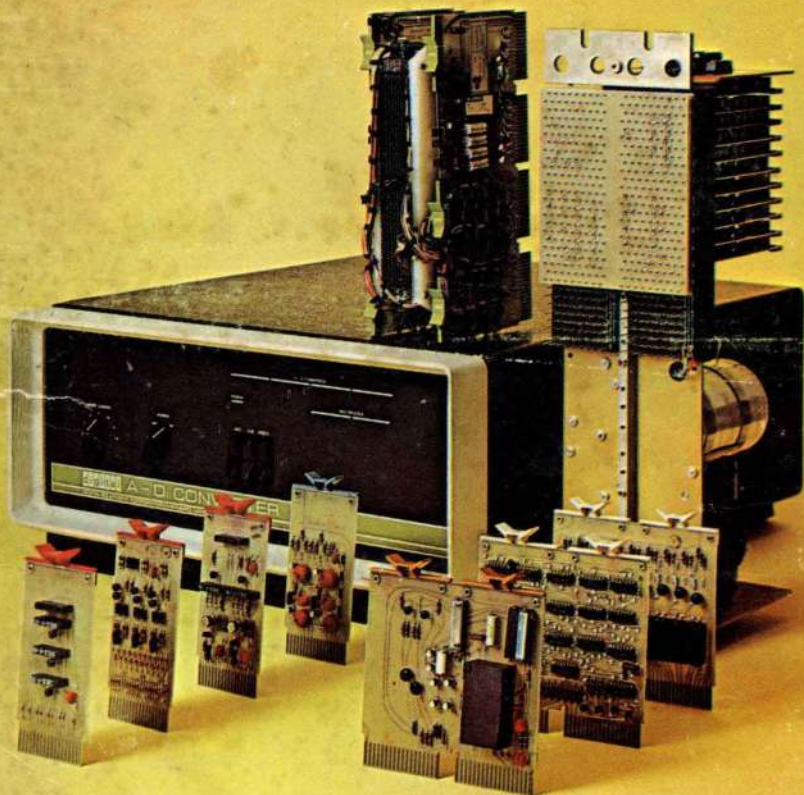


digital

LOGIC HANDBOOK



FLIP CHIP™ MODULES

DIGITAL EQUIPMENT CORPORATION

THE

digital

LOGIC HANDBOOK
FLIP CHIP™ MODULES
1967 EDITION

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PART I: DIGITAL LOGIC PRIMER

PART II: FLIPCHIP MODULES

PART III: LOGIC LABORATORY

PART IV: HARDWARE, OCTAIDS AND PANELAIDS

PART V: ANALOG - DIGITAL CONVERSION HANDBOOK

PART VI: COMPUTER CATALOG

PREFACE

GENERAL PURPOSE MODULES

The first section defines the characteristics of the FLIP-CHIP™ line of modules which cover the spectrum of application in three series:

1. The R series which operates from DC to Two Megahertz.
2. The B series which operates from DC to Ten Megahertz.
3. The W series modules for interfacing with various types of external equipment.

In addition to these various module lines, a totally new approach to subsystem design, OCTAIDS and PANELAIDS are described in detail. These design aids provide the user with a fast, accurate method of assembling such common elements as A to D converters, binary counters, and real time clocks.

ANALOG-DIGITAL CONVERSION

The second section of the Digital Logic Handbook is concerned with Analog-Digital Conversion. A primer on conversion techniques prefaces this section and the complete line of A series modules and A to D converters follow. The system designer is provided with the necessary information to select either a complete A to D converter or the various analog modules. Application notes are included to further aid in the design of special systems.

HARDWARE

A section which describes Digital's complete line of hardware is included in the Handbook. New in this issue are the 4096 x 13 bit memory and paper tape punch and reader units. All of the hardware necessary for the fabrication of a complete system are included, and each piece of hardware has been field-proven in Digital's PDP series computers.

MONOLITHIC INTEGRATED CIRCUITS

The M series is a completely new line of functional TTL monolithic integrated circuit modules for operation at speeds up to 10 megahertz. These modules are for use where speed is of primary importance and packing density a consideration. Modules are provided which perform the functions of shifting, counting, storage, binary to octal conversion, and gating.

These modules are described in detail in separate literature which can be requested by using the reply form included in this Logic Handbook.

INDUSTRIAL CONTROL MODULES

Digital's K Series Industrial Control Modules provide the answer to the problem of using solid state logic in the high noise environment encountered in control systems. All silicon semiconductors and monolithic integrated circuits have been designed into modules providing all necessary functions formerly accomplished by awkward relay devices. K series modules and hardware are designed for installation in standard NEMA enclosures. Connectors for these modules are the field-proven FLIP CHIP™ connectors which have been used on two generations of Digital's computers and with modules in every conceivable application from steel mills to lathe controls. Connection between terminal strips and electronics are also pluggable, allowing the logic to be installed after field wiring is complete. Standard functions of gating, storage, and counting are provided, plus industrial-oriented AC Input Converter, AC Switch, Timer, Interface Block, and Glow Tube (Indicator) Driver. Sensing and output circuits operate at 115 volts AC for complete electromechanical compatibility. Solid state AC switches are fully protected against false triggering, and provisions for interlocking are included.

Checkout and trouble shooting are easy with K series modules. Each system input and output has a built-in indicator light and a special test probe provides its own local illumination and built in memory for transient signals as well as steady states.

K series modules provide the solid-state advantages of size reduction, reliability, flexibility, and low cost logic with an added bonus of easy interconnection. For a complete set of specifications and helpful design examples send for the Industrial Controls Handbook by using the reply form attached.

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R AND B SERIES MODULE FEATURES

COMPLETENESS OF LINE

A full selection of high-volume standard modules with sufficient types and accessory hardware for building complete systems. 150 items in the current product line with 70 items in stock for immediate delivery.

FREQUENCY RANGE

Dc to 10 MHz in two fully compatible series.

SIGNAL LEVELS

0 volts and -3 volts.

FAN-OUT

70 ma from pulse amplifiers
18 ma from diode gates
15 ma from typical flip-flops
(typical input loads: 1-3 ma)

CLAMPED LOGIC

Signal voltages are independent of loading. All signals clamped to -3 volts.

WIDE TEMPERATURE RANGE

FLIP CHIP silicon modules operate over a temperature range of -20°C to $+65^{\circ}\text{C}$.

GOOD NOISE IMMUNITY

All low speed modules and some high speed modules have diode isolated inputs. Typical noise rejection for diode gates: at 0v — 1.0v
at -3v — 1.5v

LOW POWER DISSIPATION

Typically: 150 mw per flip-flop
40 mw per diode gate

SIMPLE POWER REQUIREMENTS

Two supply voltages required: $+10\text{v}$ and -15v . All modules have standard power connections. Complete line of power supplies available as standard items.

ULTIMATE IN LOGICAL FLEXIBILITY

Extremely flexible flip-flop configuration permits JK, RS, RST, or T memory elements to be constructed without modifying modules.
Gates and power amplifiers may be paralleled for performing positive OR functions.
A wide range of interfacing modules are available for converting standard DEC levels to external equipment requirements.

GENERAL CHARACTERISTICS— R AND B SERIES MODULES

FREQUENCY RANGES

Dc to 2 MHz (R Series)
Dc to 10 MHz (B Series)

LOGIC LEVELS

0v to -0.3 upper level
-3.2 v to -3.9v lower level

HIGH FAN-OUT

High driving capability for all modules.
Typically: 70 ma — pulse amplifiers
18 ma — diode gates
15 ma — flip-flops

HIGH FAN-IN

Low input current requirements. Typically 1 ma to 3 ma. Diode gate inputs may be expanded as high as 25 inputs with gate expander modules.

ALL LOGIC LEVELS DIODE CLAMPED

Signal voltages are diode clamped at -3v independent of fan-out and independent of other input conditions at the load.

LOW POWER DISSIPATION

Typically: 150 mw per JK flip-flop
40 mw per diode gate

CONSERVATIVE DESIGN

All circuits can tolerate at least $\pm 20\%$ variations in power supply voltage.

NOISE IMMUNITY

| | At 0 volts | At -3 volts |
|------------------|------------|---------------------|
| Diode Gates | 1.0v | 1.5v |
| DCD Gates | 0.7v | Totally insensitive |
| 10 MHz Inverters | 0.5v | 0.5 volts |

TEMPERATURE RANGE

-20°C to +65°C on all silicon FLIP CHIP modules. A few W-Series power driving accessory modules include germanium semiconductors as indicated on their data sheets, reducing their upper limit to +55°C.

COMPATIBILITY

- Many specialized interface modules available providing:
 - Input voltage compatibility between $\pm 30\text{v}$.
 - Output voltage compatibility between $\pm 135\text{v}$.
 - Output currents as high as 10 amperes.

ANALOG-DIGITAL CONVERSION

- Complete selection of interface modules for building hybrid configurations including:
 - Comparators
 - D to A converter modules
 - Analog switch modules
 - Reference supplies

POWER REQUIREMENTS

- +10v nominal, module pin A
- 15v nominal, module pin B
- ground, module pin C

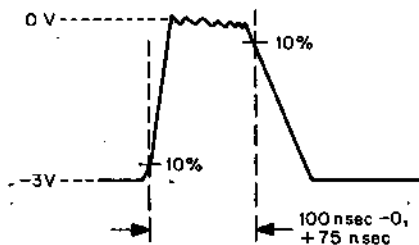
BOARD SPECIFICATIONS

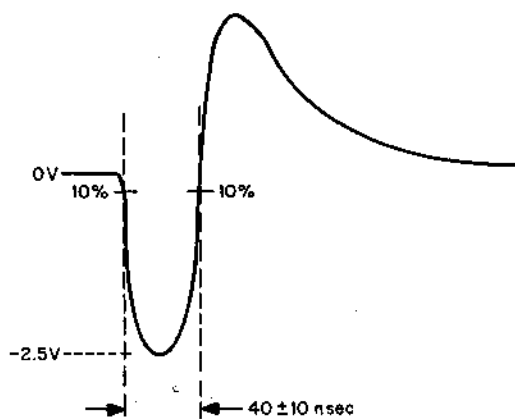
- Material — G10 FR4 Glass Epoxy
- Copper Coating — 2 oz. (0.0028 inches)
- Thickness — $0.055 \pm .003$ inches overall
- Gold Plated Contacts — 0.00015 inch gold on copper

