fuse blown versus a fuse intact distinguishes a HIGH from a LOW.

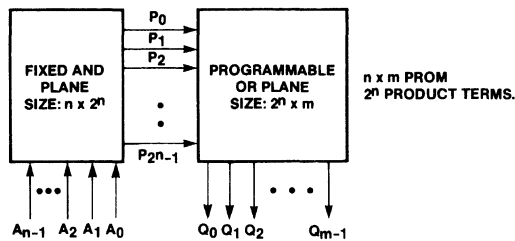


Figure 3. Block Diagram of a PROM Viewed as PLE Device. Notice that the PLE Provides Many ( $2^n$ , Where  $n$  is the Number of Inputs) Product Terms. A By-Product of this is Programmable Output Polarity: Either Active-High or Active-Low Output Polarities are Available



## High-Speed Bipolar PROMs Find New Applications as PLE Devices

Due to this special characteristic of abundant product terms, PROMs are also often used as logic devices. In this paper, PROMs are referred to as PLE (Programmable Logic Element) devices.

### Advantages of PLE Devices

PLE devices provide a cost-effective solution for many applications. Here are just some of the advantages of PLE devices:

- 1) Customizable Logic — The designer is limited to standard functions if SSI/MSI devices are used. The designer can create his own logic chips using PLE devices.
- 2) Design Flexibility — Modification of design is possible even without redesigning the PC board. For example, the address space of a microprocessor-based system can be reconfigured by merely programming a new device if the decoding is implemented in a PLE device. This feature comes in handy if you want to upgrade a system which originally used 64-K Dynamic RAMs to now use state-of-the-art 256-K Dynamic RAMs.
- 3) Reduce Errors — Errors are sometimes unavoidable and oftentimes quite expensive. Programmable devices make it easier and less expensive to correct errors.
- 4) Reduction of Printed Circuit Board Space—PLE devices save PC board space since several SSI/MSI functions can be integrated into a single package.
- 5) Fast Turnaround Time — With existing commercial programmers and development software support, a prototype of the custom tailored PLE device will be ready in just a few minutes.

### A Great Performer!



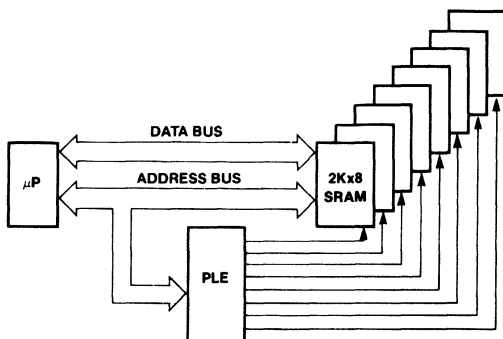
### PLE Applications

PLE applications include random logic replacement, decoder/encoders, code converters, custom ALUs, error detection and correction, look-up tables (both trigonometric and arithmetic), data scaling, compression arithmetic like Wallace Tree adders, distributed arithmetic, and residue arithmetic.

Several levels of random logic chips can be replaced by one PLE logic circuit. As discussed earlier, PLE devices can implement logic in sum of products form.

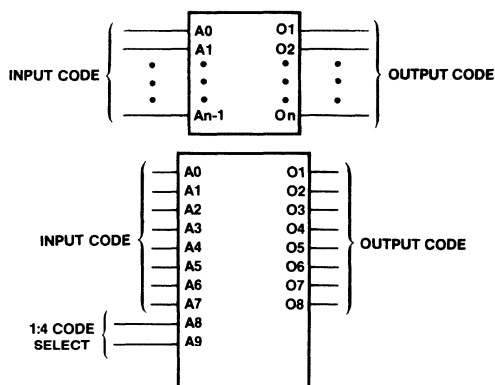


Despite the existence of dedicated encoders and decoders, many of these functions are application dependent. A standard 3-to-8 decoder/demultiplexer (74S138) can be used in decoding applications. But the decoding scheme may require several 3-to-8 decoder/demultiplexers and additional SSI OR-gates. On the other hand, a PLE device can be customized to perform the required decoding function with no additional gates. Simple decoders, such as those used for decoding memory chip selects from address lines, can be implemented in a PLE device with five to ten inputs. More complex decoding may require eight to twelve inputs.



**Figure 4. PLE Address Decoding Application. The PLE Device Selects One of Eight 2Kx8 Static RAMs by Decoding Several Microprocessor Address Lines**

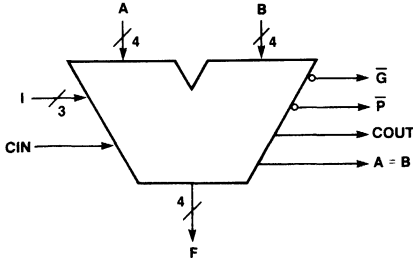
PLE devices also offer a very flexible solution for code conversion applications. Translations of codes such as from ASCII to EBCDIC, Binary to BCD (Binary Coded Decimal), or BCD to Gray code can be implemented in PLEs. The 74S184 Binary-to-BCD Converter is actually a 32x8 PROM.



**Figure 5. Two Examples of PLE Code Converters. The Second Example Illustrates How to Use Two Inputs as Code Select Lines so that Four Converters can be Provided in One PLE Device**

# High-Speed Bipolar PROMs Find New Applications as PLE Devices

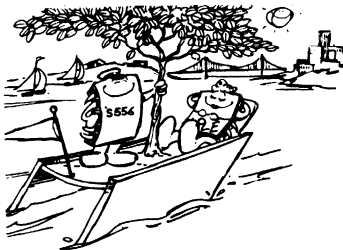
Standard ALUs (such as the 74S181) may not provide a very specialized function which a particular system requires, such as BCD arithmetic. In this case a PLE device is again a good alternative. Although the PLE device may be slower than a dedicated ALU, the presence of this specialized function is critical. For example, a 4-bit ALU can be constructed in a PLE device with twelve inputs (A3-A0, B3-B0, I2-I0, Cin) and eight outputs (F3-F0, G, P, Cout, A = B). Any eight functions can be implemented.



**Figure 6. Block Diagram for a 4-bit ALU which can be implemented in a PLE Device**

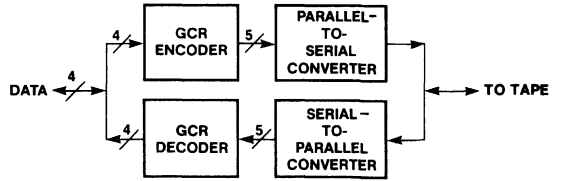
Data scaling is another PLE device application. A dedicated multiplier is not required if the scaling factor is a constant; the prescaled result can be stored in a PLE device. Fixed-bit multipliers are typically implemented in PLE devices.

Column compression technique (also called Wallace Tree Compression) is used when expanding an array of several smaller parallel multipliers to perform large wordlength multiplication. These smaller multipliers will generate partial products (intermediate results) which must be numerically summed according to bit significance in order to calculate the final wordlength multiplication. Many levels of 2-input bus adders can be used to add these partial products, but the carry propagation delays may be too long. However, partial product adders implemented in PLE devices can do compression of many levels without passing carries. Thus, the summation will be much faster.



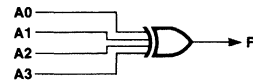
"... THE '5556, TOGETHER WITH PLE'S ORGANIZED IN A WALLACE-TREE CONFIGURATION, CAN SAIL RIGHT ALONG AT THE RATE OF FOUR 56 X 56 MULTIPLICATIONS EVERY MICROSECOND ..."

Group Code Recorder (GCR) is an encoding/decoding scheme used for error detection on tape. During a WRITE operation, each 8-bit word is divided into two 4-bit nibbles. Both nibbles are then encoded into 5-bit codes before being recorded onto tape. Both 5-bit codes are decoded back to the original 4-bit nibbles and then combined during a READ operation. PLE circuits are exceptionally useful in mapping the 4-bit data to the 5-bit code and back.



**Figure 7. GCR Encoder/Decoder Block Diagram**

Exclusive-OR gates, being half adders, are very prevalent in Error Detection and Correction (EDC) schemes. Many SSI chips are required to implement this function while PLA and PAL devices may not provide sufficient product terms. PLE devices are again an ideal solution.



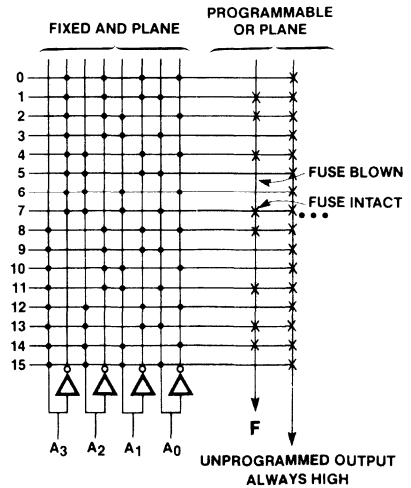
(a)

|                                 |                                 |    |    |   |   |
|---------------------------------|---------------------------------|----|----|---|---|
|                                 | A <sub>0</sub> , A <sub>1</sub> |    |    |   |   |
| A <sub>2</sub> , A <sub>3</sub> | 00                              | 01 | 11 |   |   |
|                                 | 00                              | 0  | 1  | 0 | 1 |
|                                 | 01                              | 1  | 0  | 1 | 0 |
|                                 | 11                              | 0  | 1  | 0 | 1 |
|                                 | 10                              | 1  | 0  | 1 | 0 |

(b)

$$\begin{aligned}
 F &= A_0 \oplus A_1 \oplus A_2 \oplus A_3 \\
 &= A_0 \bar{A}_1 \bar{A}_2 \bar{A}_3 + \bar{A}_0 A_1 \bar{A}_2 \bar{A}_3 \\
 &\quad + \bar{A}_0 \bar{A}_1 A_2 \bar{A}_3 + \bar{A}_0 \bar{A}_1 \bar{A}_2 A_3 \\
 &\quad + A_0 A_1 A_2 \bar{A}_3 + A_0 A_1 \bar{A}_2 A_3 \\
 &\quad + A_0 \bar{A}_1 A_2 A_3 + \bar{A}_0 A_1 A_2 A_3
 \end{aligned}$$

(c)

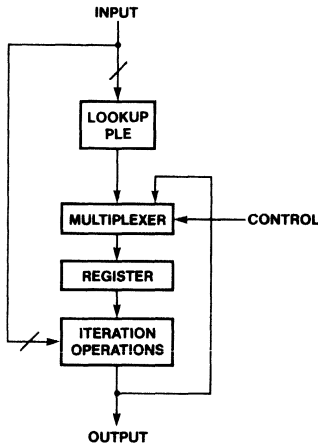


(d)

**Figure 8. Exclusive-OR Gates can be implemented in PLE Very Efficiently. A 4-Input XOR Gate (a) Maps into a Checkerboard Pattern in a Karnaugh Map (b) and Requires Eight Product Terms (c). The PLE Implementation is Shown in (d). An 8-Input XOR Gate Requires Sixteen Product Terms**

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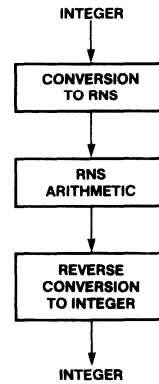
In many applications, the speed of the converging series used to generate the trigonometric functions is too slow and the accuracy obtained by direct table look-up requires too much hardware. A good compromise between speed and hardware is to store an approximation to the function in a PLE device. Then use this approximation as a starting point for an iterative algorithm (such as Newton-Raphson) to obtain additional accuracy. High-Speed division, multiplication, and square-root calculations can be performed in a similar manner.



**Figure 9. PLE Look-Up Tables and Iteration Loops can be Used to Generate Very Accurate Trigonometric and Arithmetic Functions. An Approximation to the Function is Stored and Additional Accuracy is Gained Using Iteration Operations**

Distributed arithmetic is used for performing convolution operations without using multiplier/accumulators. If the coefficients are constant, a look-up table for convolution can be stored in a PLE device, thus replacing the multiplier.

Residue arithmetic (also called Carry-Independent arithmetic) is a technique used to perform very fast integer arithmetic. High speed is achieved by using numbers in residue representation so that the sequential delay of carries on digits of higher significance is eliminated. A Residue Numbering System (RNS) is determined using an optimum moduli when designing the system. Conversion to and from residue representation are basic mapping functions which can be conveniently done in a PLE device. Also, since operations in residue arithmetic are performed using modulo addition and multiplication without carries, these operations can also be done using PLE devices. In general, residue arithmetic should only be used for integer arithmetic which requires intensive operations.