STANDARD FLIP CHIP WAVEFORM DEFINITIONS

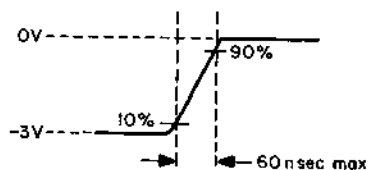
R Series

STANDARD PULSE





Edge Requirements for activation of R Series DCD pulse inputs

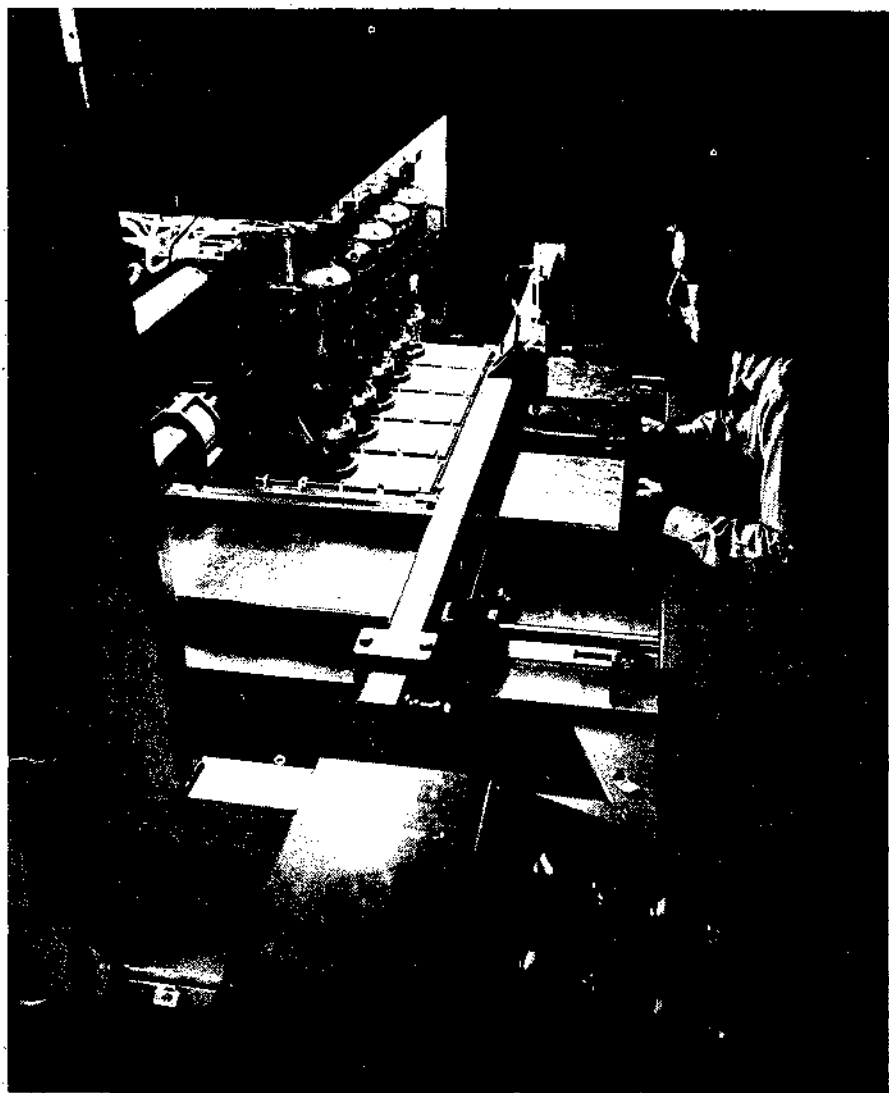




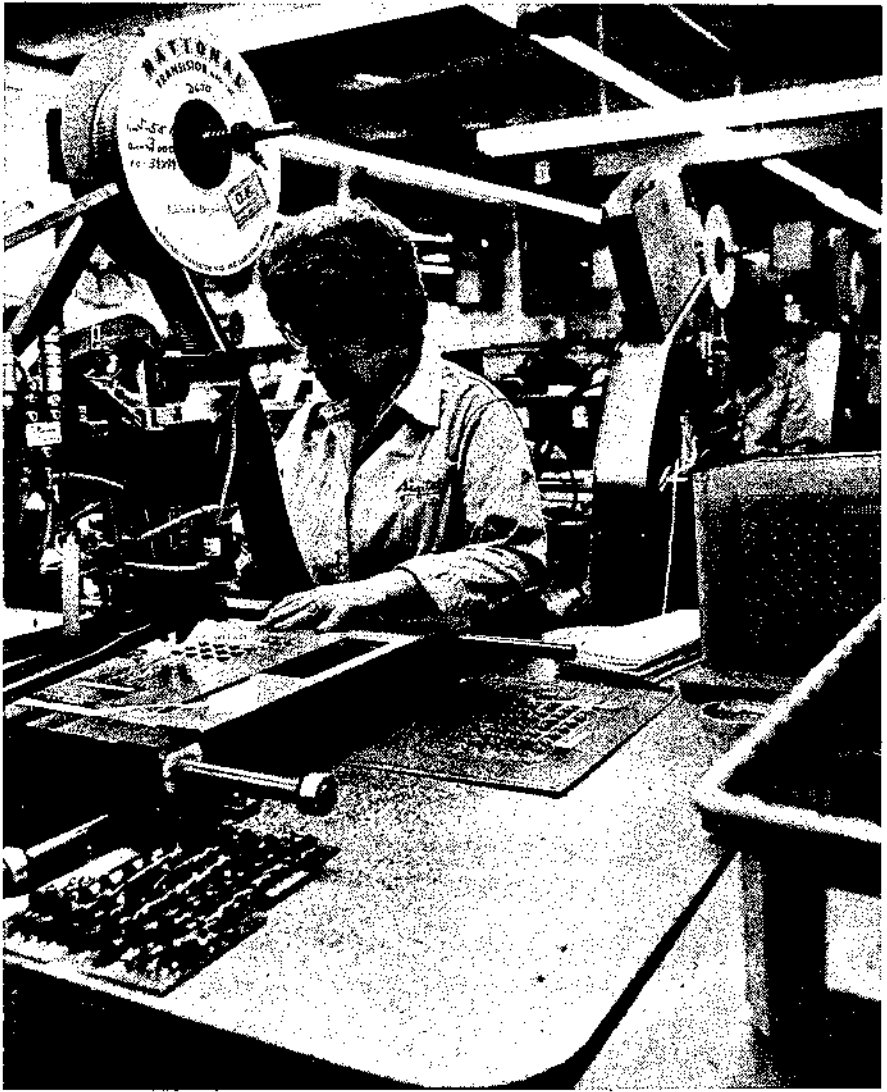
FLIP CHIP assembly line combines automated manufacturing steps with computer controlled checkout for lower cost, more reliable circuits.



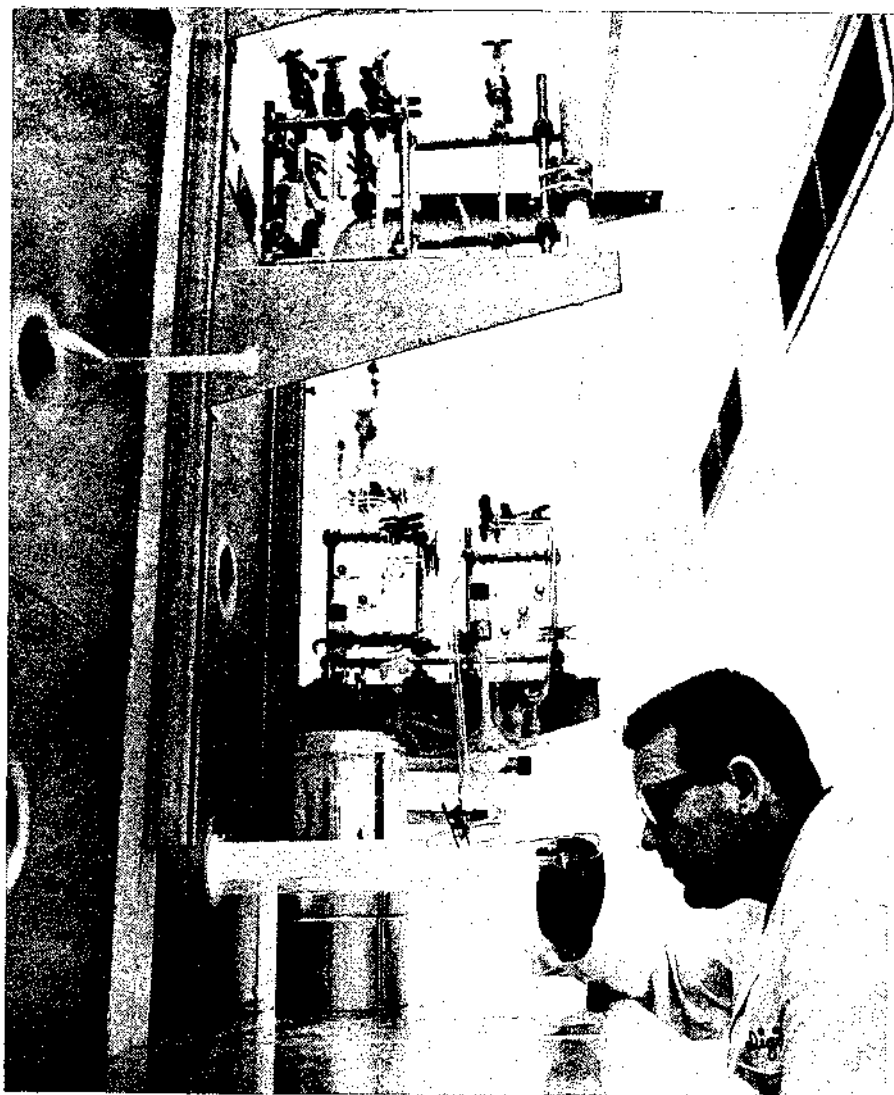
Printed circuits on FLIP CHIP boards are produced in an etching-plating line which includes an 18-step process to gold-plate the plug-in contacts.



Ten spindle automatic machine drills 40 boards simultaneously, provides precision component layout.



Discrete components are positioned and crimped in place at rates up to 30 per minute on pantograph controlled inserting machine.



High quality diffusion furnaces used for the generation of semiconductor junctions.



Substrate screening and semiconductor mounting operations are performed under clean room conditions.



Thermal compression bonding ties semiconductors into hybrid networks.



To insure reliability, a wide variety of dynamic tests are performed on-line by a computer controlled system.

PART I: DIGITAL LOGIC PRIMER

NUMBER SYSTEMS

Early number systems were crude and awkward to use. A simple system, using a mark for each unit, cannot be used to express large quantities such as a thousand. Later systems, such as Roman numerals, were a great improvement, but still extremely difficult to manipulate in ordinary arithmetic. With the Arabic, or decimal, number system, common arithmetic operations, which correspond to true to life operations, can be defined and easily used.

The decimal number system uses ten symbols representing the quantities 0 through 9. Other numbers are constructed by assigning different values (or weights) to the position of the symbol relative to the decimal point. For example, the number 008 (more commonly written simply 8) represents eight units, while the number 080 (again more commonly written just 80) represents a quantity of eighty, and the number 800 represents a quantity of eight hundred.

Each position in a decimal number has a value which is ten times the value of the next position to the right. In other words, every positional weight is a multiple of ten and can be expressed by ten raised to some power. The tens position is 10^1 , the hundreds position is 10^2 , the thousands position is 10^3 , etc.

Simple exponential arithmetic shows that the ones position is $10^0 = 1$ (in fact, any number raised to the 0 power, except 0, is equal to 1). This progression of increasing exponents can be continued as far as desired to the left of the decimal point. The same progression can also be extended to the right of the decimal point, but here the exponents will be negative. For example, the first position to the right of the decimal point is the tenths position, it has a weight of 10^{-1} or $1/10^1$.

Figure 1 represents a general skeleton for any decimal number. The symbol which is placed in any of the positions indicates how many multiples of that power of 10 are in the total quantity represented by the number.

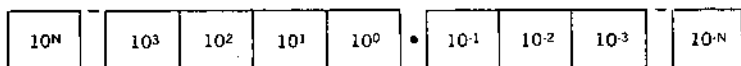


Figure 1

Ten is not a particularly magical number; there is no reason for the number of symbols to be extended to ten (or limited to ten). It would be just as simple to have twelve symbols or eight symbols or two symbols, or any other number of symbols. However, one of the features of the decimal system is that there is only one way in which any given number can be written, and on seeing a number written, there is only one value which can be ascribed to it. In order to keep this feature in a number system with a different number of symbols, it is necessary to change the weights of the different positions. The values which must be assigned, in fact, turn out to be powers of the

number of symbols available. The number of symbols used is called the radix of the number system. Figure 2 shows the skeleton of a general number system with a radix R.

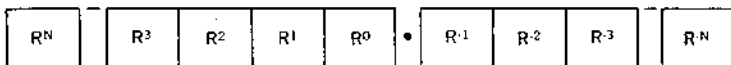


Figure 2

Examples of counting in different number systems are illustrated in Figure 3. The duodecimal number system has a radix of 12 and the symbols A and B are used here to represent the quantities 10 and 11, respectively. The octal number system has a radix of 8 and the binary number system has a radix of 2. The positional weights are given in decimal at the top of each column.

COUNTING IN DIFFERENT NUMBER SYSTEMS

| <u>DECIMAL</u> | <u>DUODECIMAL</u> | <u>OCTAL</u> | <u>BINARY</u> |
|----------------|---------------------------------|----------------------------|--------------------------------------|
| | t w e l v e s | e i g h t s | s i x t e n t s |
| | o n e s | o n e s | o n e s |
| 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 1 0 |
| 3 | 3 | 3 | 1 1 |
| 4 | 4 | 4 | 1 0 0 |
| 5 | 5 | 5 | 1 0 1 |
| 6 | 6 | 6 | 1 1 0 |
| 7 | 7 | 7 | 1 1 1 |
| 8 | 8 | 1 0 | 1 0 0 0 |
| 9 | 9 | 1 1 | 1 0 0 1 |
| 1 0 | A | 1 2 | 1 0 1 0 |
| 1 1 | B | 1 3 | 1 0 1 1 |
| 1 2 | 1 0 | 1 4 | 1 1 0 0 |
| 1 3 | 1 1 | 1 5 | 1 1 0 1 |
| 1 4 | 1 2 | 1 6 | 1 1 1 0 |
| 1 5 | 1 3 | 1 7 | 1 1 1 1 |
| 1 6 | 1 4 | 2 0 | 1 0 0 0 0 |
| 1 7 | 1 5 | 2 1 | 1 0 0 0 1 |
| 1 8 | 1 6 | 2 2 | 1 0 0 1 0 |
| 1 9 | 1 7 | 2 3 | 1 0 0 1 1 |
| 2 0 | 1 8 | 2 4 | 1 0 1 0 0 |
| 2 1 | 1 9 | 2 5 | 1 0 1 0 1 |
| 2 2 | 1 A | 2 6 | 1 0 1 1 0 |
| 2 3 | 1 B | 2 7 | 1 0 1 1 1 |
| 2 4 | 2 0 | 3 0 | 1 1 0 0 0 |

Figure 3

BINARY NUMBER SYSTEM

Since the binary number system uses two symbols, it has a radix of 2 and the positional weights are powers of 2. Examination of the binary counting sequence, Figure 3, shows that the binary number system follows the same number system skeleton which was previously outlined. Because of this, the method of performing arithmetic operations in binary numbers is the same as the methods used for decimal numbers. For example, $0 + 0 = 0$, and $0 + 1 = 1$. Since there is no symbol for two, however, $1 + 1 = 0$ and 1 to carry. The tables for performing arithmetic operations are given in Figure 4. Since there are only two symbols, the tables are considerably simpler than those required to outline the same operations in the decimal number system. This, of course, leads to considerably simpler computer circuitry also. Some typical examples of arithmetic operations in binary are shown in Figure 5.

| | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><u>Binary Addition</u></p> <p>$A + B = S$ (Sum)</p> <p>$0 + 0 = 0$</p> <p>$0 + 1 = 1$</p> <p>$1 + 0 = 1$</p> <p>$1 + 1 = 0$ & 1 to carry</p> | <p><u>Binary Subtraction</u></p> <p>$A - B = D$ (Difference)</p> <p>$0 - 0 = 0$</p> <p>$0 - 1 = 1$ & 1 to borrow</p> <p>$1 - 0 = 1$</p> <p>$1 - 1 = 0$</p> |
| <p><u>Binary Multiplication</u></p> <p>$A \times B = P$ (Product)</p> <p>$0 \times 0 = 0$</p> <p>$0 \times 1 = 0$</p> <p>$1 \times 0 = 0$</p> <p>$1 \times 1 = 1$</p> | <p><u>Binary Division</u></p> <p>$A \div B = Q$ (Quotient)</p> <p>$0 \div 0 = ?$</p> <p>$0 \div 1 = 0$</p> <p>$1 \div 0 = ?$</p> <p>$1 \div 1 = 1$</p> |

Figure 4

| | | | | | | | | | | | | | | | | | | | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|--------|--------|--------|--------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|--------|----------|---------|--------|-------|------|--|----|----|-----|--|-----|--|
| <p><u>Addition</u></p> <table style="margin-left: auto; margin-right: auto;"> <tr><td style="text-align: right;">101101</td><td style="text-align: right;">101101</td></tr> <tr><td style="text-align: right;">+ 1010</td><td style="text-align: right;">+ 1100</td></tr> <tr><td style="text-align: right; border-top: 1px solid black;">110111</td><td style="text-align: right; border-top: 1px solid black;">111001</td></tr> </table> | 101101 | 101101 | + 1010 | + 1100 | 110111 | 111001 | <p><u>Subtraction</u></p> <table style="margin-left: auto; margin-right: auto;"> <tr><td style="text-align: right;">101101</td><td style="text-align: right;">101101</td></tr> <tr><td style="text-align: right;">- 1100</td><td style="text-align: right;">- 11001</td></tr> <tr><td style="text-align: right; border-top: 1px solid black;">100001</td><td style="text-align: right; border-top: 1px solid black;">10100</td></tr> </table> | 101101 | 101101 | - 1100 | - 11001 | 100001 | 10100 | | | | | | | | |
| 101101 | 101101 | | | | | | | | | | | | | | | | | | | | |
| + 1010 | + 1100 | | | | | | | | | | | | | | | | | | | | |
| 110111 | 111001 | | | | | | | | | | | | | | | | | | | | |
| 101101 | 101101 | | | | | | | | | | | | | | | | | | | | |
| - 1100 | - 11001 | | | | | | | | | | | | | | | | | | | | |
| 100001 | 10100 | | | | | | | | | | | | | | | | | | | | |
| <p><u>Multiplication</u></p> <table style="margin-left: auto; margin-right: auto;"> <tr><td style="text-align: right;">101101</td></tr> <tr><td style="text-align: right;">× 101</td></tr> <tr><td style="text-align: right; border-top: 1px solid black;">101101</td></tr> <tr><td style="text-align: right;">00000</td></tr> <tr><td style="text-align: right; border-top: 1px solid black;">101101</td></tr> <tr><td style="text-align: right; border-top: 1px solid black;">11100001</td></tr> </table> | 101101 | × 101 | 101101 | 00000 | 101101 | 11100001 | <p><u>Division</u></p> <table style="margin-left: auto; margin-right: auto;"> <tr><td style="text-align: right;">101</td><td style="text-align: right;">1001</td></tr> <tr><td style="text-align: right;">√ 101101</td><td></td></tr> <tr><td style="text-align: right;">101</td><td style="text-align: right;">0001</td></tr> <tr><td style="text-align: right; border-top: 1px solid black;">0000</td><td></td></tr> <tr><td style="text-align: right;">10</td><td style="text-align: right;">00</td></tr> <tr><td style="text-align: right; border-top: 1px solid black;">101</td><td></td></tr> <tr><td style="text-align: right; border-top: 1px solid black;">101</td><td></td></tr> </table> | 101 | 1001 | √ 101101 | | 101 | 0001 | 0000 | | 10 | 00 | 101 | | 101 | |
| 101101 | | | | | | | | | | | | | | | | | | | | | |
| × 101 | | | | | | | | | | | | | | | | | | | | | |
| 101101 | | | | | | | | | | | | | | | | | | | | | |
| 00000 | | | | | | | | | | | | | | | | | | | | | |
| 101101 | | | | | | | | | | | | | | | | | | | | | |
| 11100001 | | | | | | | | | | | | | | | | | | | | | |
| 101 | 1001 | | | | | | | | | | | | | | | | | | | | |
| √ 101101 | | | | | | | | | | | | | | | | | | | | | |
| 101 | 0001 | | | | | | | | | | | | | | | | | | | | |
| 0000 | | | | | | | | | | | | | | | | | | | | | |
| 10 | 00 | | | | | | | | | | | | | | | | | | | | |
| 101 | | | | | | | | | | | | | | | | | | | | | |
| 101 | | | | | | | | | | | | | | | | | | | | | |

Figure 5

BINARY-DECIMAL CONVERSION

Numbers can be converted from binary to decimal and vice versa by hand by using the methods outlined in Figure 6. As shown, a binary number is converted to decimal simply by adding the positional weights of all those positions where a 1 appears. Decimal to binary conversion is more a process of trial and error. First, subtract the largest power of 2 which will go into the number that is being converted. This process is repeated on the remainder until the remainder is equal to 0. The binary number then has ones in those positions with the values corresponding to the powers of 2 which were subtracted; all other positions are 0.

BINARY TO DECIMAL CONVERSION

$$\begin{array}{cccccc}
 \underline{32} & \underline{16} & \underline{8} & \underline{4} & \underline{2} & \underline{1} \\
 1 & 0 & 1 & 1 & 0 & 1 = 32 + 8 + 4 + 1 = 45 \\
 & & 1 & 0 & 1 & 0 = 8 + 2 = 10 \\
 1 & 1 & 0 & 1 & 1 & 1 = 32 + 16 + 4 + 2 + 1 = 55
 \end{array}$$

DECIMAL BINARY CONVERSION

$$\begin{array}{r}
 \begin{array}{cccccc}
 & \underline{32} & \underline{16} & \underline{8} & \underline{4} & \underline{2} & \underline{1} \\
 45 & \longrightarrow & 1 & 0 & 1 & 1 & 0 & 1 \\
 -\underline{32} & & & & & & & \\
 13 & & & & \uparrow & \uparrow & & \uparrow \\
 -\underline{8} & \longrightarrow & & & & & & \\
 5 & & & & & & & \\
 -\underline{4} & \longrightarrow & & & & & & \\
 1 & & & & & & & \\
 -\underline{1} & \longrightarrow & & & & & & \\
 0 & & & & & & &
 \end{array}
 \end{array}$$

Figure 6

BINARY-CODED-DECIMAL NUMBERS

Since computer inputs and outputs must often be in decimal notation, a variety of special codes are used. These hybrid number systems are referred to as binary-coded-decimal or BCD.

An example of BCD is the 8421 code. This is often referred to as simply BCD since the weights of the positions are the same as in the binary number system, as illustrated below.

| <u>Decimal</u> | <u>8421 Code</u> |
|----------------|------------------|
| 0 | 0000 |
| 1 | 0001 |
| 2 | 0010 |
| 3 | 0011 |
| 4 | 0100 |
| 5 | 0101 |
| 6 | 0110 |
| 7 | 0111 |
| 8 | 1000 |
| 9 | 1001 |

The 8421 code employs four bits to represent each decimal digit. For instance, the number 987 may be represented by the 12-bit number 1001 1000 0111. Although this number contains only ones and zeros, it is not a true binary number since it does not follow the rules previously established. Arithmetic operations with BCD would be quite involved. However, it is relatively easy for the computer to convert to true binary, perform the necessary calculations, and reconvert to BCD.

BCD numbers do not always follow the pure binary number system. Special purpose number systems such as Excess Three Code, Gray Code, and Biquinary Code are often used.

OCTAL NUMBER SYSTEM

As the name implies, the octal number system has a radix of 8, i.e., it uses eight discreet symbols: 0, 1, 2, 3, 4, 5, 6, and 7. The positional weights in the octal number system are powers of 8.

The octal number system is widely used by digital engineers and computer programmers since it can easily be converted to binary. At the same time, it is considerably easier to work with, or to record, octal numbers than to use a long string of binary zeros and ones.

The binary-octal conversion may be performed quite simply due to the fact that 8 is the third power of 2. This produces a direct correlation between the successive 3-bit groups in a binary number and the octal digits. That is, an octal number may be converted to binary digit by digit, while with a decimal number the entire number must be converted to binary. The table for octal to binary conversion is shown in Figure 7.

| <u>Octal</u> | <u>Binary</u> |
|--------------|---------------|
| 0 | 000 |
| 1 | 001 |
| 2 | 010 |
| 3 | 011 |
| 4 | 100 |
| 5 | 101 |
| 6 | 110 |
| 7 | 111 |

Figure 7

Using this table, the octal number 777, for example, could be easily and directly converted to the binary number 11111111. Going in the opposite direction, the binary number 110101110 can be converted directly to 656. (As in other number systems, zeros are always assumed in the most significant bits. For example, the number 1110110 converts to 166 in octal.)

Arithmetic operations in octal are quite similar to the operations in decimal. A more detailed discussion of this can be found in some of the reference books in the bibliography.