**Figure 10. Architecture of a System Based on RNS. An Integer Number is Converted to RNS Representation Using PLE Devices, Then the RNS Arithmetic is Performed Using Some Other PLE Devices, and Finally the RNS Result is Converted Back to Integer Representation Again Using PLE Devices**



### Restrictions

The basic restrictions for using PLE devices to replace SSI/MSI parts are:

- 1) Since a memory element has a product term for every combination of literals of all the input terms, static hazard is normally unavoidable. For example, there are 5 inputs available in a 32 x 8 PROM. In order to generate a function like:

$$f = a * b * c * d$$

The actual implementation inside the PROM will be:

$$f = a * b * c * d * e + a * b * c * d * e$$

If  $a = b = c = d = \text{HIGH}$ , according to the first equation, we shall expect  $f$  to remain HIGH independent of  $e$  changing. In the actual PROM implementation, there will be no hazard if  $e$  stays either HIGH or LOW. But if  $e$  changes, depending on whether  $e$  or  $\bar{e}$  will occur first, there exists the possibility that both product terms in the second equation will be LOW momentarily, which may cause a static logic hazard (HIGH to LOW to HIGH) for  $f$ . This hazard is commonly called a "glitch". Static hazards are not a problem for many applications, like those offered in this paper, but extreme care must be taken if the output of a PLE device is used to strobe another device.



# High-Speed Bipolar PROMs Find New Applications as PLE Devices

```

PLE5P8
P5000
BASIC GATES
MMI SANTA CLARA, CALIFORNIA
.ADD I0 I1 I2 I3 I4
.DAT O1 O2 O3 O4 O5 O6 O7 O8

O1 = I0 ; BUFFER
O2 = /I0 ; INVERTER
O3 = I0 * I1 * I2 * I3 * I4 ; AND GATE
O4 = I0 + I1 + I2 + I3 + I4 ; OR GATE
O5 = /I0 + /I1 + /I2 + /I3 + /I4 ; NAND GATE
O6 = /I0 * /I1 * /I2 * /I3 * /I4 ; NOR GATE
O7 = I0 :+ I1 :+ I2 :+ I3 :+ I4 ; EXCLUSIVE OR GATE
O8 = I0 :* I1 :* I2 :* I3 :* I4 ; EXCLUSIVE NOR GATE
    
```

### FUNCTION TABLE

```

I0 I1 I2 I3 I4 O1 O2 O3 O4 O5 O6 O7 O8
:INPUT - - OUTPUTS FROM BASIC GATES - -
:O1234 BUF INV AND OR NAND NOR XOR XNOR COMMENTS
-----
LLLLL L H L L L H L L L ALL ZEROS
HHHHH H L H H L L L H H ALL ONES
HLHLH H L L H H L H H ODD CHECKERBOARD
LHLHL L H L H H L L L EVEN CHECKERBOARD
    
```

### DESCRIPTION

THIS EXAMPLE ILLUSTRATES THE USE OF PLEs TO IMPLEMENT THE BASIC GATES: BUFFER, INVERTER, AND GATE, OR GATE, NAND GATE, NOR GATE, EXCLUSIVE OR GATE, AND EXCLUSIVE NOR GATE.

NOTE ALSO THAT THREE-STATE OUTPUTS ARE PROVIDED WITH ONE ACTIVE LOW OUTPUT ENABLE CONTROL (/OE).

PLEASM GENERATES THE PROM TRUTH TABLE FROM THE LOGIC EQUATIONS AND SIMULATES THE FUNCTION TABLE IN THE LOGIC EQUATIONS.

**Figure 12a. PLE Design Specification. This is the Source Code for PLEASM Software. PLEASM Software Generates the Truth Table and Programming Formats from the Equations. PLEASM Software Also Exercises the Function Table in the Equation and Reports Errors**

```

BASIC GATES
.ADD I0 I1 I2 I3 I4
.DAT O1 O2 O3 O4 O5 O6 O7 O8
    
```

```

ADD A0 A1 A2 A3 A4 O1 O2 O3 O4 O5 O6 O7 O8
-----
0 L L L L L L H L L H H L L
1 H L L L L L H L L H H L L
2 L H L L L L L H L H H L L
3 H H L L L L H L L H H L L
4 L L H L L L L H L H H L L
5 H L H L L L H L L H H L L
6 L H H L L L L H L H H L L
7 H H H L L L H L L H H L L
8 L L H L L L L H L H H L L
9 H L L H L L H L L H H L L
10 L H L H L L L H L H H L L
11 H H L H L L H L L H H L L
12 L L H H L L L H L H H L L
13 H L H H L L L L L H H L L
14 L H H H L L L L L H H L L
15 H H H H L L H L L H H L L
16 L L L L H L L H L H H L L
17 H L L L H H L L L H H L L
18 L H L L H L L H L H H L L
19 H H L L H H L L L H H L L
20 L L H L H L L H L H H L L
21 H L H L H H L L L H H L L
22 L H H L H L L L L H H L L
23 H H L H L L H L L H H L L
24 L L L H H L L H L H H L L
25 H L L H H H L L L H H L L
26 L H L H H H L L L H H L L
27 H H L H H H L L L H H L L
28 L L H H H L L L L H H L L
29 H L H H H L L L L H H L L
30 L H H H H L L L L H H L L
31 H H H H H L L L L H H L L
    
```

HEX CHECK SUM = 00F3C

**Figure 12b. Truth Table. PLEASM Software Generates This Truth Table which can be Used for Verifying Your Design**

```

BASIC GATES
.ADD I0 I1 I2 I3 I4
.DAT O1 O2 O3 O4 O5 O6 O7 O8
    
```

| ADD | HEX ADDRESS | HEX DATA |
|-----|-------------|----------|
| 0   | 000         | 32       |
| 1   | 001         | D9       |
| 2   | 002         | DA       |
| 3   | 003         | 19       |
| 4   | 004         | DA       |
| 5   | 005         | 19       |
| 6   | 006         | 1A       |
| 7   | 007         | D9       |
| 8   | 008         | DA       |
| 9   | 009         | 19       |
| 10  | 00A         | 1A       |
| 11  | 00B         | D9       |
| 12  | 00C         | 1A       |
| 13  | 00D         | D9       |
| 14  | 00E         | DA       |
| 15  | 00F         | 19       |
| 16  | 010         | DA       |
| 17  | 011         | 19       |
| 18  | 012         | 1A       |
| 19  | 013         | D9       |
| 20  | 014         | 1A       |
| 21  | 015         | D9       |
| 22  | 016         | DA       |
| 23  | 017         | 19       |
| 24  | 018         | 1A       |
| 25  | 019         | D9       |
| 26  | 01A         | DA       |
| 27  | 01B         | 19       |
| 28  | 01C         | DA       |
| 29  | 01D         | 19       |
| 30  | 01E         | 1A       |
| 31  | 01F         | CD       |

HEX CHECK SUM = 00F3C

**Figure 12c. Hex Table. PLEASM Software Generates This Truth Table in Hexadecimal Form for Verification of Locations in the PLE**

```

32 D9 DA 19 DA 19 1A D9 DA 19 1A D9 DA 19 DA 19
DA 19 1A D9 1A D9 DA 19 1A D9 DA 19 DA 19 1A CD
00F3C
    
```

**Figure 12d. ASCII Hex Programming Format. PLEASM Software Generates this ASCII Hex Programming Format with Hex Check Sum. Control Characters are Included so that the Information can be Downloaded Directly to a PROM Programmer**

```

:1000000032D9DA19DA191AD9DA191AD91AD9DA1940
:10001000DA191AD91AD9DA191AD9DA19DA191ACD54
:00000001FF
    
```

**Figure 12e. Intel Hex Programming Format. PLEASM Software Generates this Intel Hex Programming Format with a Hex Check Sum Following Every 16 Bytes of Data**



## High-Speed Bipolar PROMs Find New Applications as PLE Devices

### PLE Family

Monolithic Memories carries a family of fast PROMs which can be used as Memory or PLE devices. Since the critical parameter for logic applications is speed, our series of fast PROMs have

worst-case memory access times (or propagation delays) ranging from 15 ns for small PROMs to 40 ns for large PROMs. The Logic Symbols for four of the PLE devices are given in Figure 13 and a summary of the PLE family is given below:

### PLE Selection Guide

| PART NUMBER | INPUTS | OUTPUTS | PRODUCT TERMS | OUTPUT REGISTERS | t <sub>PD</sub> (ns) MAX* |
|-------------|--------|---------|---------------|------------------|---------------------------|
| PLE5P8      | 5      | 8       | 32            |                  | 25                        |
| PLE5P8A     | 5      | 8       | 32            |                  | 15                        |
| PLE8P4      | 8      | 4       | 256           |                  | 30                        |
| PLE8P8      | 8      | 8       | 256           |                  | 28                        |
| PLE9P4      | 9      | 4       | 512           |                  | 35                        |
| PLE9P8      | 9      | 8       | 512           |                  | 30                        |
| PLE10P4     | 10     | 4       | 1024          |                  | 35                        |
| PLE10P8     | 10     | 8       | 1024          |                  | 35†                       |
| PLE11P4     | 11     | 4       | 2048          |                  | 35                        |
| PLE11P8     | 11     | 8       | 2048          |                  | 35                        |
| PLE12P4     | 12     | 4       | 4096          |                  | 35                        |
| PLE12P8     | 12     | 8       | 4096          |                  | 40                        |
| PLE9R8      | 9      | 8       | 512           | 8                | 15                        |
| PLE10R8     | 10     | 8       | 1024          | 8                | 15                        |
| PLE11RA8    | 11     | 8       | 2048          | 8                | 15                        |
| PLE11RS8    | 11     | 8       | 2048          | 8                | 15                        |

\*Clock to output time for registered outputs

† Preliminary data.

NOTE: Commercial limits specified.

### Acknowledgements

Several of the designs discussed in this paper were proposed by our good friend and colleague Ulrik Mueller, who is now studying Computer Science in his native country, Denmark, and our Monolithic Memories Pal Zahir Ebrahim. Special thanks also go to Ranjit Padmanabhan for writing the PLEASM simulator.

### Summary

There are many interesting applications for high-speed PROMs used as PLE devices. A software package called "PLEASM" software is available as a development tool.

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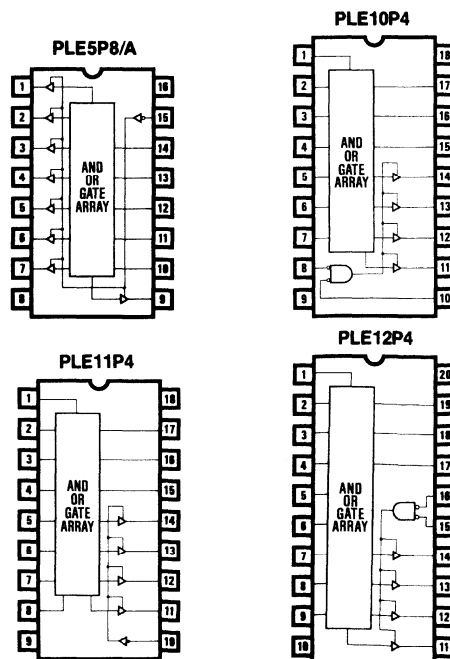


Figure 13. Four Sample PLE Logic Symbols

# ABEL™, A Complete Design Tool For Programmable Logic

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As the use of PAL® and PLE devices (PROMs) increases, the need for high-level design tools becomes necessary. Designers need easier, faster, and more efficient ways to design with such programmable devices. With the more complex devices currently being introduced to the market, this need is even greater. Additionally, a designer should be able to specify logic designs in a way that makes sense in engineering terms; he or she should not have to learn a new way of thinking about designs.

ABEL™, a complete logic design tool for PAL devices, PLE devices and FPLA devices meets these requirements. ABEL™ incorporates a high-level design language and a set of software programs that process logic designs to give correct and efficient designs.

The ABEL™ design language offers structures familiar to designers: state diagrams, truth tables, and Boolean equations. The designer can choose any of these structures or combine them to describe a design. Macros and directives are also available to simplify complex designs.

The ABEL™ software programs process designs described with the high-level language. Processing includes syntax checking, automatic logic reduction, automatic design simulation, verification that a given design can be implemented in a chosen device, and automatic generation of design documentation.

To use ABEL™, the designer uses an editor to create a source file containing an ABEL™ design description. He then processes the source file with the ABEL™ software programs to produce a programmer load file. The programmer load file is used by logic and PLE programmers to program devices. Several programmer load file formats are supported by ABEL™ so that different programmers may be used.

The source file created by the designer must contain test vectors if simulation is to be performed. Test vectors describe the desired (expected) input-to-output function of the design in a truth table format. The ABEL™ simulator applies the inputs contained in the test vectors to the design and checks the obtained outputs against the expected outputs in the vectors. If the outputs obtained during simulation do not match those specified in the test vectors, an error is reported.

Following are two designs described in the ABEL™ design language. These designs would be processed to verify their correctness and to reduce the number of terms required to implement them. The first design is for a PAL device, the second for a PLE logic circuit.

ABEL™ is a trademark of DATA I/O.

## 6809 MEMORY ADDRESS DECODER

Address decoding is a typical application of programmable logic devices, and the following describes the ABEL™ implementation of such a design.

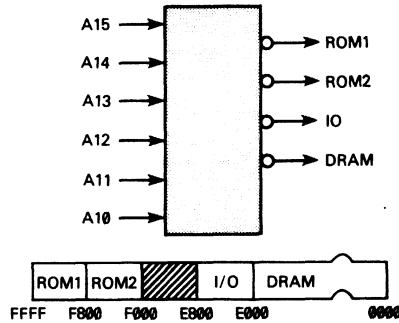


Figure 1. Block Diagram: 6809 Memory Address Decoder

### Design Specification

Figure 1 shows a block diagram for the design and a continuous block of memory divided into sections containing dynamic RAM (DRAM), I/O (I/O), and two sections of ROM (ROM1 and ROM2). The purpose of this decoder is to monitor the six high-order bits (A15-A10) of a sixteen-bit address bus and select the correct section of memory based on the value of these address bits. To perform this function, a simple decoder with six inputs and four outputs is designed with a 14L4 PAL device.

Table 1 shows the address ranges associated with each section of memory. These address ranges can also be seen in figure 1.

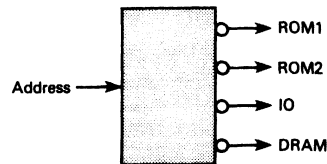


Figure 2. Simplified Block Diagram: 6809 Memory Address Decoder

### Design Method

Figure 2 shows a simplified block diagram for the address decoder. The address decoder is implemented with simple

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Boolean equations employing both relational and logical operators as shown in figure 3. A significant amount of simplification is achieved by grouping the address bits into a set named *Address*. The lower-order ten address bits that are not used for the address decode are given "don't care" values in the address set. In this way, the designer indicates that the address in the overall design (that beyond the decoder) contains sixteen bits, but that bits 0-9 do not affect the decode of that address. This is opposed to simply defining the set as, *Address = [A15,A14,A13,A12,A11,A10]*, which ignores the existence of the lower-order bits. Specifying all 16 address lines as members of the address set also allows full 16-bit comparisons of the address value against the ranges shown in table 1.

| Memory Section | Address Range (hex) |
|----------------|---------------------|
| DRAM           | 0000-DFFF           |
| I/O            | E000-E7FF           |
| ROM2           | F000-F7FF           |
| ROM1           | F800-FFFF           |

Table 1. Address Ranges for 6809 Controller

### Test Vectors

In this design, the test vectors are a straightforward listing of the values that must appear on the output lines for specific address values. The address values are specified in hexadecimal notation on the left side of the "->" symbol. Input to a design always appear on the left side

of the test vectors. The expected outputs are specified to the right of the "->" symbol. The designer chose in this case to use the symbols *H* and *L* instead of the binary values 1 and 0 to describe the outputs. The correspondence between the symbols and the binary values was defined in the constant declaration section of the source file, just above the section labeled *equations*.

```

module m6809a
title '6809 memory decode
Jean Designer      Data I/O Corp Redmond WA   24 Feb 1984'

                U09      device 'P14L4';
A15,A14,A13,A12,A11,A10 pin 1,2,3,4,5,6;
ROM1,IO,ROM2,DRAM  pin 14,15,16,17;

H,L,X   = 1,0,.X.;
Address = [A15,A14,A13,A12, A11,A10,X,X, X,X,X,X, X,X,X,X];

equations
!DRAM   = (Address <= ^hDFFF);

!IO     = (Address >= ^hE000) & (Address <= ^hE7FF);

!ROM2   = (Address >= ^hF000) & (Address <= ^hF7FF);

!ROM1   = (Address >= ^hF800);

test_vectors (Address -> [ROM1,ROM2,IO,DRAM])
^h0000 -> [ H,  H,  H,  L ];
^h4000 -> [ H,  H,  H,  L ];
^h8000 -> [ H,  H,  H,  L ];
^hC000 -> [ H,  H,  H,  L ];
^hE000 -> [ H,  H,  L,  H ];
^hE800 -> [ H,  H,  H,  H ];
^hF000 -> [ H,  L,  H,  H ];
^hF800 -> [ L,  H,  H,  H ];

end m6809a

```

Figure 3. Source File: 6809 Memory Address Decoder



**Seven-Segment Display Decoder**

This display decoder decodes a four-bit binary number to display the decimal equivalent on a seven-segment LED display. The design incorporates the ABEL™ truth table format and is implemented on a RA5P8 PLE.

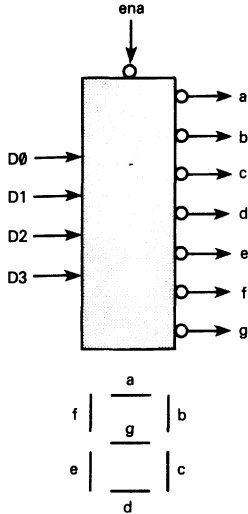


Figure 4. Block Diagram: Seven-Segment Display Decoder

**Design Specification**

Figure 4 shows a block diagram for the decoder design and a drawing of the display with each of the seven segments labeled to correspond to the decoder outputs. To light up any one of the segments, the corresponding line must be driven low. Four input lines *D0-D3* are decoded to drive the correct output lines. The outputs are named *a, b, c, d, e, f, and g* corresponding to the display segments. All outputs are active low. An enable, *ena*, is provided. When *ena* is low, the decoder is enabled; when *ena* is high, all outputs are driven to high impedance.

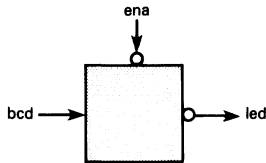


Figure 5. Simplified Block Diagram: Seven-Segment Display Decoder

**Design Method**

Figures 5 and 6 show the simplified block diagram and the source file for the ABEL™ implementation of the display decoder. The FLAG statement is used to make sure that the programmer load file is in the Motorola Exorciser format. The binary inputs and the decoded outputs are grouped into the sets *bcd* and *led* to simplify notation. The constants *ON*

and *OFF* are declared so that the design can be described in terms of turning a segment on or off. To turn a segment on, the appropriate line must be driven low, thus *ON* is declared as 0 and *OFF* as 1.

The design is described in two sections: an equations section and a truth table section. The decoding function is described with a truth table that specifies the outputs required for each combination of inputs. The first line of the truth table (the truth table header) names the inputs and outputs. In this example, the inputs are contained in the set named *bcd* and the outputs are in *led*. The body of the truth table defines the input-to-output function. Because the design decodes a number to a seven-segment display, values for *bcd* are expressed as decimal numbers, and values for *led* are expressed with the constants *ON* and *OFF* that were defined in the declarations section of the source file. This makes the truth table easy to read and understand; the incoming value is a number and the outputs are on and off signals to the LED.

The input and output values could have just as easily been described in another form. Take for example the line in the truth table:

5 -> [ON,OFF,ON,ON,OFF,ON,ON]

This could have been written in the equivalent form:

[0,1,0,1] -> 36

In this second form, 5 was expressed as a set containing binary values, and the LED set was converted to decimal. (Remember that *ON* was defined as 0 and *OFF* was defined as 1.) Either of the two forms is valid, but the first is more appropriate for this design. The first form can be read as, "the number five turns on the first segment, turns off the second,..." whereas the second form cannot be so easily translated into terms meaningful for this design.

**Test Vectors**

The test vectors for this design test the decoder outputs for the ten valid combinations of input bits. The enable is also tested by setting *ena* high for the different combinations. All outputs should be at high impedance whenever *ena* is high. If they are not, an error has occurred.

**Summary**

Two designs described with the ABEL™ design language have been shown. The first design shows how Boolean equations with logical and relational operators are used to describe an address decoder. The second design shows how a truth table describes a seven-segment display decoder design for a PLE logic circuit. In both designs, test vectors were written to test the function of the design using ABEL™'s simulator. In addition to the Boolean equations and truth table shown in these examples, ABEL™ features a state diagram structure. The state diagram allows the designer to fully describe state machines in terms of their states and state transitions.

Regardless of the method used to describe logic, ABEL™'s automatic logic reduction and simulation ensure that the design uses as few terms as possible and that it operates as the designer intended. The end results are savings in time, devices, board space, and money.

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```

module bcd7rom flag '-d82'
title 'seven segment display decoder
Data I/O Corp Redmond WA 16 Mar 1984'
"
"      a
"      ---          BCD-to-seven-segment decoder similar to the 7449
"      f; g ;b
"      ---          segment identification
"      e; d ;c
"      ---
"
" | | | | | | | | | | | |
" | | | | | | | | | | | |
" | | | | | | | | | | | |
" ---

U6      device 'RASPB';

D3,D2,D1,D0 pin 10,11,12,13;
a,b,c,d,e,f,g pin 1,2,3,4,5,6,7;
ena      pin 15;

bcd      = [D3,D2,D1,D0];
led      = [a,b,c,d,e,f,g];

ON,OFF   = 0,1;
L,H,X,Z  = 0,1,.X.,.Z.;

truth_table (bcd -> led)
" input          outputs
"
"      a      b      c      d      e      f      g
0 -> [ ON,  ON,  ON,  ON,  ON,  ON,  OFF];
1 -> [ OFF,  ON,  ON,  OFF,  OFF,  OFF,  OFF];
2 -> [ ON,  ON,  OFF,  ON,  ON,  OFF,  ON];
3 -> [ ON,  ON,  ON,  ON,  OFF,  OFF,  ON];
4 -> [ OFF,  ON,  ON,  OFF,  OFF,  ON,  ON];
5 -> [ ON,  OFF,  ON,  ON,  OFF,  ON,  ON];
6 -> [ ON,  OFF,  ON,  ON,  ON,  ON,  ON];
7 -> [ ON,  ON,  ON,  OFF,  OFF,  OFF,  OFF];
8 -> [ ON,  ON,  ON,  ON,  ON,  ON,  ON];
9 -> [ ON,  ON,  ON,  ON,  OFF,  ON,  ON];

test_vectors ([ena,bcd] -> led)
" inputs          outputs
"
"      a      b      c      d      e      f      g
[L,1] -> [ OFF,  ON,  ON,  OFF,  OFF,  OFF,  OFF];
[L,2] -> [ ON,  ON,  OFF,  ON,  ON,  OFF,  ON];
[L,3] -> [ ON,  ON,  ON,  ON,  OFF,  OFF,  ON];
[L,4] -> [ OFF,  ON,  ON,  OFF,  OFF,  ON,  ON];
[L,5] -> [ ON,  OFF,  ON,  ON,  OFF,  ON,  ON];
[L,6] -> [ ON,  OFF,  ON,  ON,  ON,  ON,  ON];
[L,7] -> [ ON,  ON,  ON,  OFF,  OFF,  OFF,  OFF];
[L,8] -> [ ON,  ON,  ON,  ON,  ON,  ON,  ON];
[L,9] -> [ ON,  ON,  ON,  ON,  OFF,  ON,  ON];
[L,0] -> [ ON,  ON,  ON,  ON,  ON,  ON,  OFF];
[H,5] -> [ Z,  Z,  Z,  Z,  Z,  Z,  Z];
[H,9] -> [ Z,  Z,  Z,  Z,  Z,  Z,  Z];
[H,0] -> [ Z,  Z,  Z,  Z,  Z,  Z,  Z];
end      bcd7rom

```

Figure 6. Source File: Seven-Segment Display Decoder

CUPL is the first software CAD tool designed especially for the support of all programmable logic devices (PLDs), including PALs and PROMs. It was developed specifically for YOU, the Hardware Design Engineer. Each feature of the CUPL language has been chosen to make using programmable logic easier and faster than conventional TTL logic design.

### MAJOR FEATURES OF CUPL

#### 1. UNIVERSAL

- a. **PRODUCT SUPPORT:** CUPL supports products from every manufacturer of programmable logic. With CUPL you are free to use not only PALs, but also other programmable logic devices.
- b. **PALASM CONVERSIONS:** CUPL has a PALASM to CUPL language translator which allows for an easy conversion from your previous PALASM designs to CUPL.
- c. **LOGIC PROGRAMMER COMPATIBILITY:** CUPL produces a standard JEDEC download file and is compatible with any logic programmer that uses JEDEC files.

#### 2. HIGH LEVEL LANGUAGE

High Level Language means that the software has features that allow you to work in terms that are more like the way you think than like the final PLD programming pattern. Examples of these are:

- a. **FLEXIBLE INPUT:** CUPL gives the engineer complete freedom in entering logic descriptions for their design:
  - EQUATIONS
  - TRUTH TABLES
  - STATE MACHINE SYNTAX
- b. **EXPRESSION SUBSTITUTION:** This allows you to pick a name for an equation and then, rather than write the equation each time it is used, you need only use the name. CUPL will properly substitute the equation during the compile process.

## CUPL™ Universal Compiler for Programmable Logic

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- c. SHORTHAND FEATURES: Instead of writing out fully expanded equations CUPL provides various shorthand capabilities such as:
- LIST NOTATION: Rather than [A7,A6,A5,A4,A3,A2,A1,A0]  
CUPL only requires [A7..0]
  - BIT FIELDS: A group of bits may be assigned to a name,  
asin FIELD ADDR = [A7..0]  
Then ADDR may be used in other expressions
  - RANGE FUNCTION: Rather than A15 & !A14 #  
A15 & A14 & !A13 #  
A15 & A14 & A13 & !A12  
CUPL only requires ADDR:[8000..EFFF]
  - THE DISTRIBUTIVEPROPERTY:  
From Boolean Algebra, where A & (B # C)  
is replaced by A & B # A & C
  - DeMORGAN'S THEOREM:  
From Boolean Algebra, where !(A & B)  
is replaced by !A # !B

### 3. SELF DOCUMENTING

CUPL provides a template file which provides a standard "fill-in-the-blanks" documentation system that is uniform among all CUPL users. Also, CUPL allows for free form comments through out your work so there can be detailed explanations included in each part of the project.

### 4. ERROR CHECKING

CUPL includes a comprehensive error checking capability with detailed error messages designed to lead you to the source of the problem.

### 5. LOGIC REDUCTION

CUPL contains the fastest and most powerful minimizer offered for Programmable Logic equation reduction. The minimizer allows the choice of various levels of minimization ranging from just fitting into the target device to the absolute minimum.

### 6. SIMULATION

With CSIM, the CUPL Simulator, you can simulate your logic prior to programming an actual device. Not only can this save devices but it can help in debugging a system level problem.

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### **7. TEST VECTOR GENERATION**

Once the stimulus/response function table information has been entered into the simulator, CSIM will verify the associated test vectors and append them to the JEDEC file for downloading to the logic programmer. The programmer will verify not only the fuse map, but also the functionality of the PLD, giving you added confidence in the operation of your custom part.

### **8. EXPANDABILITY**

CUPL is designed for growth so as new PALs and other devices are introduced you will be kept current with updated device libraries and product enhancements.

### **DESIGN EXAMPLE USING CUPL**

In the following design example, a single PAL (or PROM) is used to replace four TTL packages on the interface card for an IBM-PC computer. The Prototype I/O Channel Interface Card, as supplied by IBM, uses four SSI packages to decode the ten bit I/O address and control the direction and enable for the bus buffer on the PCB. The PAL approach conserves real estate and also adds flexibility to decode not only the pre-assigned address, but the ability to change the board address to any location in the I/O map by merely replacing the programmable device.

#### **1. CIRCUIT OPERATION**

The inputs to the decoding logic are the expansion bus addresses A0 thru A9. The logic compares the address on the expansion bus and asserts the "IO\_DECODE" signal when the correct address range of 3F0-3FF is seen. In addition, the "ENABLE" signal is also asserted if either the I/O READ or I/O WRITE signals are active during this time. The READ signal, which controls the direction of the data bus buffer, is asserted whenever I/O READ is active and AEN, the DMA Address enable signal is inactive. The AEN signal is negated when the microprocessor has control of the address bus and is generating an I/O cycle.

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### 2. DESIGN METHOD

First, all device pins are assigned in the logic description file (see figure 1) using CUPL's pin declaration statements. Note the use of indexed variables for the address bus allows a simple assignment for pins 1 thru 8. The active polarity for input and output pins are made in these declarations, so the designer need only be concerned with the logic instead of voltage levels.

The address bus is assigned a name using the FIELD statement. This lets the designer then describe the desired address range with the single equation:

```
range = ioadr:[300..31F] ;
```

instead of the difficult to understand

```
range = a9 & a8 & !a7 & !a6 & !a5 ;
```

This range expression is then used in the output equation for IO\_DECODE and ENABLE. Since ENABLE may be asserted whenever IOR or IOW are true, the intermediate variable IOREQ is created to define this condition. The resultant CUPL equation for ENABLE is simply

```
enable = range & ioreq ;
```

Finally, the READ signal is created using the active IOR and the inactive AEN signals as follows:

```
read = ior & !aen ;
```

Note that for a device such as the PAL16L8 which has a fixed inverting buffer on all of its output pins, CUPL will automatically convert the logic equations when an output is desired to be active-level HI, as with the READ output above.

### 3. CUPL OUTPUT FILES

CUPL will create a standard JEDEC output file which is compatible with most logic programmers. A simple serial download link is all that is usually required to transfer the fuse information to the programmer. In addition, CUPL generates an extensive documentation file which assists the designer in analyzing his/her design. Figure 2 shows a small section of this file, illustrating such features as pin and variable names, product term utilization, and other information.

## CUPL™ Universal Compiler for Programmable Logic

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```

PARTNO    P90001234 ;
NAME      PC10 ;
DATE      02/14/85 ;
REV       01 ;
DESIGNER  Kahl/Osann ;
COMPANY   Assisted Technology ;
ASSEMBLY  PC Proto Board ;
LOCATION   U2 ;

/*****
/* This device provides a one-chip I/O interface for an equivalent */
/* of the IBM-PC proto board. This logic description may be placed */
/* in either a PROM or PAL without alteration.                      */
/*****
/* Allowable Target Device Types : PAL--> PAL16L8, PAL16P8          */
/*                               PROM-> PLE12P4                      */
/*****

/** Inputs **/

PIN [1..8] = [a2..9] ; /* CPU Address bits 0 thru 9 */
PIN 9      = aen      ; /* DMA Address Enable */
PIN 17     = !ior     ; /* I/O Read Strobe (active LO) */
PIN 18     = !iow     ; /* I/O Write Strobe (active LO) */

/** Outputs **/

PIN 12     = read     ; /* Direction Control For Bus Buffer */
PIN 13     = !enable  ; /* Enable For Bus Buffer */
PIN 14     = !io_decode ; /* Decoded I/O Strobe for On Board Use */

/** Declarations and Intermediate Variable Definitions **/

field ioadr = [a9..2] ; /* Name the I/O Address Bus "ioadr" */

ioreq = ior # iow ; /* Define I/O Request */

range = ioadr:[300..31F] & !aen ; /* Decoded I/O Address Range and */
/* not DMA cycle */

/** Logic Equations **/

enable = range & ioreq ;

io_decode = range ;

read = ior & !aen ;

/* Change the intermediate variable "range" for other I/O Locations */
```

Figure 1.

## CUPL™ Universal Compiler for Programmable Logic

---

```

CUPL          2.02a
Device        p1618  DLIB-c-18-5
Partno       P90001234
Name         PC10
Revision     01
Date        02/14/85
Designer     Kahl/Osann
Company      Assisted Technology
Assembly     PC Proto Board
Location     U2
    
```

```

=====
                          Symbol Table
=====
    
```

| Pol | Name      | Ext | Pin | Type | Used | Max |
|-----|-----------|-----|-----|------|------|-----|
| --- | ----      | --- | --- | ---- | ---- | --- |
|     | a2        |     | 1   | V    | -    | -   |
|     | a3        |     | 2   | V    | -    | -   |
|     | a4        |     | 3   | V    | -    | -   |
|     | a5        |     | 4   | V    | -    | -   |
|     | a6        |     | 5   | V    | -    | -   |
|     | a7        |     | 6   | V    | -    | -   |
|     | a8        |     | 7   | V    | -    | -   |
|     | a9        |     | 8   | V    | -    | -   |
|     | aen       |     | 9   | V    | -    | -   |
| !   | enable    |     | 13  | V    | 2    | 7   |
| !   | io_decode |     | 14  | V    | 1    | 7   |
|     | ioadr     |     | 0   | F    | -    | -   |
| !   | ior       |     | 17  | V    | -    | -   |
|     | ioreq     |     | 0   | I    | 2    | -   |
| !   | iow       |     | 18  | V    | -    | -   |
|     | range     |     | 0   | I    | 1    | -   |
|     | read      |     | 12  | V    | 2    | 7   |
|     | enable    | oe  | 13  | D    | 1    | 1   |
|     | io_decode | oe  | 14  | D    | 1    | 1   |
|     | ior       | oe  | 17  | D    | 1    | 1   |
|     | iow       | oe  | 18  | D    | 1    | 1   |
|     | read      | oe  | 12  | D    | 1    | 1   |

```

LEGEND   D : default var   F : field       I : intermediate var
          U : undefined     V : var         X : extended var
          .N : node         M : extended node
    
```

Figure 2.



## **CUPL™ Universal Compiler for Programmable Logic**

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### **CUPL-GTS DRAW LOGIC SCHEMATICS FOR PAL DESIGNS!**

In recent years, programs like CUPL and ABEL have become available to provide high level language support for PAL designs. These languages allow the designer to represent a PAL function in terms of high-level equations, truth tables or state machines. All of these logic description formats are non-graphical in nature and require a good working knowledge of the computer they run on.

Many hardware designers, however, are most comfortable with the traditional logic schematic and have historically had little reason to use a computer in the design process. Use of a high-level PAL design language presents most of us with a variety of simultaneous unknowns:

1. The computer and its operating system.
2. The full screen editor necessary to create the logic description file.
3. The logic compiler or assembler language syntax.
4. Boolean algebra theory.
5. PAL architectures.

Where this combination places an unnecessary burden on the designer, an alternative is now available.

CUPL-GTS is a powerful combination of hardware and software which turns an IBM-PC type computer into a programmable logic workstation which allows the user to draw logic schematics for the function of a PAL. A basic premise in creating CUPL-GTS was to provide a friendly environment where the user is isolated from the traditional keyboard as much as possible. To this end, virtually all functions can be actuated with one button by way of the mouse and a series of pop-up menus which ease the user's task. An area is provided at the top of the CUPL-GTS screen for prompting the user regarding the next operation in a command sequence. Highlighting of various elements on the screen is coordinated with these prompts to enhance their effectiveness. For the most part, the user need only utilize the conventional keyboard for defining symbolic names for wires, pins, objects, and files.

An on-screen HELP facility is provided to aid the user with CUPL-GTS commands. In addition to the basic set of object types which can be easily picked from a pop-up menu, the ability to call up macro-objects is also provided. These macro-objects have been previously drawn using CUPL-GTS and stored away on the disk under their own symbolic name.

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After a logic schematic has been entered, the user may quickly check to see if the design fits in a specific PAL. This is done by selecting the "Translate to PLD" command from the main menu which automatically invokes the GTS translation programs. These programs run in an on-screen window which overlays the graphical information, providing feedback in the form of error messages displayed in this window. Following the automatic execution of these programs, the cursor is returned to the user who can then continue to work in the graphics environment without ever having fully left. In this way many errors can be quickly determined and remedied without ever having to let go of the mouse.

When the user wishes a hard copy version of a design, the print command from the main menu may be selected. This causes the GTS print program to execute in an on-screen window according to the printer configuration file (PRINTCAP) which is stored on the disk. The PRINTCAP file allows the user to configure the GTS print function for any dot matrix printer they might have.

Often a logic description not fit in a particular PAL due to a logic capacity (product-term) limitation. When this occurs, the universal capability of CUPL-GTS will easily allow the user to try placing this same logic in a different PAL of similar architecture.

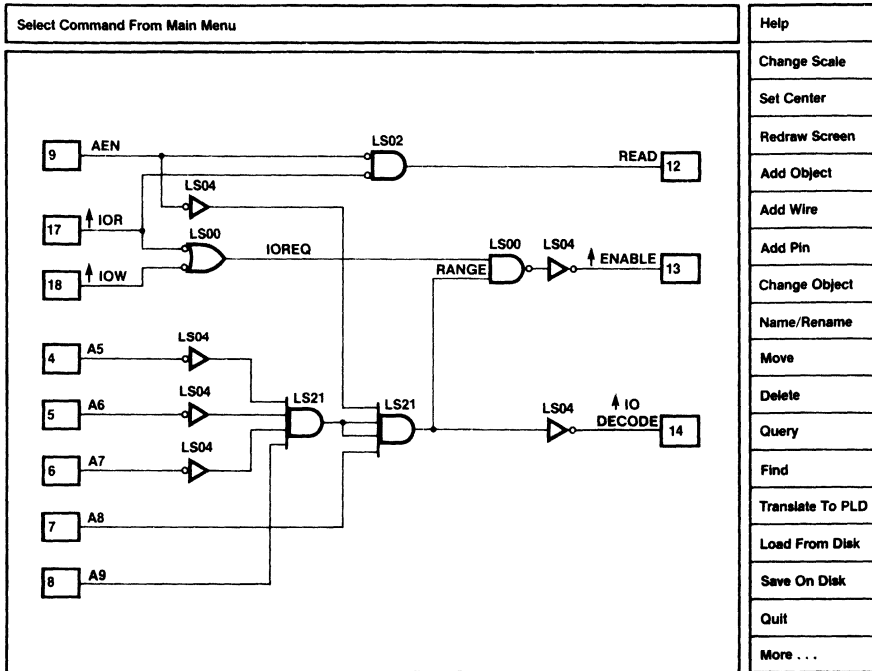
Since CUPL-GTS incorporates CUPL the high level language in its internal operation, it also benefits from CUPL's powerful "Quine Procedure" logic minimizer. This is especially advantageous for CUPL-GTS as logic descriptions showing many levels of gates can be very deceptive in their ability to consume the logic capacity of a PAL. The presence of the logic minimizer can eliminate unnecessary and redundant logical functions, and maximizes the probability that a design will fit in a target PAL.

Also included with CUPL-GTS is the CUPL simulator, CSIM, which allows the user to simulate a logic design prior to physically creating a programmed PAL. Not only can this save devices, but it can help significantly in debugging a system level problem.

CUPL-GTS is designed for growth and expandability. As new programmable logic devices are introduced users will be kept current with updated device libraries and product enhancements.

Most of us first use PAL devices to replace TTL in order to shrink a design and/or add functionality. The following example shows how the simple I/O decoder design previously discussed would appear on the CUPL-GTS screen prior to translation to a PAL16L8, PAL16P8 or PLE12P4.