NOTATION

When there may be some doubt as to the number system being employed, it is customary to indicate this by writing the radix of the number system (in decimal) as a subscript to the number. For example, 777_8 indicates that this is the number 777 written in the octal number system. The same number in the decimal system would be 511_{10} .

In working with different number systems it is extremely important to be certain which system is being used. For example, take that tricky little question, "what's two and two?"

$$2 \div 2 = (\text{meaningless for radix of } 2)$$

$$2 + 2 = 11_3$$

$$2 + 2 = 10_4$$

$$2 + 2 = 4_6 \text{ or more.}$$

BOOLEAN ALGEBRA

Boolean algebra was introduced in 1847 by an English mathematician, George Boole. The purpose of the algebra was to find a shorthand notation for the system of logic originally set forth by Aristotle. Aristotle's system dealt with statements which were considered to be either true or false, but never partially true or false. Boole's algebra was based on a single valued function with two discrete possible states.

Boolean algebra lay almost dormant until recent times. Today, however, it is gaining widespread recognition as an efficient method for handling any single valued function with only two possible states. When it is applied to binary arithmetic, the two states are 0 and 1. When discussing a switch, the two values are open and closed.

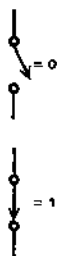


Figure 8 Switch Analogy

The convention used will be that the open state corresponds to the 0 state, while the closed state corresponds to the 1 state.

OR FUNCTION

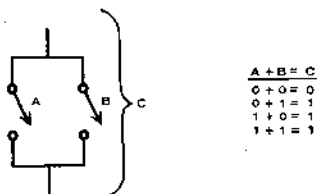


Figure 9 OR Function

If two switches, A and B, are connected in parallel to form a gate, inspection shows that the gate can only transmit information if A or B or both are in the transmitting state,

i.e., closed. This is written in equation form as

$$A + B = C$$

(A or B equals C)

Figure 9 shows the parallel combination of two switches along with a table giving the value of C for all possible values of A and B.

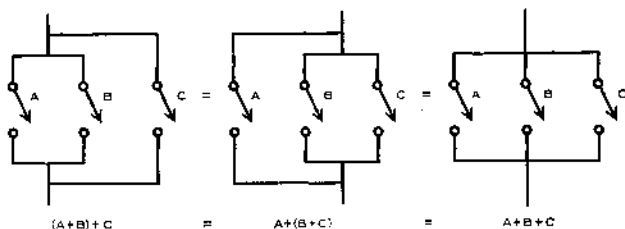


Figure 10 Compound OR Functions

By adding a third gate in parallel, as in Figure 10 it becomes obvious how the OR function may be extended to any number of variables. This figure also serves to illustrate that the commutative and associative laws are valid for the OR function, i.e.,

$$A + B = B + A$$

$$(A + B) + C \equiv A + (B + C) \equiv A + B + C$$

AND FUNCTION

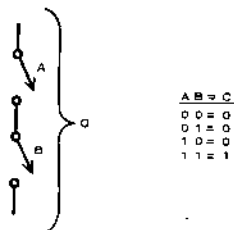


Figure 11 AND Function

If two or more gates are placed in series, the result is known as an AND gate. Inspection of the arrangement in Figure 11 shows that the resulting gate will transmit only if both A and B are closed, i.e., equal to 1. The equivalent equation in Boolean form is

$$AB = C$$

(A and B equals C)

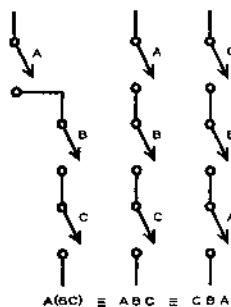


Figure 12 Compound AND Functions

Figure 12 demonstrates how the AND function is applied to more than one variable. The commutative and associative laws also hold.

$$AB = BA$$

$$A(BC) \equiv (AB)C \equiv ABC$$

IDENTITIES

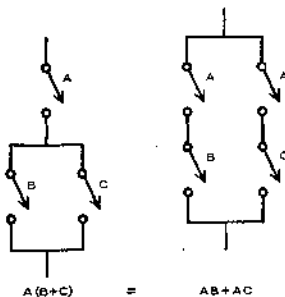
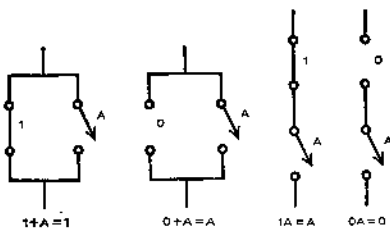


Figure 13 Identities

To enable the simplification of Boolean functions, there are many identities which are helpful. In Figure 13 the combination of switches and corresponding equations demonstrate these identities.

COMPLEMENT

If two gates are connected so that the same signal will open both of them or close both of them simultaneously, the switches are given the same symbol. If two gates are connected so that a single signal will open one gate while closing the other gate, and vice versa, these gates are said to be the complement of each other. Thus, if one gate is labeled A, the other gate will be labeled \bar{A} (read "not A" or "A not").

An entire function may also be complemented. For example,

$$\begin{array}{l} \text{if} \\ \text{then} \end{array} \quad \begin{array}{l} D = A(B + C) \\ \bar{D} = \overline{A(B + C)} \end{array}$$

The use of one label for more than one gate makes the following identities helpful:

$$\begin{array}{lll} A + \bar{A} = 1 & A + \bar{A} = 1 & \bar{\bar{A}} = A \\ A\bar{A} = 0 & A\bar{A} = 0 & \end{array}$$

DE MORGAN'S LAWS

Two unique laws which can be applied only to Boolean algebra are known as De Morgan's laws.

$$\begin{array}{l} \overline{A + B + C + \dots + N} = \bar{A}\bar{B}\bar{C}\dots\bar{N} \\ \overline{ABC\dots N} = \bar{A} + \bar{B} + \bar{C} + \dots + \bar{N} \end{array}$$

These laws may be verified by constructing a table of various possible values.

BOOLEAN ALGEBRA FOR USE WITH VOLTAGE LEVELS

Since DEC voltage levels have only two possible values, Boolean algebra can also be useful in the study of these levels.

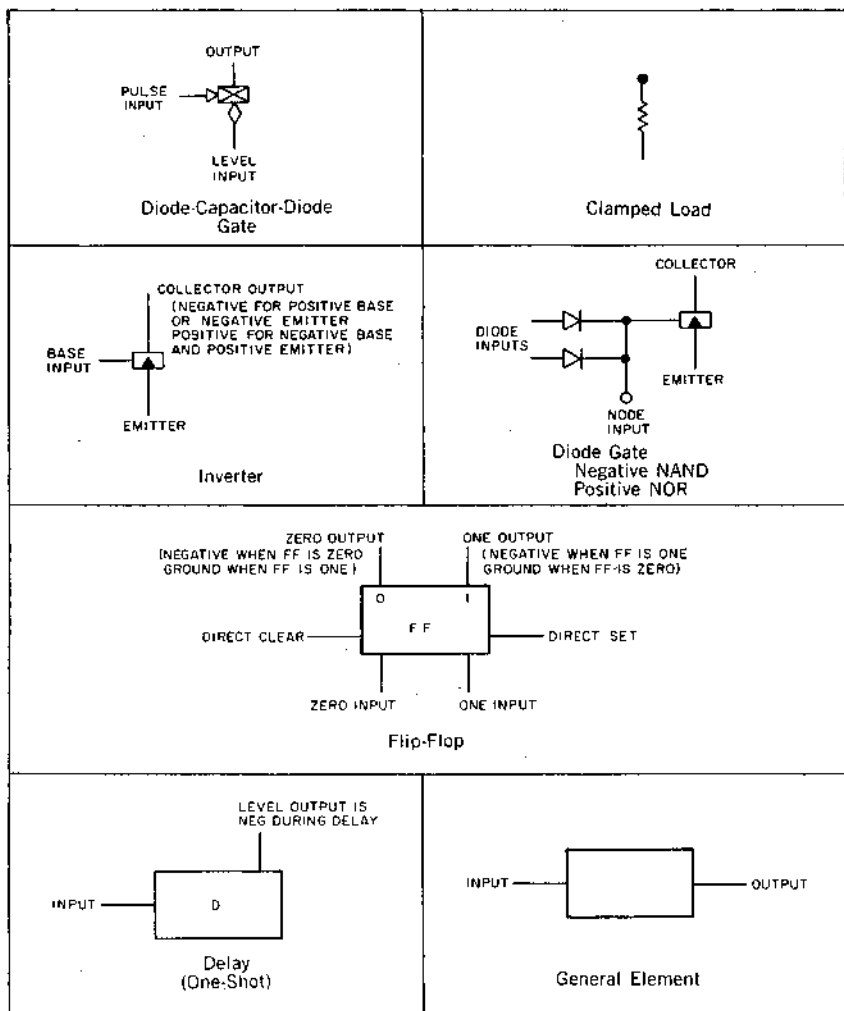


Figure 14 Device Symbols

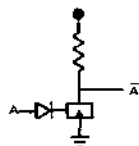


Figure 15 Inverter

An inverter or single input diode gate may be used to perform a complement. If the emitter is at ground and a signal is applied to the base, the resulting output is the complement of the base input as shown in Figure 15.

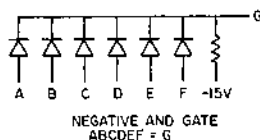


Figure 16 Diode AND Gate

R, B, and W Series Standard levels are defined as -3 volts = 1, and 0 volts = 0, hence a simple AND gate is formed by diodes shown in Figure 16. Only if A and B and C and D and E and F are negative will the resulting output G be negative.

Inspection of these diode units shows that the AND gate becomes an OR gate if the levels are defined in the opposite manner; i.e., if ground is defined as a 1 and -3 volts is defined as a 0. This is a demonstration of De Morgan's law.

The use of symbols for signal definitions helps the designer keep track of these definitions if he wants to change conventions in a system. The symbols used are shown in Figure 17. Figure 18 shows the basic diode gate with its corresponding negative and positive logic definitions.

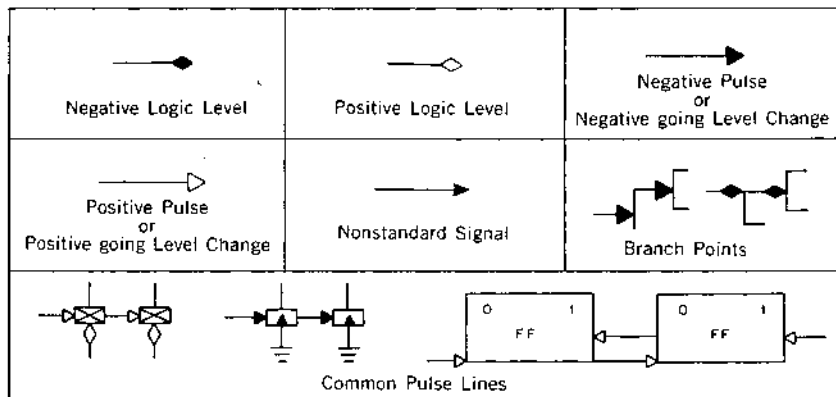


Figure 17 Symbols for Standard Signals

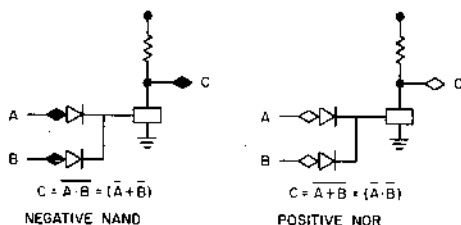


Figure 18 Diode Gate Definitions

Regardless of level convention chosen, there is only one unique state which indicates coincidence of inputs for the diode gate shown. That is, if, and only if both inputs are -3 volts, the output will be at ground. This means that in a decoding situation, the only active decoder output is ground in either definition of logic levels.

The circuit design is such that a number of gates may be connected together at a common point to produce a positive OR function. In Figure 19, if either gate output goes to ground, the output of the logic will be ground. Thus a convenient function is derived.