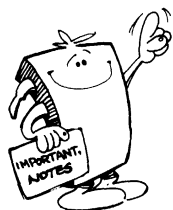
## CUPL™ Universal Compiler for Programmable Logic

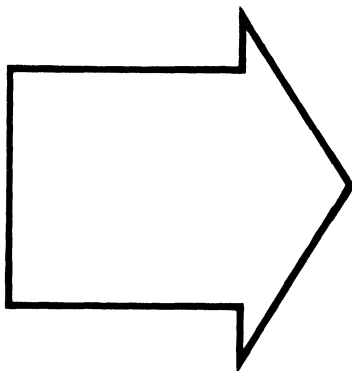


A CUPL-GTS Design Screen

## Notes

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|   |           |
|---|-----------|
| <b>PAL® Device Introduction</b>         | <b>1</b>  |
| <b>PAL®/HAL® Device Specifications</b>  | <b>2</b>  |
| <b>PAL Device Programmer Ref. Guide</b> | <b>3</b>  |
| <b>HAL/ZHAL™ Devices</b>                | <b>4</b>  |
| <b>Logic Cell Array™</b>                | <b>5</b>  |
| <b>PALASM® Software Syntax</b>          | <b>6</b>  |
| <b>PAL Device Applications</b>          | <b>7</b>  |
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## Definition of Terms and Waveforms

### Clock Frequency

#### Maximum clock frequency, $f_{max}$

The highest rate at which the clock input of a bistable circuit can be driven through its required sequence while maintaining stable transitions of logic level at the output with input conditions established that should cause changes of output logic level in accordance with the specification.

### Current

#### High-level input current, $I_{IH}$

The current into\* an input when a high-level voltage is applied to that input.

#### High-level output current, $I_{OH}$

The current into\* an output with input conditions applied that according to the product specification will establish a high level at the output.

#### High-level output current, $I_{CEX}$

The high-level leakage current of an open collector output.

#### Low-level input current, $I_{IL}$

The current into\* an input when a low-level voltage is applied to that input.

#### Low-level output current, $I_{OL}$

The current into\* an output with input conditions applied that according to the product specification will establish a low level at the output.

#### Off-state (high-impedance-state) output current (of a three-state output), $I_{OZ}$

The current into\* an output having three-state capability with input conditions applied that according to the product specification will establish the high-impedance state at the output.

#### Short-circuit output current, $I_{OS}$

The current into\* an output when that output is short-circuited to ground (or other specified potential) with input conditions applied to establish the output logic level farthest from ground potential (or other specified potential).

#### Supply current, $I_{CC}$

The current into\* the  $V_{CC}$  supply terminal of an integrated circuit.

\*Current out of a terminal is given as a negative value.

### Hold Time

#### Hold time $t_h$

The interval during which a signal is retained at a specified input terminal after an active transition occurs at another specified input terminal.

NOTES: 1. The hold time is the actual time between two events and may be insufficient to accomplish the intended result. A minimum value is specified that is the shortest interval for which correct operation of the logic element is guaranteed.

2. The hold time may have a negative value in which case the minimum limit defines the longest interval (between the release of data and the active transition) for which correct operation of the logic element is guaranteed.

### Output Enable and Disable Time

#### Output enable time (of a three-state output) to high level, $t_{PZH}$ (or low level, $t_{PZL}$ )

The propagation delay time between the specified reference points on the input and output voltage waveforms with the three-state output changing from a high-impedance (off) state to the defined high (or low) level.

#### Output enable time (of a three-state output) to high or low level, $t_{PZX}$

The propagation delay time between the specified reference points on the input and output voltage waveforms with the three-state output changing from a high-impedance (off) state to either of the defined active levels (high or low).

#### Output disable time (of a three-state output) from high level, $t_{PHZ}$ (or low level, $t_{PLZ}$ )

The propagation delay time between the specified reference points on the input and output voltage waveforms with the three-state output changing from the defined high (or low) level to a high-impedance (off) state.

#### Output disable time (of a three-state output) from high or low level, $t_{PXZ}$

The propagation delay time between the specified reference points on the input and output voltage waveforms with the three-state output changing from either of the defined active levels (high or low) to a high-impedance (off) state.

$t_{EA}$  is the output enable access time of memory devices.

$t_{ER}$  is the output disable (enable recovery) time of memory devices.

### Propagation Time

#### Propagation delay time, $t_{PD}$

The time between the specified reference points on the input and output voltage waveforms with the output changing from one defined level (high or low) to the other defined level.

#### Propagation delay time, low-to-high-level output, $t_{PLH}$

The time between the specified reference points on the input and output voltage waveforms with the output changing from the defined low level to the defined high level.

#### Propagation delay time, high-to-low-level output, $t_{PHL}$

The time between the specified reference points on the input and output voltage waveforms with the output changing from the defined high level to the defined low level.

$t_{AA}$  is the address (to output) access time of memory devices.

### Pulse Width

#### Pulse width, $t_w$

The time interval between specified reference points on the leading and trailing edges of the pulse waveform.

## Definition of Terms and Waveforms

### Setup Time

#### Setup time, $t_{su}$

The time interval between the application of a signal that is maintained at one specified input terminal and a consecutive active transition at another specified input terminal.

NOTES: 1. The setup time is the actual time between two events and may be insufficient to accomplish the setup. A minimum value is specified that is the shortest interval for which correct operation of the device is guaranteed.

2. The setup time may have a negative value in which case the minimum limit defines the longest interval (between the active transition and the application of the other signal) for which correct operation of the device is guaranteed.

### Voltage

#### High-level input voltage, $V_{IH}$

An input voltage within the more positive (less negative) of the two ranges of values assumable by a binary variable.

NOTE: A minimum is specified that is the least positive value of high-level voltage for which operation of the logic element within specification limits is guaranteed.

#### High-level output voltage, $V_{OH}$

The voltage at an output terminal with input conditions applied that will establish a high level at the output. The actual input conditions needed are determined by the individual product specification.

#### Input clamp voltage, $V_{IC}$

An input voltage in a region of relatively low differential resistance that serves to limit the input voltage swing.

#### Low-level input voltage, $V_{IL}$

An input voltage level within the less positive (more negative) of the two ranges of values assumable by a binary variable.

NOTE: A maximum is specified that is the most positive value of low-level input voltage for which operation of the logic element within specification limits is guaranteed.

#### Low-level output voltage, $V_{OL}$

The voltage at an output terminal with input conditions applied that will establish a low level at the output. The actual input conditions needed are determined by the individual product specification.

#### Negative-going threshold voltage $V_{T-}$

The voltage level at an input that causes a transition as the input voltage falls from a level above the positive-going threshold voltage,  $V_{T+}$ .

#### Positive-going threshold voltage, $V_{T+}$

The voltage level at an input that causes a transition as the input voltage rises from a level below the negative-going threshold voltage,  $V_{T-}$ .

### Truth Table Explanations

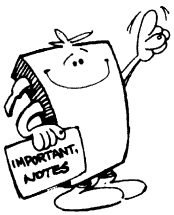
|             |   |
|-------------|---|
| H           | = high level (steady-state)   |
| L           | = low level (steady-state)  |
| ↑           | = transition from low-to-high level   |
| ↓           | = transition from high-to-low level   |
| X           | = don't care (any input, including transitions)   |
| Z           | = off (high-impedance) state of a three-state output  |
| a..h        | = the level of steady-state inputs at inputs A through H respectively   |
| $Q_0$       | = level of Q before the indicated steady-state input conditions were established                                |
| $\bar{Q}_0$ | = complement of $Q_0$ or level of $\bar{Q}$ before the indicated steady-state input conditions were established |
| $Q_n$       | = level of Q before the most recent active transition indicated by ↓ or ↑                                       |

If, in the input columns, a row contains only the symbols H, L, and/or X, this means the indicated output is valid whenever the input configuration is achieved and regardless of the sequence in which it is achieved. The output persists as long as the input configuration is maintained.

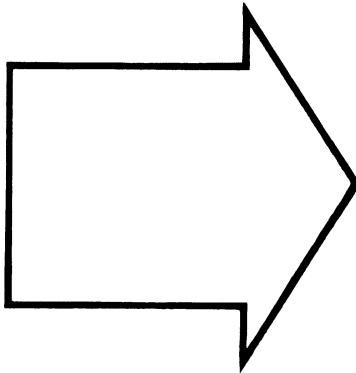
If, in the input columns, a row contains H, L, and/or X together with ↑ and/or ↓, this means the output is valid whenever the input configuration is achieved and the indicated transition has occurred (the transition(s) must occur following the achievement of the steady-state levels). If the output is shown as a level (H, L,  $Q_0$ , or  $\bar{Q}_0$ ), it persists as long as the steady-state input levels and the levels that terminate indicated transitions are maintained. Unless otherwise indicated, input transitions in the opposite direction to those shown have no effect at the output.

# Notes

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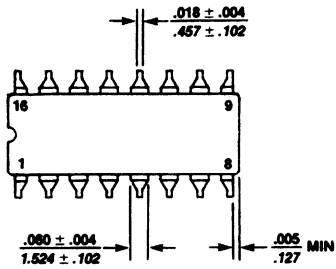


|   |           |
|---|-----------|
| <b>PAL® Device Introduction</b>         | <b>1</b>  |
| <b>PAL®/HAL® Device Specifications</b>  | <b>2</b>  |
| <b>PAL Device Programming and Guide</b> | <b>3</b>  |
| <b>HAL/ZHAL™ Devices</b>                | <b>4</b>  |
| <b>Logic Cell Array</b>                 | <b>5</b>  |
| <b>PALASM® Software Syntax</b>          | <b>6</b>  |
| <b>PAL Device Applications</b>          | <b>7</b>  |
| <b>Logic Tutorial</b>                   | <b>8</b>  |
| <b>PLE™ Devices</b>                     | <b>9</b>  |
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| <b>General Information</b>              | <b>12</b> |
| <b>Package Drawings</b>                 | <b>13</b> |
| <b>Representatives and Distributors</b> | <b>14</b> |

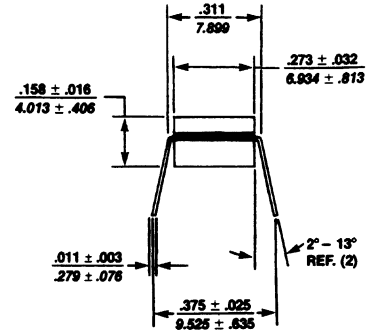
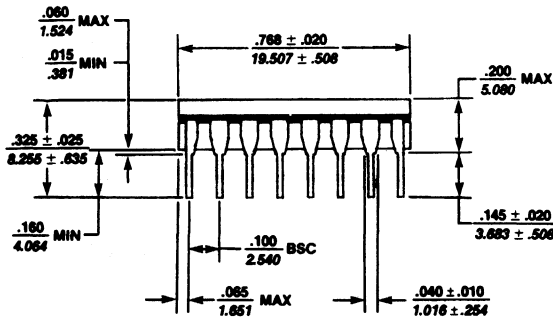
# Package Drawings

## Package Drawings

16J Ceramic DIP  
 (5/16" x 3/4")  
 MN-M-38510,  
 Appendix C, D-2



UNLESS OTHERWISE SPECIFIED:  
 ALL DIMENSIONS MIN.-MAX. IN INCHES  
 ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
 ALL TOLERANCES ARE  $\pm .007$  INCHES



Notes:

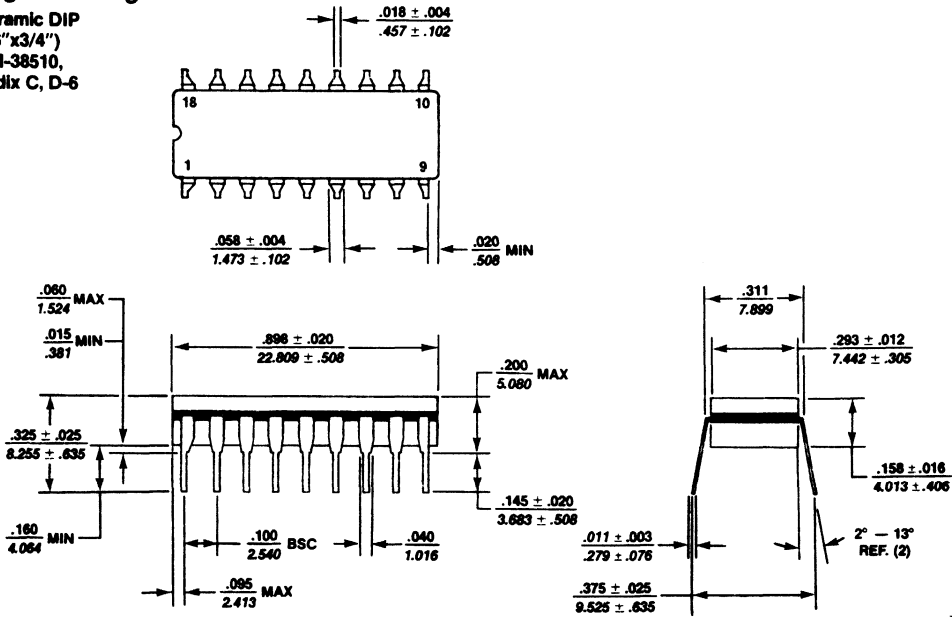
1. Specified body dimensions allow for differences between SSI, MSI and LSI packages.
2. Lead material tolerances are for tin plate finish only. Solder dip finish adds 2 - 10 mils thickness to all lead tip dimensions.

PC00010M

## Package Drawings

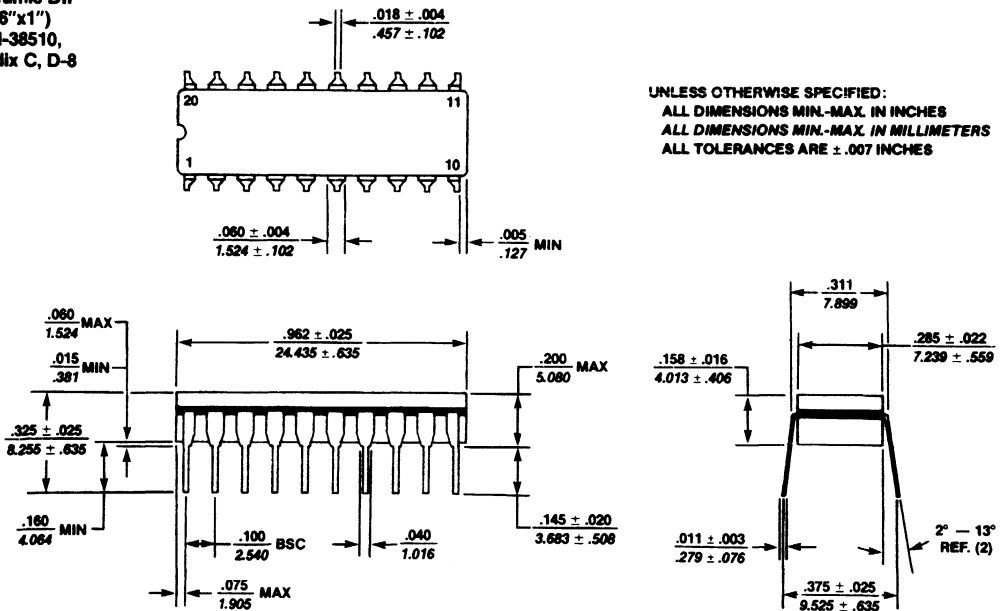
### Package Drawings

**18J Ceramic DIP**  
 (5/16" x 3/4")  
 MH-M-38510,  
 Appendix C, D-6



PO00020M

**20J Ceramic DIP**  
 (5/16" x 1")  
 MH-M-38510,  
 Appendix C, D-8



UNLESS OTHERWISE SPECIFIED:  
 ALL DIMENSIONS MIN.-MAX. IN INCHES  
 ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
 ALL TOLERANCES ARE  $\pm .007$  INCHES

PO00030M

**Notes:**

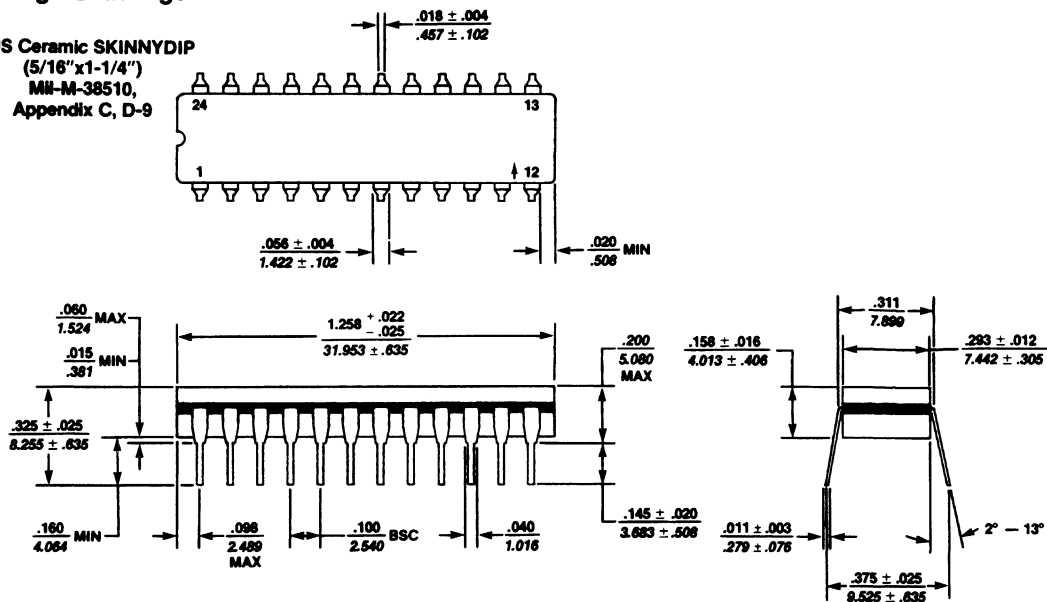
1. Specified body dimensions allow for differences between SSI, MSI and LSI packages.
2. Lead material tolerances are for tin plate finish only. Solder dip finish adds 2 - 10 mils thickness to all lead tip dimensions.

13

# Package Drawings

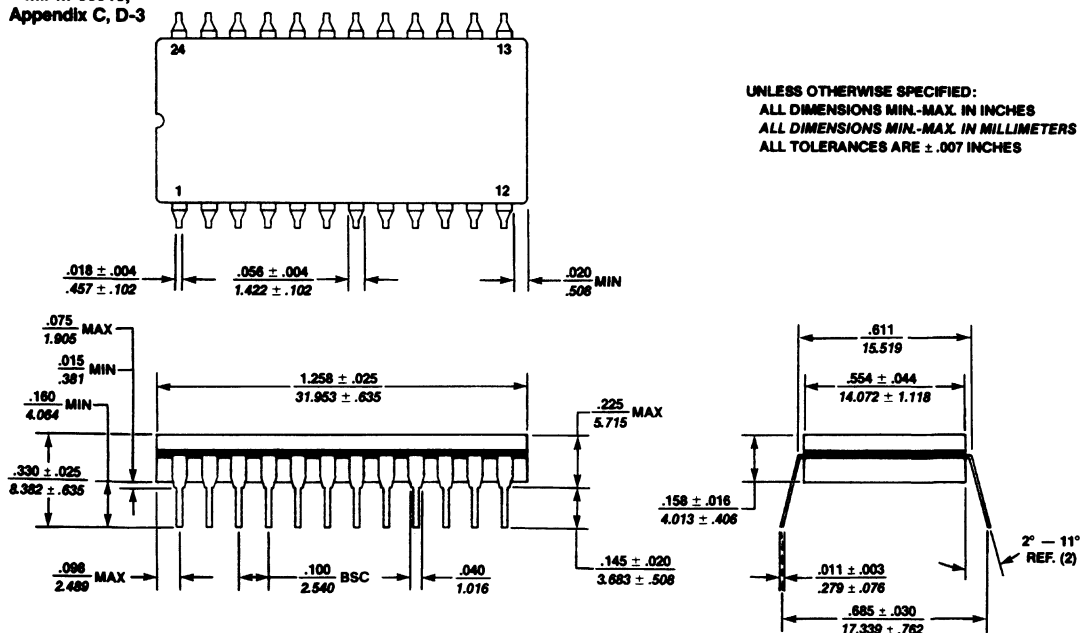
## Package Drawings

**24JS Ceramic SKINNYDIP**  
(5/16" x 1-1/4")  
MH-M-38510,  
Appendix C, D-9



PC00040M

**24J Ceramic DIP**  
MH-M-38510,  
Appendix C, D-3



UNLESS OTHERWISE SPECIFIED:  
ALL DIMENSIONS MIN.-MAX. IN INCHES  
ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
ALL TOLERANCES ARE  $\pm .007$  INCHES

**Notes:**

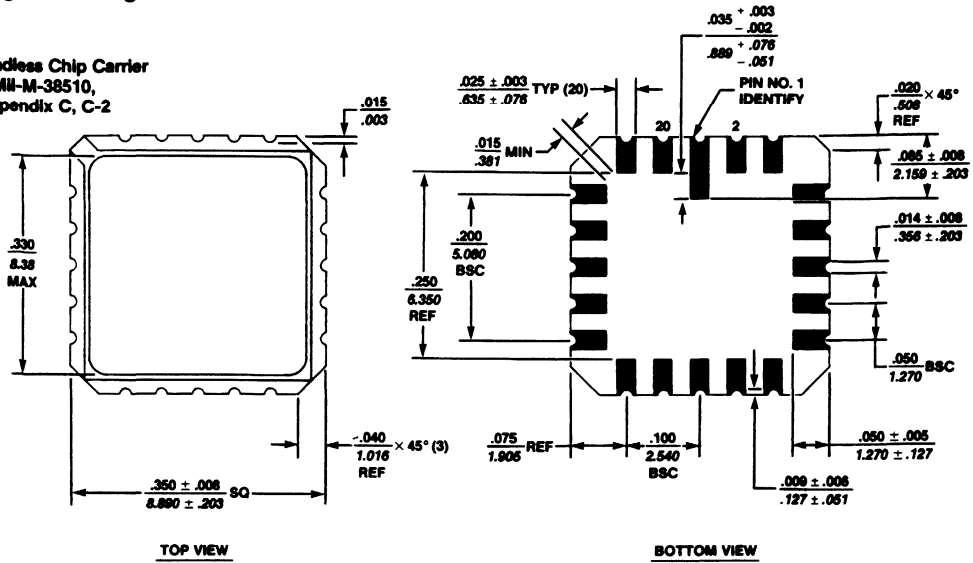
1. Specified body dimensions allow for differences between MSI and LSI packages.
2. Lead material tolerances are for tin plate finish only. Solder dip finish adds 2 - 10 mils thickness to all lead tip dimensions.

PC00040M

# Package Drawings

## Package Drawings

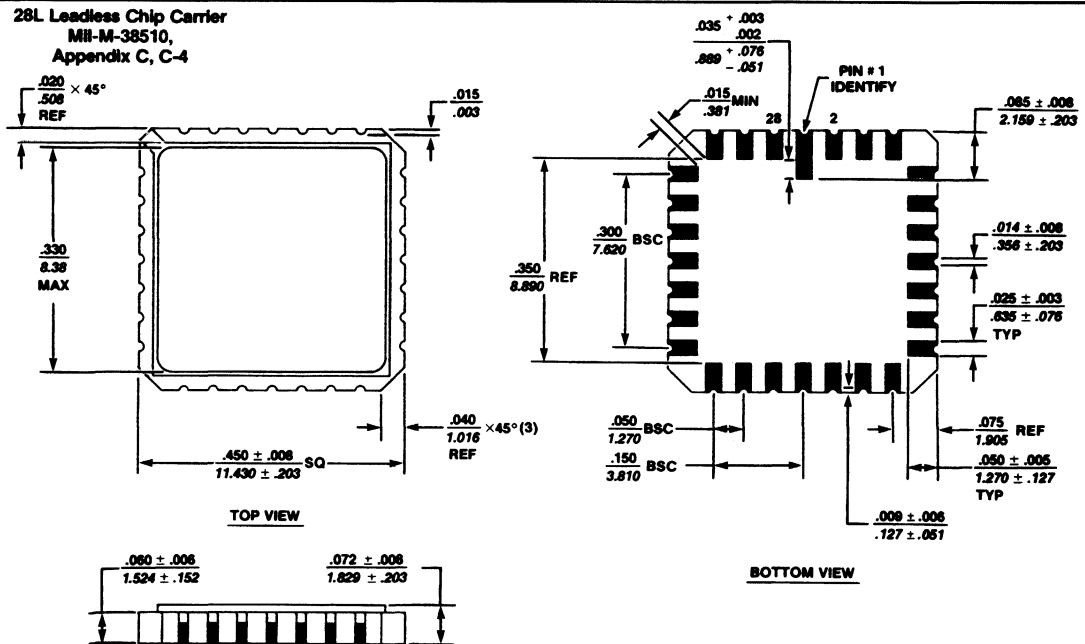
20L Leadless Chip Carrier  
Mil-M-38510,  
Appendix C, C-2



UNLESS OTHERWISE SPECIFIED:  
ALL DIMENSIONS MIN.-MAX. IN INCHES  
ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
ALL TOLERANCES ARE  $\pm .007$  INCHES

PC00000M

28L Leadless Chip Carrier  
Mil-M-38510,  
Appendix C, C-4



13

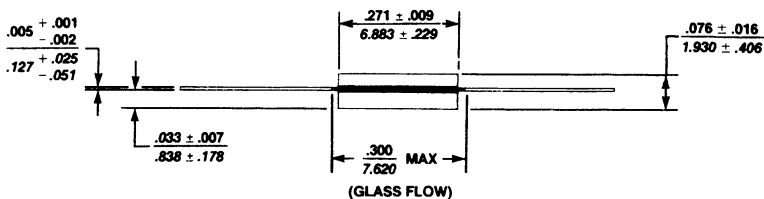
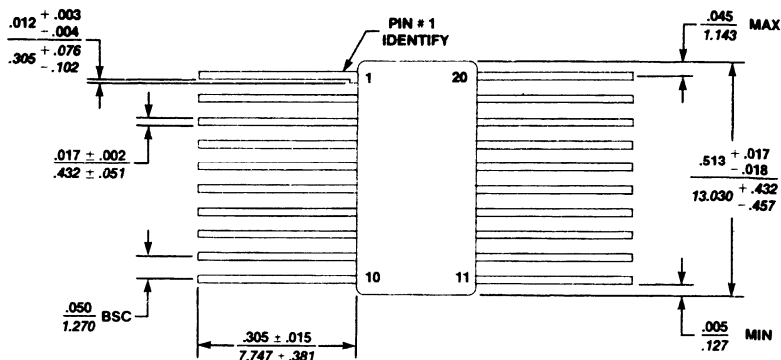
Notes:  
1. Solder fillets on lid edges not shown.