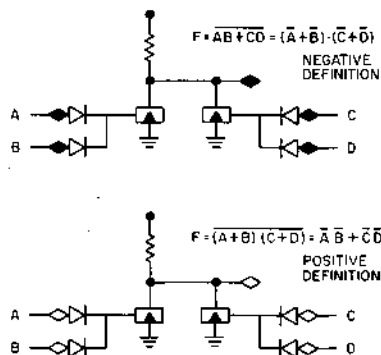


Figure 19 OR Gate Definitions

The DCD gate performs a positive AND function. If the DCD gate could be used as a separate logic element (not in conjunction with pulse amplifiers or flip-flops) its positive and negative definitions would be as shown in Figure 20.

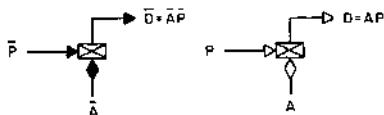


Figure 20 DCD Gate Definitions

When DCD gates are used in conjunction with an R602 Pulse Amplifier, for example, the functions of the combined elements are defined as shown in Figure 21.

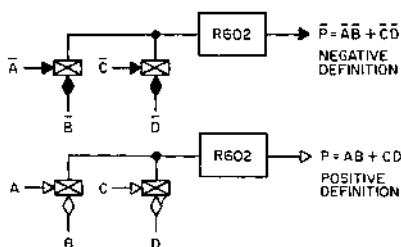


Figure 21 Definitions, DCD Gates with Pulse Amplifier

BINARY-CODED DECIMAL CODES

The digital computer can be thought of as an assemblage of two-state devices because it manipulates the ones and zeros of the binary number system. People, on the other hand, are more accustomed to decimal numbers, and for this reason it is often desirable to build a computing system which can be operated in decimal.

To build a decimal computer with two-state devices, it is necessary to encode the decimal digits with binary bits. Four binary bits are needed. Although only 10 of the 16 permutations possible with the 4-bit decade will be used, all are available. The number of codes that can be generated is calculated as follows:

$$\frac{16!}{6!} \approx 2.9 \times 10^{10}$$

The choice of a code is obviously important. Desirable features of the code are: ease in performing arithmetic operation, economy of storage space, economy of gating operations, error detection and correction, and simplicity. Several possible codes are shown below, followed by a detailed explanation of arithmetic operations using two especially convenient codes, the 8 4 2 1 and the Excess 3.

FOUR-BIT CODES

The 8 4 2 1 code is commonly referred to simply as binary-coded decimal because the weights of the positions are the same as in the binary number system. Arithmetic operations are easily performed using the same basic method as in binary since the number sequence is the same.

In the Excess 3 code, a decimal number D is represented by the binary equivalent of the number $D + 3$. The Excess 3 code is not a weighted code, but since it follows the same number sequence as binary, it is useful in arithmetic operations. Addition is facilitated since the need for a correction factor is easily detected and easily implemented. Because it is self-complementing, the Excess 3 code is also useful in subtraction.

The 2 4 2 1 is a self-complementing weighted code which is commonly employed in counting systems. Other examples of four-bit weighted codes include the 5 4 2 1, the 5 3 1 1, and the 7 4 -2 -1 code. All of these codes are shown in Figure 22.

More than four bits may be used in each decade to provide additional special features such as the detection of errors and the simplification of decoding.

| | | | |
|---------|------|----------|------|
| DECIMAL | 8421 | Excess 3 | 2421 |
| 0 | 0000 | 0011 | 0000 |
| 1 | 0001 | 0100 | 0001 |
| 2 | 0010 | 0101 | 0010 |
| 3 | 0011 | 0110 | 0011 |
| 4 | 0100 | 0111 | 0100 |
| 5 | 0101 | 1000 | 1011 |
| 6 | 0110 | 1001 | 1100 |
| 7 | 0111 | 1010 | 1101 |
| 8 | 1000 | 1011 | 1110 |
| 9 | 1001 | 1100 | 1111 |
| DECIMAL | 5421 | 5311 | 7421 |
| 0 | 0000 | 0000 | 0000 |
| 1 | 0001 | 0001 | 0111 |
| 2 | 0010 | 0011 | 0110 |
| 3 | 0011 | 0100 | 0101 |
| 4 | 0100 | 0101 | 0100 |
| 5 | 1000 | 1000 | 1010 |
| 6 | 1001 | 1001 | 1001 |
| 7 | 1010 | 1011 | 1000 |
| 8 | 1011 | 1100 | 1111 |
| 9 | 1100 | 1101 | 1110 |

Figure 22 Four-bit decimal codes

ARITHMETIC OPERATIONS WITH THE 8 4 2 1 OR EXCESS 3 CODES

Because the 8 4 2 1 and the Excess 3 codes follow the same number sequence as the binary number system, standard binary methods may be used. However, in binary notation sixteen states are represented with four bits. In binary-coded decimal only ten of these states are used; therefore, special correction factors must be added to account for the six unused states.

Counting

In a binary-coded decimal (BCD) counter, the corrective action is very simple. The counter is divided into four-bit decades, and special gating is added to each decade. This gating detects the number 9 and reroutes the next count pulse so that it will reset the decade to 0 and generate a carry to the next decade.

In a down counter, the same approach is used. Starting with a standard binary down counter, the number 0 is detected, and the next count input resets the counter to the appropriate 9 designation and produces a borrow.

A reversible BCD counter may be implemented by combining the techniques for the individual up and down counters. Such a counter, however, is more difficult to construct than a single direction counter since provision must be made for isolating the carry and borrow chains and for assuring that count up and count down signals do not occur simultaneously.

Addition

A common method of performing BCD addition is to add two numbers in the binary adder and, if necessary, add or subtract an appropriate correction factor (see Figure A19). When addition is to be performed in a decade by decade fashion (serial addition with parallel decades), either code is useful. If addition is performed in parallel, however, the Excess 3 code is superior to the 8 4 2 1 code.

In 8 4 2 1 code the sum will be correct if it does not exceed 9. If the decimal sum is between 10 and 15, it is necessary to add +6 to the binary sum and generate a carry to the next decade. If the decimal sum exceeds 15, a carry signal is generated by the initial addition, but the correction factor +6 must still be added to the binary sum.

Addition of 8 4 2 1 coded numbers has the disadvantage that a carry signal can be generated during the correction process. For this reason each decade in the adder has to be corrected individually. Therefore it is not a desirable code in a parallel adder (see Figure 23).

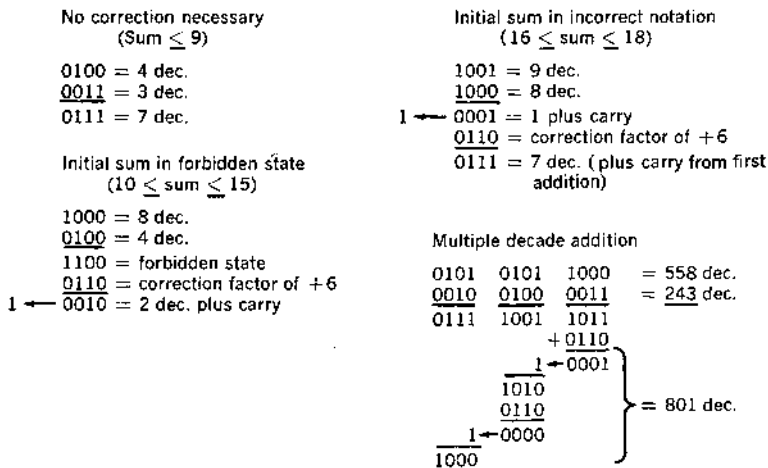


Figure 23 Addition with the 8 4 2 1 code

When two Excess 3 numbers are added, the sum will contain an excess 6; if the decimal sum is 9 or less, it is necessary to subtract 3 in order to return to Excess 3 notation; if the decimal sum is greater than 9, the excess 6 contained in the sum cancels the effect of the six unused binary states, but it is necessary to add 3 to return to the Excess 3 notation.

Whether the correction factor is +3 or -3 is determined by whether or not a carry signal appears during the initial addition. An initial carry requires a positive correction; no carry, a negative correction. The correction process will never yield an additional carry, thus simultaneous correction of all decades is possible.

The steps for performing Excess 3 addition are:

1. Add the two BCD numbers in binary fashion
2. Check each decade for a carry signal
3. Subtract 3 from each decade in which a carry has not occurred, while simultaneously adding 3 to each decade in which the carry signal has occurred.

The +3 correction is made by adding 0011 to the appropriate decade. Subtracting 3 from a decade is done by adding 1100 and using the end around carry from the most significant bit of the decade. This is a method of 9's complement subtraction, described under subtraction below.

| Sum ≤ 9 | Sum ≥ 10 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\begin{array}{r} 0111 = 4 \text{ dec.} \\ 0110 = 3 \text{ dec.} \\ \hline 1101 = \text{uncorrected sum} \\ -0011 = \text{correction factor of } -3 \\ \hline 1010 = 7 \text{ dec.} \end{array}$ | $\begin{array}{r} 1011 = 8 \text{ dec.} \\ 0111 = 4 \text{ dec.} \\ \hline 1010 = \text{uncorrected sum} \\ 1 \leftarrow 0011 = \text{correction factor of } +3 \\ \hline 0101 = 2 \text{ dec., plus carry from} \\ \text{initial addition} \end{array}$ |

| Multiple Decade Addition | | | |
|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| $\begin{array}{r} 1000 \\ \underline{0101} \\ 1110 \\ -0011 \\ \hline 1011 \end{array}$ | $\begin{array}{r} 1000 \\ \underline{0111} \\ 0000 \\ +0011 \\ \hline 0011 \end{array}$ | $\begin{array}{r} 1011 = \\ \underline{0110} = \\ 0001 \\ +0011 \\ \hline 0100 = \end{array}$ | $\begin{array}{l} 558 \text{ dec.} \\ 243 \text{ dec.} \\ \\ 801 \text{ dec.} \end{array}$ |

Figure 24 Addition with the Excess 3 code

Subtraction

Since subtraction is the inverse of addition, the same circuits may be used for both operations. Subtractions by this process is known as the system of adding complements. The 9's complement of any number is that number which is obtained by subtracting each individual digit from 9. With a self-complementing BCD code, such as Excess 3, the 9's complement of any number can be easily obtained by changing all zeros to ones and all ones to zeros. Figure 25 illustrates Excess 3 code with 9's complement notation.

| DECIMAL | EQUIVALENT CODE | | |
|---------|-----------------|-------------|-------------|
| | sign | tens decade | ones decade |
| +99 | 0 | 1100 | 1100 |
| +98 | 0 | 1100 | 1011 |
| +10 | 0 | 0100 | 0011 |
| +3 | 0 | 0011 | 0110 |
| +2 | 0 | 0011 | 0101 |
| +1 | 0 | 0011 | 0100 |
| +0 | 0 | 0011 | 0011 |
| -0 | 1 | 1100 | 1100 |
| -1 | 1 | 1100 | 1011 |
| -2 | 1 | 1100 | 1010 |
| -3 | 1 | 1100 | 1001 |
| -10 | 1 | 1011 | 1100 |
| -98 | 1 | 0011 | 0100 |
| -99 | 1 | 0011 | 0011 |

Figure 25 Nines complement, Excess 3 code

To subtract with Excess 3, 9's complement code, the subtrahend is first complemented then added to the minuend. During the first step of the addition process the individual bits (in the decimal decades and in the sign bits) are added just as in binary. Carries propagate from each digit to the digit of more significance and from the most significant digit to the sign bit. If the sign bit produces a carry, it is added to the least significant decade, a process known as end around carry.

| | | | | |
|----------|-------------|-------------|-------------------------|-----------|
| 0 | 1000 | 0100 | 51 dec. | + 51 dec. |
| <u>1</u> | <u>1001</u> | <u>1000</u> | (complement of 34 dec.) | - 34 dec. |
| 0 | 0001 | 1100 | | |
| | | <u>1</u> | end around carry | |
| 0 | 0001 | 1101 | | |
| - | 0011 | 1100 | correction factor | |
| | 0100 | 1001 | | |
| | | <u>1</u> | end around carry | |
| 0 | 0100 | 1010 | 17 dec. | + 17 dec. |
| <hr/> | | | | |
| 0 | 0110 | 0111 | 34 dec. | + 34 dec. |
| <u>1</u> | <u>0111</u> | <u>1011</u> | (complement of 51 dec.) | - 51 dec. |
| 1 | 1110 | 0010 | | |
| - | 1100 | 0011 | correction factor | |
| | 1010 | 0101 | | |
| | <u>1</u> | | end around carry | |
| 1 | 1011 | 0101 | - 17 dec. | - 17 dec. |

Figure 26 Subtraction with the Excess 3 code, 9's complement notation

After this initial portion of the subtraction, a correction factor must be applied just as in addition. That is, a binary 3 (0011) must be added to each decade in which a carry signal has occurred, and binary 3 must be subtracted from each decade in which a carry signal did not occur.