PC00070M

# Package Drawings

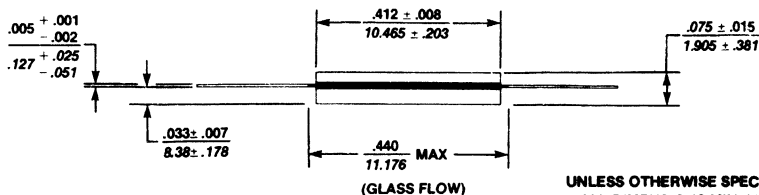
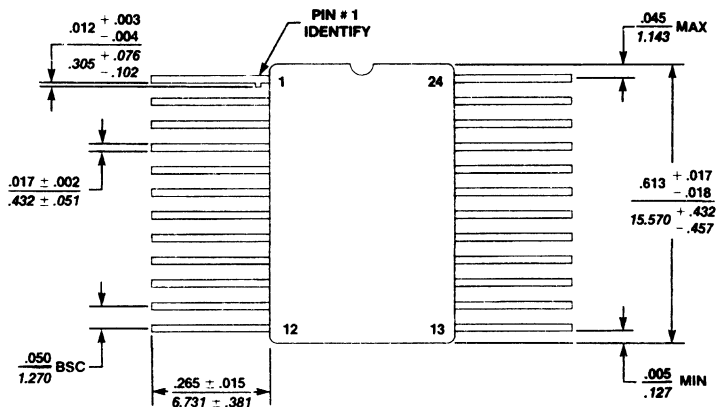
## Package Drawings

20W Cerpack  
 MIL-M-38510,  
 Appendix C, F-9



PC00080A

24W Cerpack  
 MIL-M-38510,  
 Appendix C, F-6



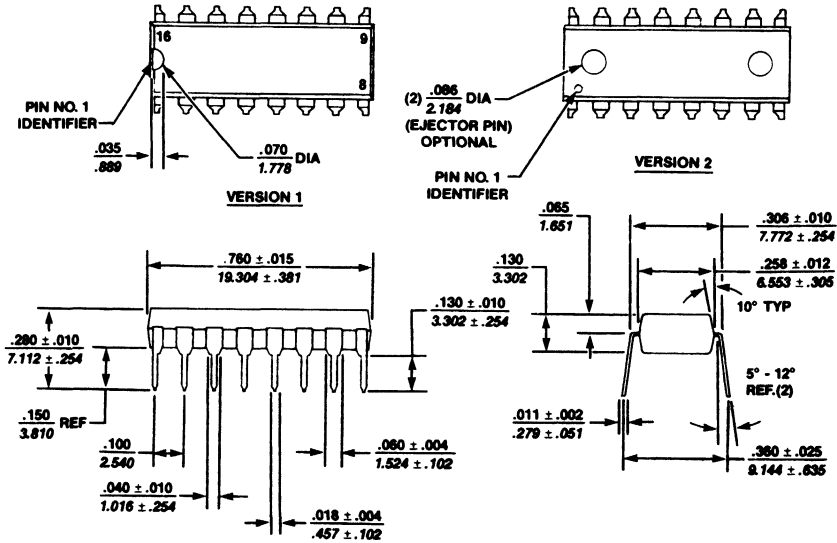
UNLESS OTHERWISE SPECIFIED:  
 ALL DIMENSIONS MIN.-MAX IN INCHES  
 ALL DIMENSIONS MIN.-MAX IN MILLIMETERS  
 ALL TOLERANCES ARE ± .007 INCHES

PC00080A

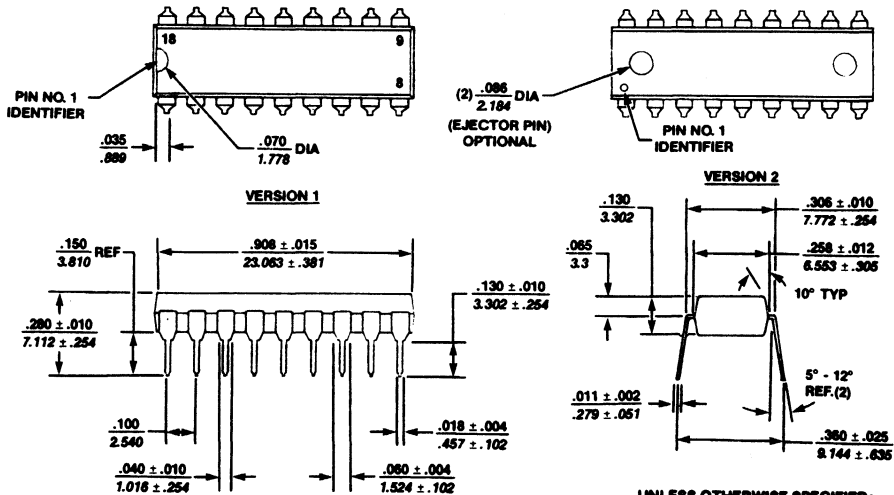
## Package Drawings

### Package Drawings

**16N Molded DIP**  
(1/4"x3/4")



**18N Molded DIP**  
(1/4"x7/8")



**UNLESS OTHERWISE SPECIFIED:**  
ALL DIMENSIONS MIN.-MAX. IN INCHES  
ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
ALL TOLERANCES ARE  $\pm .007$  INCHES

**Notes:**

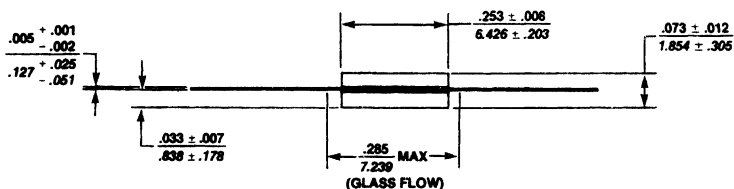
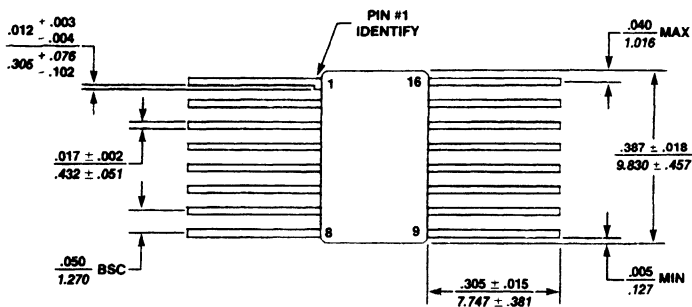
1. Lead material tolerances are for tin plate finish only. Solder dip finish adds 2 - 10 mils thickness to all lead tip dimensions.
2. Both Version 1 and Version 2 configurations are manufactured interchangeably.
3. Ejector pin marks on Version 1 are optional.

PC00110M

# Package Drawings

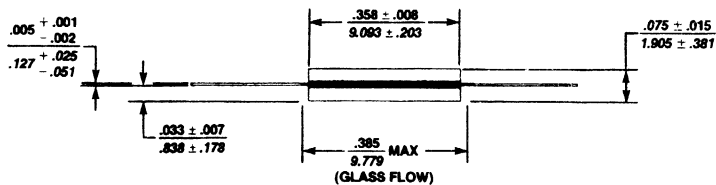
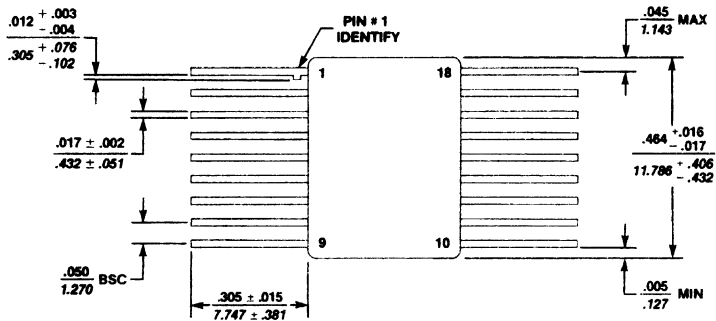
## Package Drawings

16W Cerpack  
 MH-M-38510,  
 Appendix C, F-5



PC00120M

## 18W Cerpack



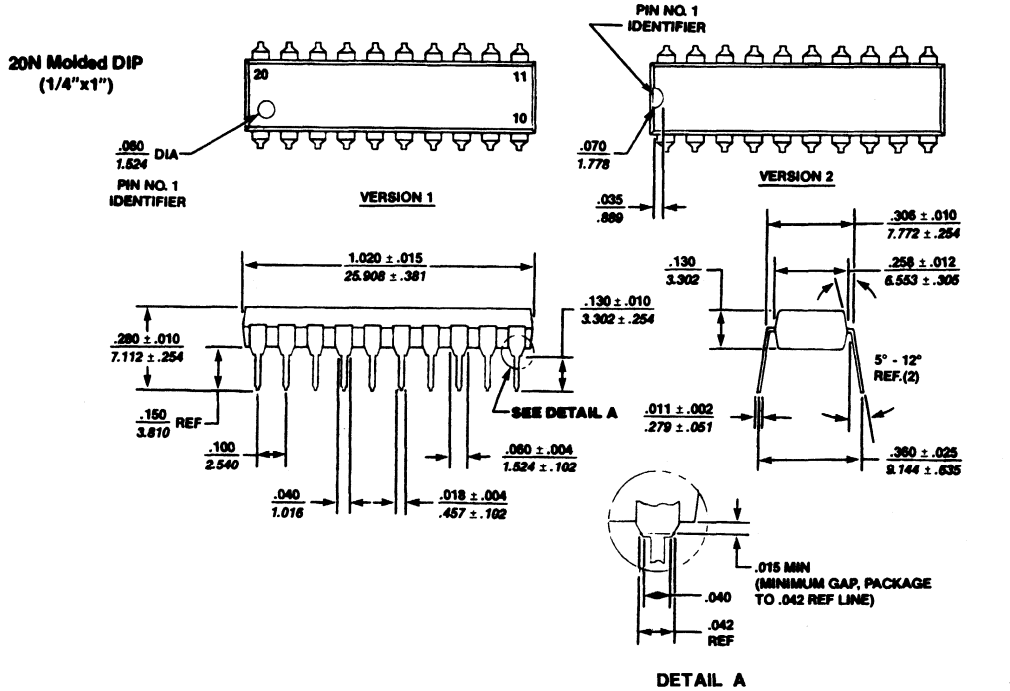
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 ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
 ALL TOLERANCES ARE  $\pm .007$  INCHES

PC00120M



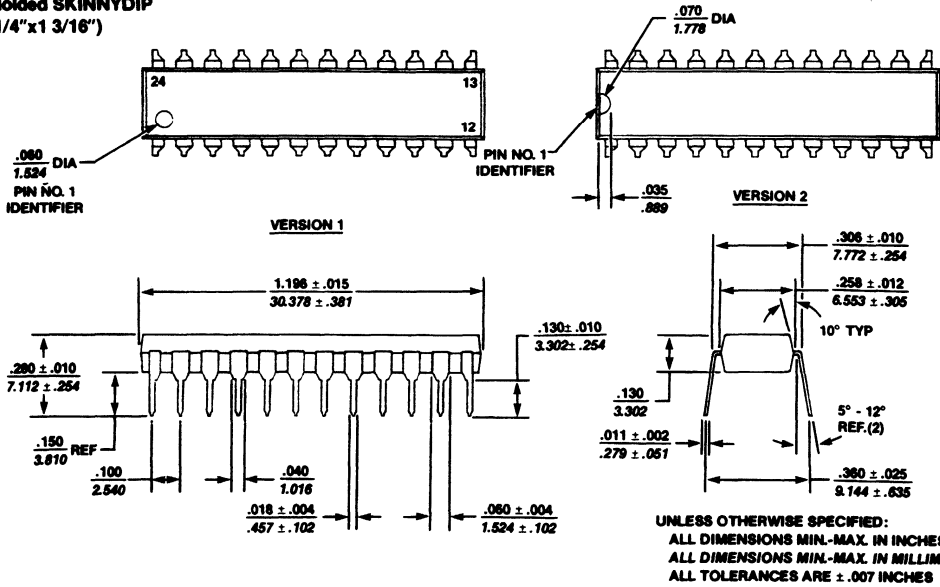
# Package Drawings

## Package Drawings



PO00140M

**24NS Molded SKINNYDIP (1/4"x1 3/16")**



PO00150M

**Notes:**

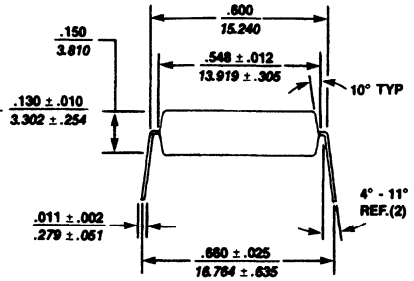
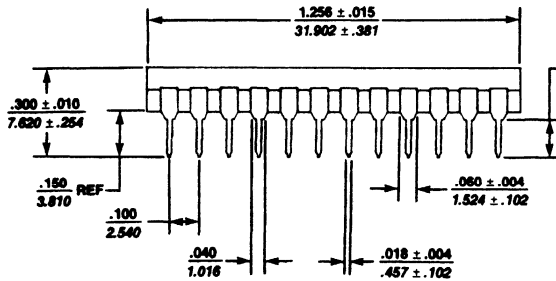
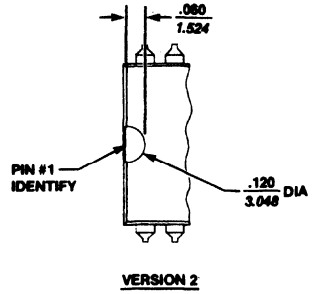
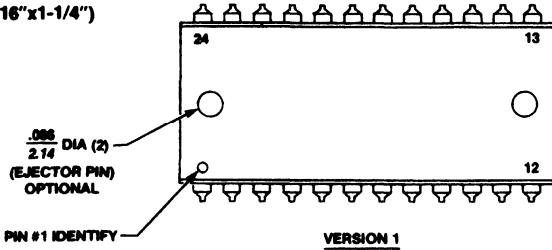
1. Lead material tolerances are for tin plate finish only. Solder dip finish adds 2 - 10 mils thickness to all lead tip dimensions.
2. Both Version 1 and Version 2 configurations are manufactured interchangeably.
3. Ejector pin marks on Version 1 are optional.

**13**

# Package Drawings

## Package Drawings

24N Molded DIP  
(9/16" x 1-1/4")



Notes:

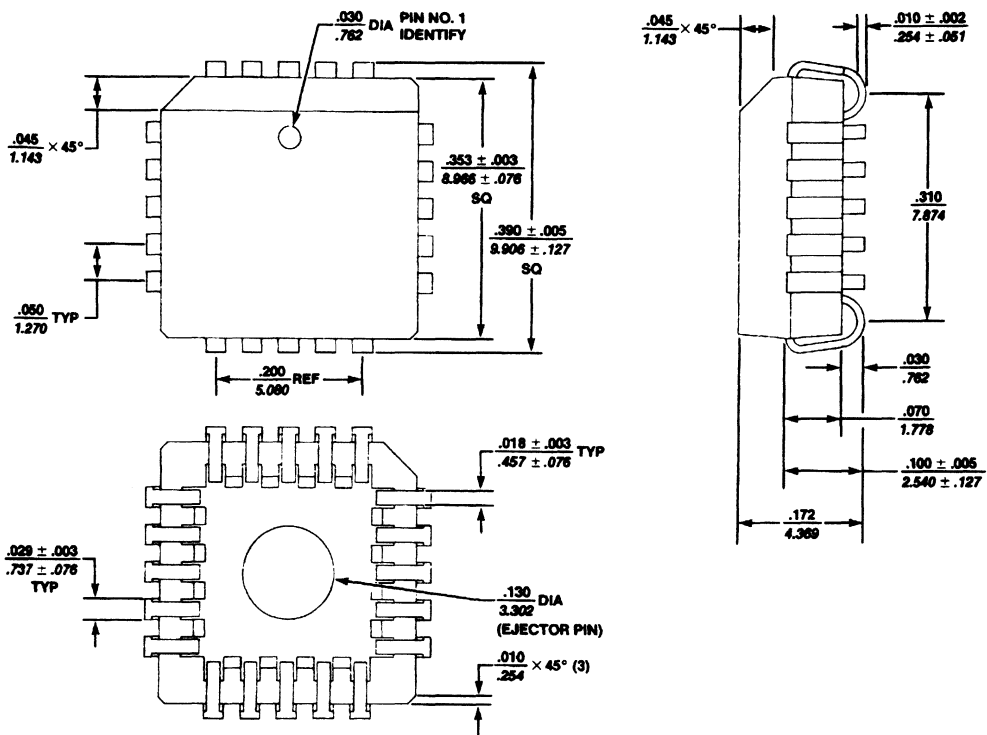
1. Lead material tolerances are for tin plate finish only. Solder dip finish adds 2 - 10 mils thickness to all lead tip dimensions.
2. Both Version 1 and Version 2 configurations are manufactured interchangeably.
3. Ejector pin marks on Version 1 are optional.

PO00180M

## Package Drawings

### Package Drawings

20NL Molded Chip Carrier  
(.351" x .351")



UNLESS OTHERWISE SPECIFIED:  
ALL DIMENSIONS MIN.-MAX. IN INCHES  
ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
ALL TOLERANCES ARE  $\pm .007$  INCHES

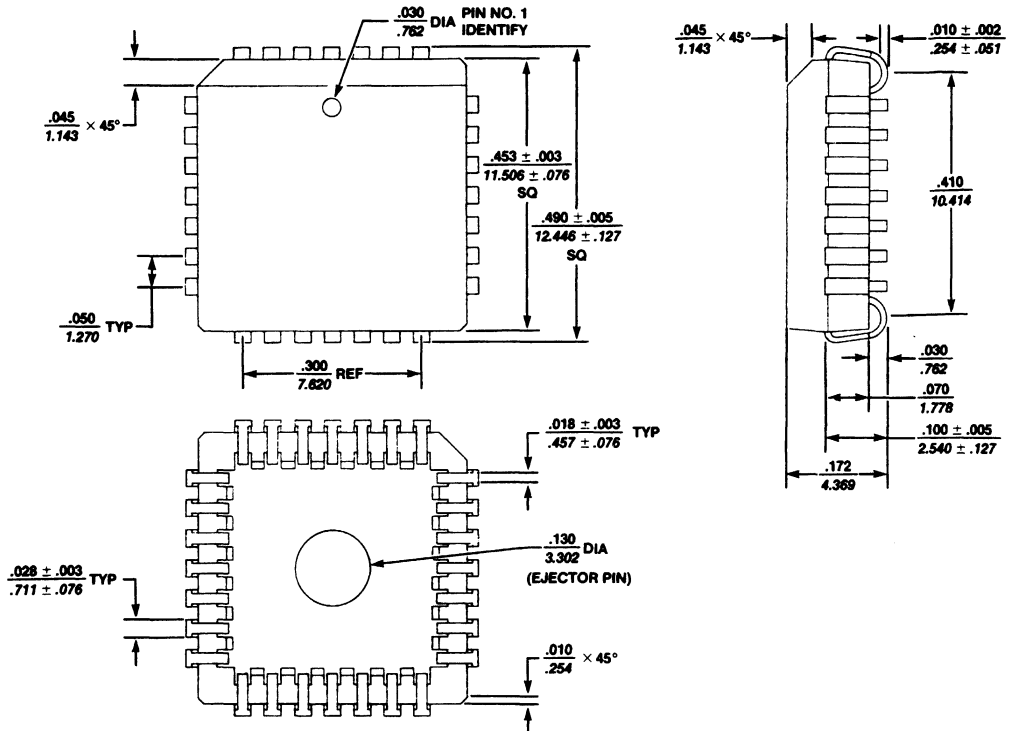
**13**

PC00170M

# Package Drawings

## Package Drawings

28NL Molded Chip  
(.451" x .451")

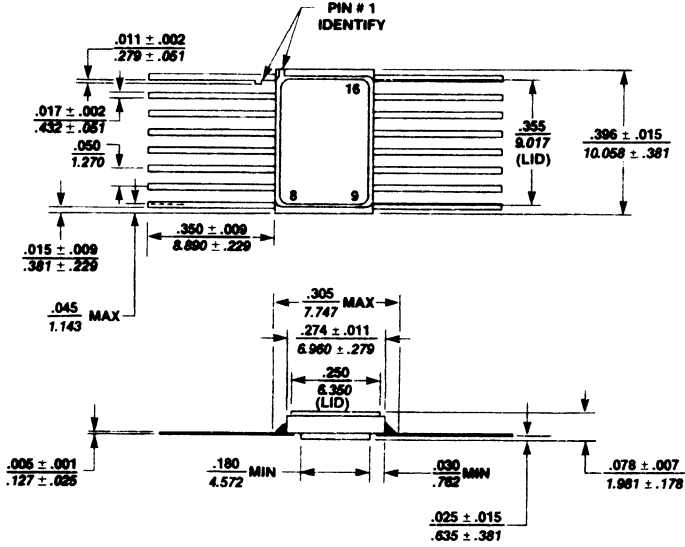


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ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
ALL TOLERANCES ARE  $\pm .007$  INCHES

PO00180M

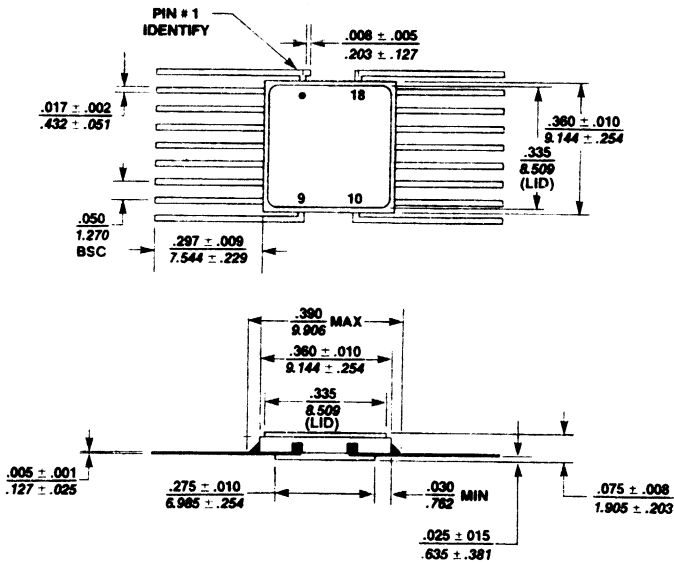
## Package Drawings

**Package Drawings**  
**16F-4/5 Flat Pack**  
 (1/4"x3/8")



PC00190M

**18F-2/3 Flat Pack**  
 (3/8"x3/8")

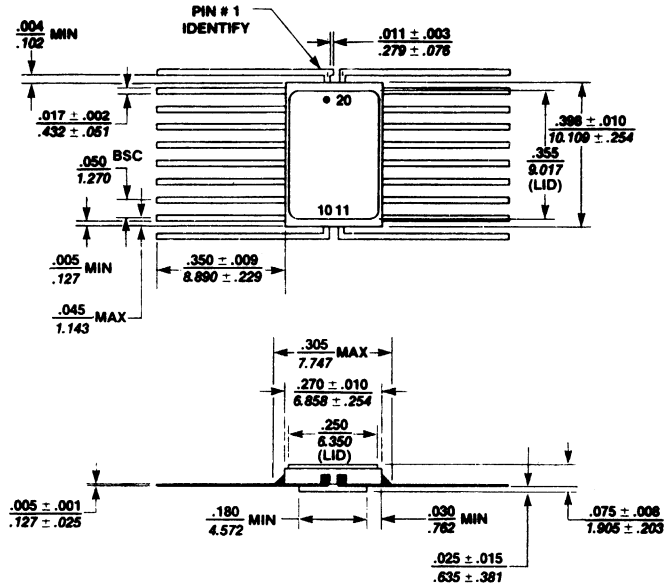


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 ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
 ALL TOLERANCES ARE  $\pm .007$  INCHES

PC00209M

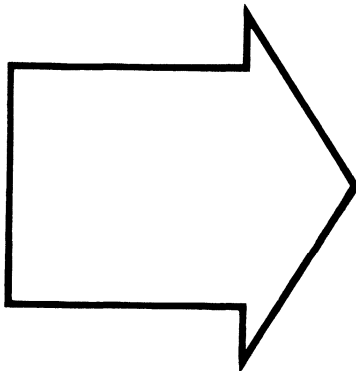
# Package Drawings

## Package Drawings 20F-3 Flat Pack (1/4" x 3/8")



UNLESS OTHERWISE SPECIFIED:  
ALL DIMENSIONS MIN.-MAX. IN INCHES  
ALL DIMENSIONS MIN.-MAX. IN MILLIMETERS  
ALL TOLERANCES ARE  $\pm .007$  INCHES

PO002104



|   |           |
|---|-----------|
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| <b>Logic Cell Array™</b>                | <b>5</b>  |
| <b>PALASM® Software Syntax</b>          | <b>6</b>  |
| <b>PAL Device Applications</b>          | <b>7</b>  |
| <b>Logic Tutorial</b>                   | <b>8</b>  |
| <b>PLE™ Devices</b>                     | <b>9</b>  |
| <b>PLE Circuit Applications</b>         | <b>10</b> |
| <b>Article Reprints</b>                 | <b>11</b> |
| <b>General Information</b>              | <b>12</b> |
| <b>Package Drawings</b>                 | <b>13</b> |
| <b>Representatives and Distributors</b> | <b>14</b> |





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