Subtraction of the correction factor may be performed in the same way as well as the overall subtraction. However, the subtraction in this case operates only on the individual digits. Thus, if a carry occurs from the most significant bit of the digit, it is not carried out to the next digit; rather, it is added into the least significant bit of the same digit.

A second method of performing subtraction is through the use of the 10's complement notation. The 10's complement of any number may be obtained by adding 1 to the 9's complement. Operations are similar to those used in the 9's complement notation except that the end around carry is not required. Hence this is useful in systems where a feed back loop would be particularly time consuming.

CODES GREATER THAN FOUR BITS

| DECIMAL | BIQUINARY | RING COUNTER CODE |
|---------|---------------------|------------------------------|
| | 5, 0, 4, 3, 2, 1, 0 | 9, 8, 7, 6, 5, 4, 3, 2, 1, 0 |
| 0 | 0 1 0 0 0 0 1 | 0 0 0 0 0 0 0 0 1 |
| 1 | 0 1 0 0 0 1 0 | 0 0 0 0 0 0 0 1 0 |
| 2 | 0 1 0 0 1 0 0 | 0 0 0 0 0 0 0 1 0 0 |
| 3 | 0 1 0 1 0 0 0 | 0 0 0 0 0 0 0 1 0 0 0 |
| 4 | 0 1 1 0 0 0 0 | 0 0 0 0 0 0 1 0 0 0 0 |
| 5 | 1 0 0 0 0 0 1 | 0 0 0 0 1 0 0 0 0 0 0 |
| 6 | 1 0 0 0 0 1 0 | 0 0 0 1 0 0 0 0 0 0 0 |
| 7 | 1 0 0 0 1 0 0 | 0 0 1 0 0 0 0 0 0 0 0 |
| 8 | 1 0 0 1 0 0 0 | 0 1 0 0 0 0 0 0 0 0 0 |
| 9 | 1 0 1 0 0 0 0 | 1 0 0 0 0 0 0 0 0 0 0 |

| DECIMAL | SWITCH TAIL RING COUNTER CODE | | | | | DECODING |
|---------|-------------------------------|---|---|---|---|----------|
| | A | B | C | D | E | |
| 0 | 0 | 0 | 0 | 0 | 0 | A E |
| 1 | 0 | 0 | 0 | 0 | 1 | D E |
| 2 | 0 | 0 | 0 | 1 | 1 | C D |
| 3 | 0 | 0 | 1 | 1 | 1 | B C |
| 4 | 0 | 1 | 1 | 1 | 1 | A B |
| 5 | 1 | 1 | 1 | 1 | 1 | A E |
| 6 | 1 | 1 | 1 | 1 | 0 | D E |
| 7 | 1 | 1 | 1 | 0 | 0 | C D |
| 8 | 1 | 1 | 0 | 0 | 0 | B C |
| 9 | 1 | 0 | 0 | 0 | 0 | A B |

Figure 27 Codes greater than four bits.

Codes greater than four bits are often used for error detection and simplicity in decoding (Figure 27). The biquinary code is commonly used when error detection is required. It is a 7-bit weighted code in which two ones and five zeros appear in the representation of any number; thus it is always possible to detect single errors, and it is often possible to detect multiple errors.

The ten-bit weighted code shown in Figure 27 allows any number to be represented with a single 1 and nine zeros. This code is often used in counting operations; the counter is a ten-stage shift register with the final stage connected to the initial stage. This counter, often given the name of ring counter, requires no carrying propagate time and the numbers may be decoded into ten lines without additional gates.

The switch-tail ring counter is a five-stage ring counter with reversed feed-back from the initial stage to the final stage. It requires fewer flip-flops than the ring counter and has the same advantage that no carry propagate time is required. Any state may be decoded by a two-input gate conditioned by two neighboring flip-flops.

PART II: FLIP CHIP MODULES

R SERIES

R-SERIES BASIC CIRCUITS

DIODE GATE

The basic element of digital logic described in this chapter is the diode gate. The diode gate is used in the R (2-megahertz) series to combine, amplify, invert, and standardize the signals which represent various logic functions. Figure 1 is a schematic of a simple diode gate with one input.

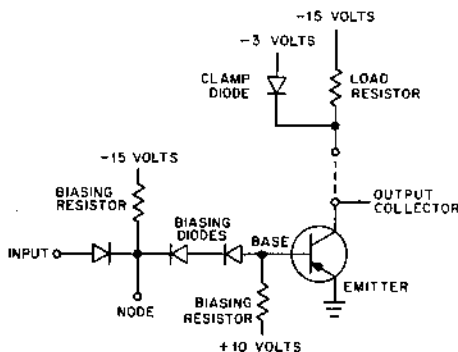


Figure 1 Single Input Diode Gate

When the input is negative, the node point is also negative and current flows from the transistor emitter through the biasing diodes and the biasing resistor to minus 15 volts (-15v). As a result, the PNP transistor is turned on, forming a short circuit between the collector and the emitter. Thus, when the input voltage is negative, the output voltage is ground. Since the output is from a saturated transistor, it has a low output impedance and good driving power.

When the diode gate input voltage is ground, the biasing diodes and the resistor, which is connected to the 10v supply, hold the transistor base more positive than the emitter, and the transistor is turned off. The output is then an open circuit, and it will follow the voltage of any other circuit connected to it.

If the load resistor and clamp diode are attached to the transistor collector, they serve as a voltage source and hold the output at -3v while the transistor is off. When the transistor is on, the diode is cut off and the load resistor follows the output to ground.

The single-input diode gate therefore has three functions. First, it inverts the input signal. Second, it standardizes the output voltage to -3v or ground (if the clamped load diode and resistor are connected). Third, since the output current available from the transistor is much greater than the required input current, the diode gate amplifies.

A fourth function, gating, is obtained by adding more diode inputs to the node point, as shown in Figure 2.

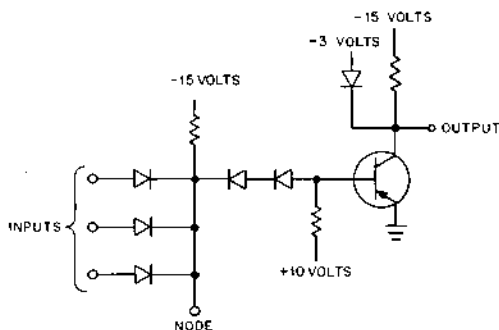


Figure 2 Multiple Input Diode Gate

The node terminal in this diagram will be at approximately the same voltage as the most positive input. Thus, when any input terminal is grounded, the node terminal is also at ground and the circuit output is at -3v . If all of the inputs are negative, the node terminal will be negative and the circuit output will be at ground.

Gating functions may also be performed by wiring together two or more diode gate outputs and one load resistor, as shown in Figure 3. When any input is negative, it saturates the corresponding transistor and forces the output line to ground. If all inputs are at ground, all of the transistors are open circuits and the output voltage, determined by the clamped load resistor, is -3v .

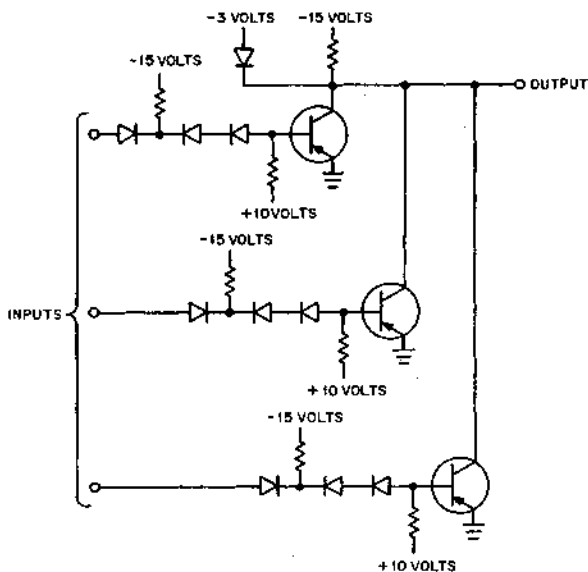


Figure 3 Diode Gates in Parallel

The basic diode gate can be used to construct very complex logical functions. A drawing that showed all of the circuit components, however, would be tedious to draw and difficult to read. For this reason, the diagrams that follow use a shorthand notation which represents one or more components as a single functional unit. Referring to Figure 4, diodes are shown in the conventional way. The transistor circuit, including the biasing resistors and diodes, is shown as a simple rectangle with an arrowhead indicating the direction of the transistor emitter. This part of the circuit is called an inverter because of the function it performs. The load resistor is shown as a resistor with a large dot at the top indicating that it is diode clamped to $-3v$. With these symbols, one can easily and quickly draw complex logical functions.

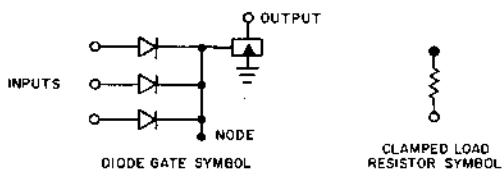


Figure 4 Diode Gate and Clamped Load Resistor Symbols

Assertion input and output voltage levels are shown by diamonds. A solid diamond indicates a $-3v$ level, and an open diamond indicates a ground level. In the 2-input diode gate of Figure 5, for example, if input A and input B are both negative, the output will be at ground. If either A or B is at ground, the output will be negative.

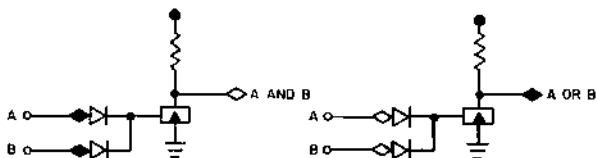


Figure 5 Diamonds Indicating the Voltage Levels

DIODE-CAPACITOR-DIODE GATES

The diode-capacitor-diode (DCD) gate is used to standardize the input to various units such as flip-flops, delays, and pulse amplifiers. It provides logical isolation between pulse and level inputs and produces a logical delay which is essential for sampling flip-flops at the same time they are being changed. It also acts as a logical AND gate since both pulse and level inputs must meet certain requirements for a signal to appear at the output. Either positive pulses or positive-going level changes (both $-3v$ to ground) may be used as the pulse input.

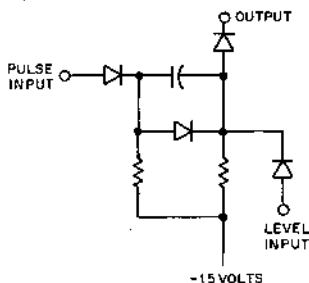


Figure 6 Diode-Capacitor-Diode Gate Circuit

A schematic drawing of a DCD gate is shown in Figure 6. If the level input is held at ground and the pulse input is held at $-3v$, the capacitor will become charged after the setup time has passed. If the pulse input then suddenly goes to ground, a positive-going pulse will appear at the output. There is delay at the level input, but the pulse input goes to the output without delay. Even if the level input changes simultaneously with a positive transition at the pulse input, the delay acts as a temporary memory: the pulse input is gated according to the level input that existed during the interval before the pulse.

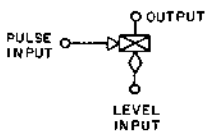


Figure 7 Diode-Capacitor-Diode Gate Symbol

The symbol for the DCD gate (Figure 7) is distinguished from the diode gate by an X in the rectangle. The output is at the top, the delayed (level) input is at the bottom, and the differentiating (level change or pulse) input is on the side. The input signal to be differentiated, whether a level change or a pulse, is indicated by an arrowhead, rather than a diamond. The pulse symbols are hollow when positive-going and solid when negative-going. In the DCD gate, the pulse input must be positive-going.

Since many DCD gates may be driven by the same pulse, the side of the rectangle opposite the pulse may be used to show a continuation of the same line, as in Figure 8. The illustration on the left below is a simplified version of the identical logical configuration on the right.

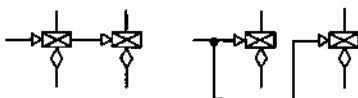


Figure 8 Pulse Lines to Multiple Gates

FLIP-FLOPS

The flip-flop provides a convenient means of storing logical conditions within a digital system. It has two stable states representing 0 and 1, and remains in one of these states until an appropriate command to change state is received. Three commands may be given: set, which puts the flip-flop in the 1 state; clear, which puts the flip-flop in the 0 state; and complement, which changes the state of the flip-flop regardless of its previous state.

TABLE 1 FLIP-FLOP COMMANDS

| Command | State Before Command | State After Command |
|------------|----------------------|---------------------|
| Set | 1 | 1 |
| | 0 | 1 |
| Clear | 1 | 0 |
| | 0 | 0 |
| Complement | 1 | 0 |
| | 0 | 1 |

Figure 9 shows a schematic diagram and the symbolic equivalent of an R series flip-flop. The flip-flop consists of two diode gates, connected "back-to-back." When transistor Q1 is off, its output is negative. This holds transistor Q2 on, which in turn maintains the off condition of transistor Q1. Direct set and direct clear inputs are provided for operation of the flip-flops directly from external logical elements. When the flip-flop is set to the 1 state, the 1 output is at -3v .

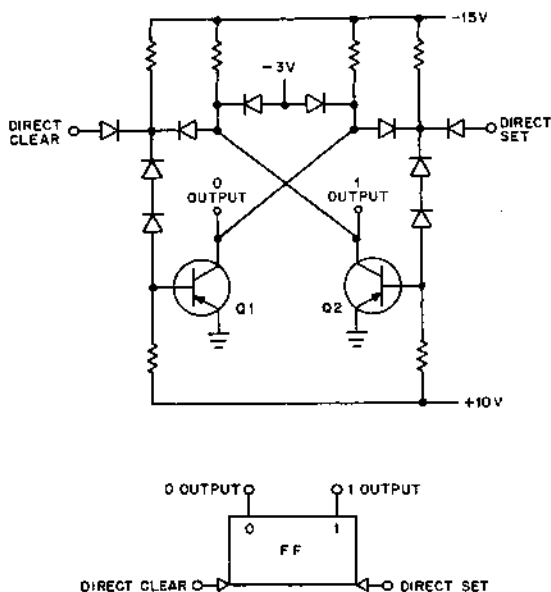


Figure 9 Flip-Flop Schematic and Symbol

Inputs to this flip-flop are often made through DCD gates as shown in Figure 10. The gates provide sufficient delay so that information may be read out of one flip-flop and into another at the same time that the first flip-flop receives a command to change state. The DCD gate can also be used to perform additional logical operations, since it is basically an AND gate. That is, both the pulse and level inputs of the DCD gate must meet the proper input requirements for an output signal to occur.

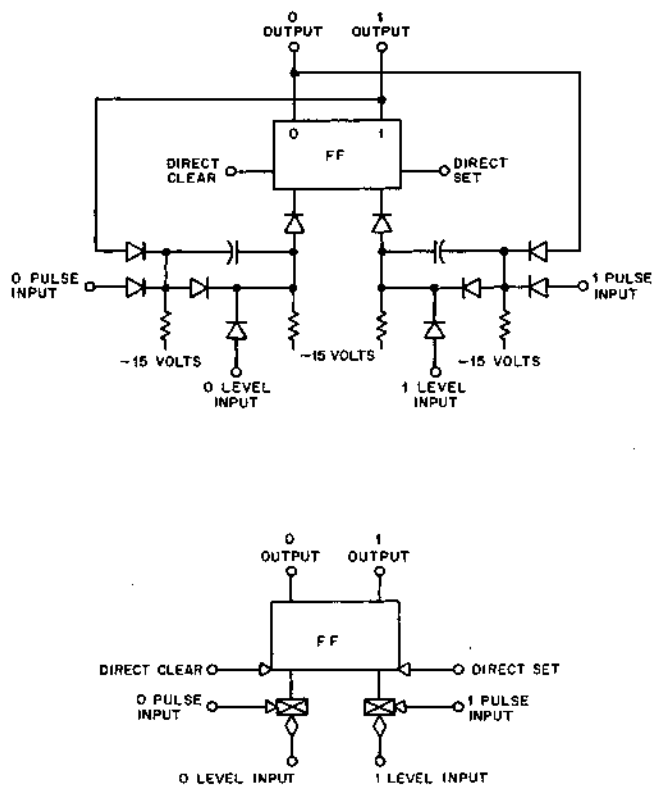


Figure 10 Flip-Flop with DCD Gates, Schematic and Symbol

As can be seen from the schematic in Figure 10, the DCD gate level inputs are conditioned by the flip-flop outputs. Thus, a set signal will reach the flip-flop only if the flip-flop was previously in the 0 state. Similarly, a clear command reaches a flip-flop only if it was previously in the 1 state. For simplicity, this conditioning is not shown on the symbol but should be remembered because it is a very powerful element of the flip-flop.

A complement terminal can be made simply by tying the set and clear pulse inputs together as shown in Figure 11. The gate inputs are still available for external enables. This technique allows a flip-flop with its DCD gates to be used in such varied applications as up counter, down counter, up-down counter, shifting, multiple source buffering, jam transfer register, ring counter, BCD counting, and special counts of 2^R ($2^R + 1$) all without need for additional gate modules.

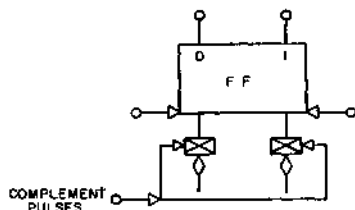
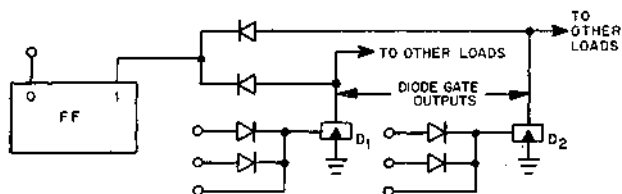
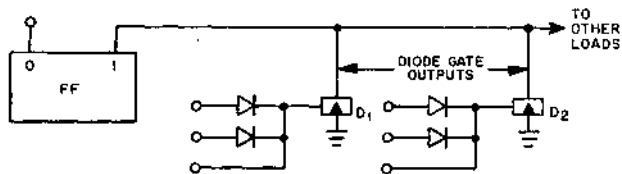


Figure 11 Complementing

Flip-flops may be collector-triggered by tying a flip-flop output to the output of one or more diode gates. As illustrated in Figure 12, when the output of either diode gate D_1 or D_2 is asserted (at ground), the corresponding flip-flop is cleared (put to 0). If the gates are attached to the flip-flop through diode networks (Figure 12a), the diode gate outputs (D_1 and D_2) can be logically independent. If they are attached in parallel without diode networks (Figure 12b), the outputs will be dependent. That is, if any output is at ground, the output of all gates connected in parallel with it will be at ground.



(A) WITH DIODE NETWORK--DIODE GATE OUTPUTS INDEPENDENT



(B) WITHOUT DIODE NETWORK--DIODE GATE OUTPUTS DEPENDENT

Figure 12 Collector Triggering of a Flip-Flop

DELAYS

The delay one-shot, or monostable multivibrator, is a basic timing element. The input to the delay, like that of the flip-flop, is through a DCD gate (see Figure 13). When the gate is properly enabled, and when its pulse input terminal is brought to ground by a positive pulse or a positive-going level change, the output of the delay changes from its normal ground level to a $-3v$ level for a fixed, but adjustable, period of time. After the fixed time has elapsed, the output returns to ground. This delayed output is suitable for driving many R series modules. A pulse output can be obtained with the addition of a pulse amplifier to the delay output.

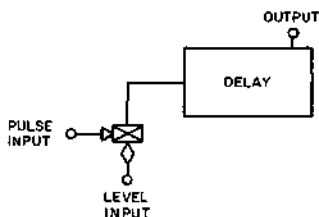


Figure 13 Delay One-Shot

Delay units are particularly useful in generating delayed pulses or signals of arbitrary width. The network of delays in Figure 14a will produce the waveform shown in Figure 14b.

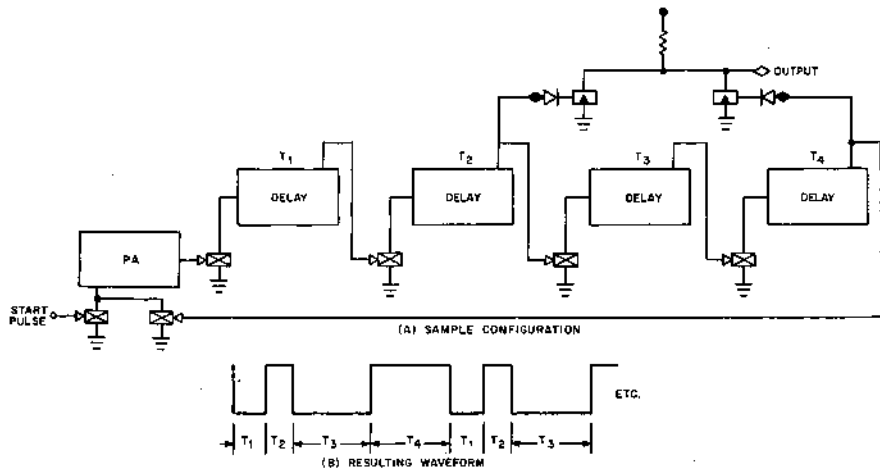


Figure 14 Typical Application of Delay Units

PULSE AMPLIFIERS

Pulse amplifiers are extremely versatile elements since they not only amplify and standardize various signals into standard 100-nanosecond pulses ($-3v$ to ground), but they may also be used to carry the results of gating to many units. For example, when the same gating is to be done on an entire register of flip-flops, it is most economically performed at the input to the pulse amplifier which drives the register.

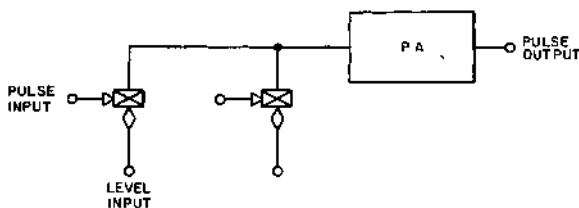


Figure 15 Pulse Amplifier with Gates

Several pulse amplifier outputs may be ORed together by simply connecting their outputs in parallel (Figure 16). Thus two levels of logic can be performed by pulse amplifiers.

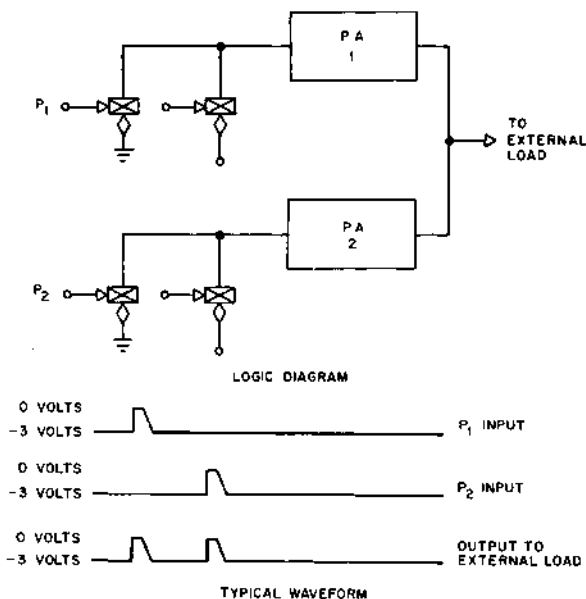


Figure 16 ORed Pulse Amplifiers

Flip-flops may be collector-triggered by connecting the output of one or more pulse amplifiers to the output terminals of the flip-flop (Figure 17). This connection may be made directly or through the diode networks shown in Figure 12.

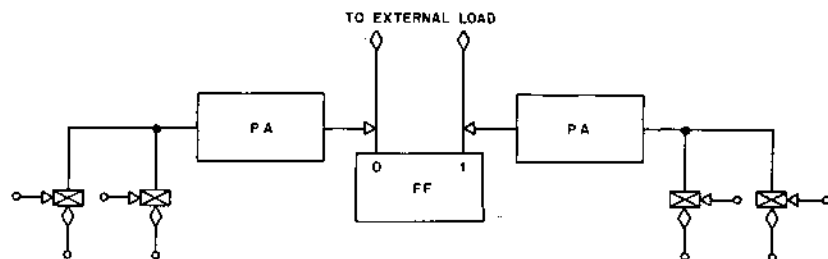


Figure 17 Collector Triggering of Flip-Flops

CLOCKS

Variable R series clocks produce standard, 100-nsec pulses ($-3v$ to ground) from stable RC-coupled oscillators. These clocks are often used as a primary source of timing for large systems (Figure 18).

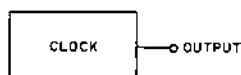


Figure 18 Clock

Where precise timing is required, a clock with a single frequency crystal oscillator may be used.

LOADING RULES

When interconnecting basic circuits to perform logical operations, it is important to keep the load on each circuit within its driving ability. The R series loading rules are simple because all inputs draw current from the same direction and because all inputs are either diode gate circuits or DCD circuits.

Each diode gate input draws 1 ma (milliampere) and the output drives 20 ma. The load resistor draws 2 ma; so a diode gate with a clamped load resistor tied to it can drive 18 ma.

A flip-flop is two slightly modified diode gates cross-connected. The direct set and clear terminals draw 1 ma. The output will drive 21 ma less 3 ma for the load resistor permanently connected in the flip-flop and less 1 ma for conditioning the opposite side of the flip-flop for a remainder of 17 ma.

The single shot delay has a similar output circuit with a built-in load resistor. It will drive 20 Ω or 18 ma.

The pulse amplifiers will drive loads of up to 70 ma.

The DCD gates on flip-flops, delays, and pulse amplifiers draw 2 ma at the level inputs and 3 ma at the pulse inputs. When two DCD gates are driving both sides of the same flip-flop, the load on both pulse inputs totals only 4 ma. When the level inputs are tied together as in a complement configuration, the total input load is only 3 ma, as shown in Figure 19.

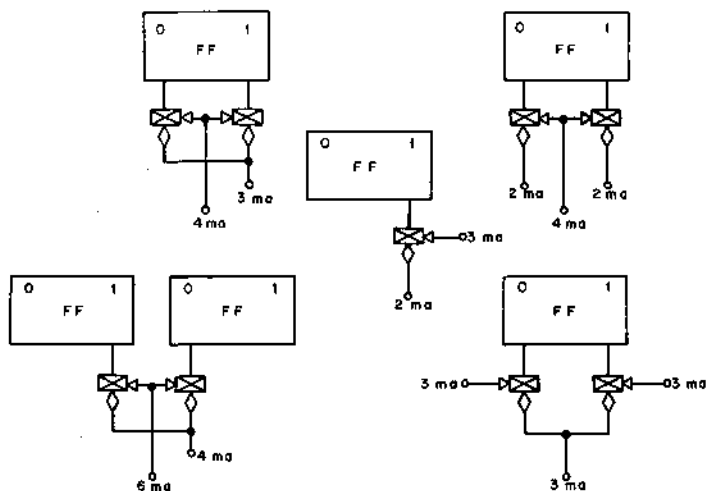


Figure 19 Flip-Flop Input Loads

On flip-flops which have built-in DCD gates, the output driving ability is less because the internal diode capacitor gate draws current from the flip-flop. Table 2 lists the output driving capability for each of the six types of flip-flops.

Table 2 Flip-Flop Output Driving Capability

| Flip-Flop | 0 Output | 1 Output |
|-----------|----------|----------|
| R200 | 17 | 17 |
| R201 | 11 | 13 |
| R202 | 15 | 15 |
| R203 | 15 | 17 |
| R204 | 17 | 17 |
| R205 | 13 | 15 |

R-SERIES LOGIC CONFIGURATIONS

COUNTERS

Counting, a basic digital operation, is performed by a wide variety of counter circuits. Examples follow of how some of these circuits are built using R series modules.

The Binary Up-Counter

A typical binary-up counter is shown in Figure 20. When a flip-flop changes from the 1 to the 0 state, its 1 output complements the next flip-flop in the counting chain. Flip-flop C, the first in the chain, complements on each input pulse. Flip-flop B complements when C changes from 1 to 0, and so on through the counter. Note that a flip-flop complements only if all preceding flip-flops are in the 1 state when the next input pulse arrives. The time required for a "carry" to propagate up the chain is 70 nsec per stage. The input load for the complete circuit is only that required to complement flip-flop C.

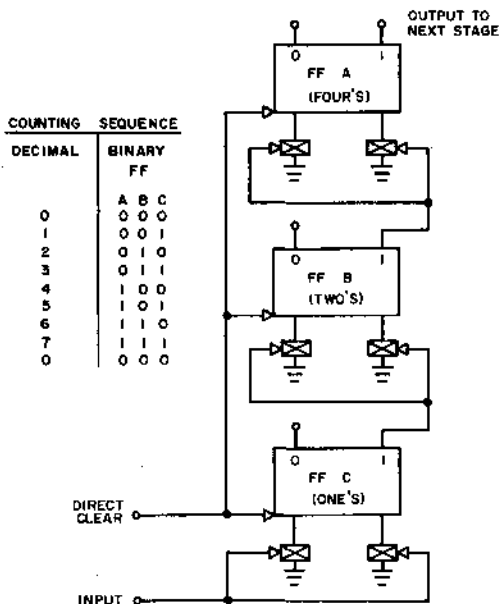


Figure 20 Three-Bit Binary Up Counter
(R201, R202, or R205 Flip-Flops)

The Direct Clear input resets the counter to 0. This input requires a 400-nsec pulse, $-3v$ to ground, (rather than a standard, 100-nsec pulse) or a level that remains at ground for more than 400 nsec. This time is needed to hold all flip-flops in the 0 state while the carries die out.

Binary Down-Counter

The binary down-counter is identical to the binary up-counter, except that the complementing level change comes from the 0 terminal of the preceding flip-flop rather than the 1 terminal. In the down-counter the direct set rather than the direct clear requires 400-nsec pulses. The counting sequence is the reverse of the up counter, that is 111, 110, . . . , 001, 000 or 7, 6, . . . , 1, 0.

Binary Up-Down Counter

The binary up-down counter is a combination of the up counter and the down counter. All pulse inputs are standard positive pulses, $-3v$ to ground. (Both direct set and direct clear require 400-nsec pulses.)

In order to avoid counting in both directions simultaneously, the DCD gate level inputs must be used. The two control lines must not be grounded simultaneously. Input pulses must not follow control line changes sooner than 400 nsec to allow for DCD gate set up time. Control line changes must not follow input pulses closer than $70(M-1)$ nsec, to allow an M bit counter time for carry propagation. Count sequence is shown in Table 3, and an example of a four-bit binary up-down counter is illustrated in Figure 21.

TABLE 3 COUNTING SEQUENCES

| Up Counting Sequence | | | | Down Counting Sequence | | | | | |
|----------------------|-----------|---|---|------------------------|--------|-----------|---|---|---|
| Decimal | Binary | | | Decimal | Binary | | | | |
| | Flip-Flop | | | | | Flip-Flop | | | |
| | A | B | C | D | | A | B | C | D |
| 0 | 0 | 0 | 0 | 0 | 15 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 1 | 14 | 1 | 1 | 1 | 0 |
| 2 | 0 | 0 | 1 | 0 | 13 | 1 | 1 | 0 | 1 |
| 3 | 0 | 0 | 1 | 1 | 12 | 1 | 1 | 0 | 0 |
| 4 | 0 | 1 | 0 | 0 | 11 | 1 | 0 | 1 | 1 |
| 5 | 0 | 1 | 0 | 1 | 10 | 1 | 0 | 1 | 0 |
| 6 | 0 | 1 | 1 | 0 | 9 | 1 | 0 | 0 | 1 |
| 7 | 0 | 1 | 1 | 1 | 8 | 1 | 0 | 0 | 0 |
| 8 | 1 | 0 | 0 | 0 | 7 | 0 | 1 | 1 | 1 |
| 9 | 1 | 0 | 0 | 1 | 6 | 0 | 1 | 1 | 0 |
| 10 | 1 | 0 | 1 | 0 | 5 | 0 | 1 | 0 | 1 |
| 11 | 1 | 0 | 1 | 1 | 4 | 0 | 1 | 0 | 0 |
| 12 | 1 | 1 | 0 | 0 | 3 | 0 | 0 | 1 | 1 |
| 13 | 1 | 1 | 0 | 1 | 2 | 0 | 0 | 1 | 0 |
| 14 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| 15 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 15 | 1 | 1 | 1 | 1 |

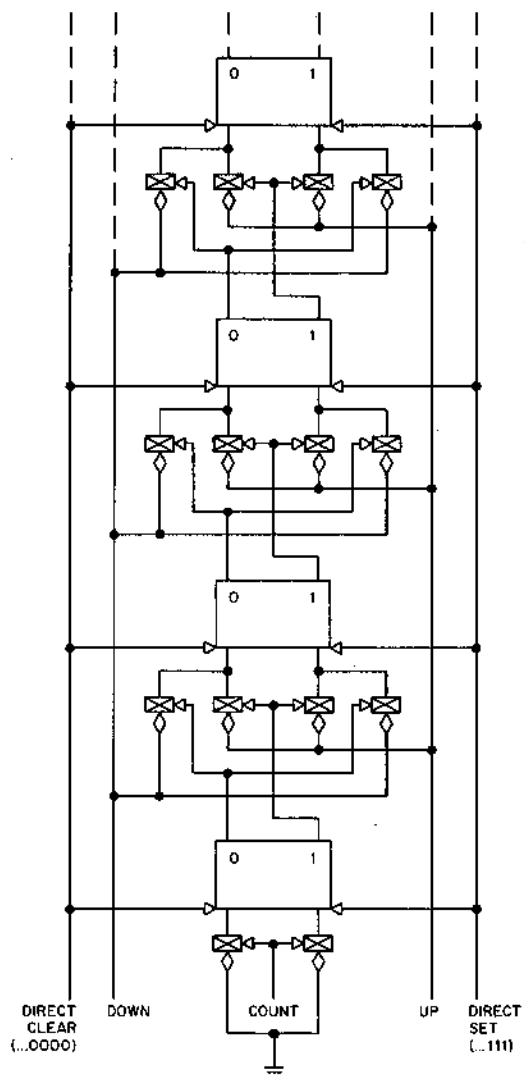


Figure 21 Four-Bit Binary Up-Down Counter
(R201 Flip-Flops)

Special Counts

It is often desirable to build a counter that produces a signal after a particular number of events, N , has occurred. If N is an integral power of 2, the output is automatically produced by the final digit of a counter of the appropriate length. If N is not a power of 2, gating must be performed to detect the desired number, produce a signal, and reset the counter to 0.

Diode gates may be used to sense the number $N-1$, gate off the input to the counter, and reroute the N th input pulse so that it will clear the counter and generate an output signal. This method may be used for any value of N (Figure 22).

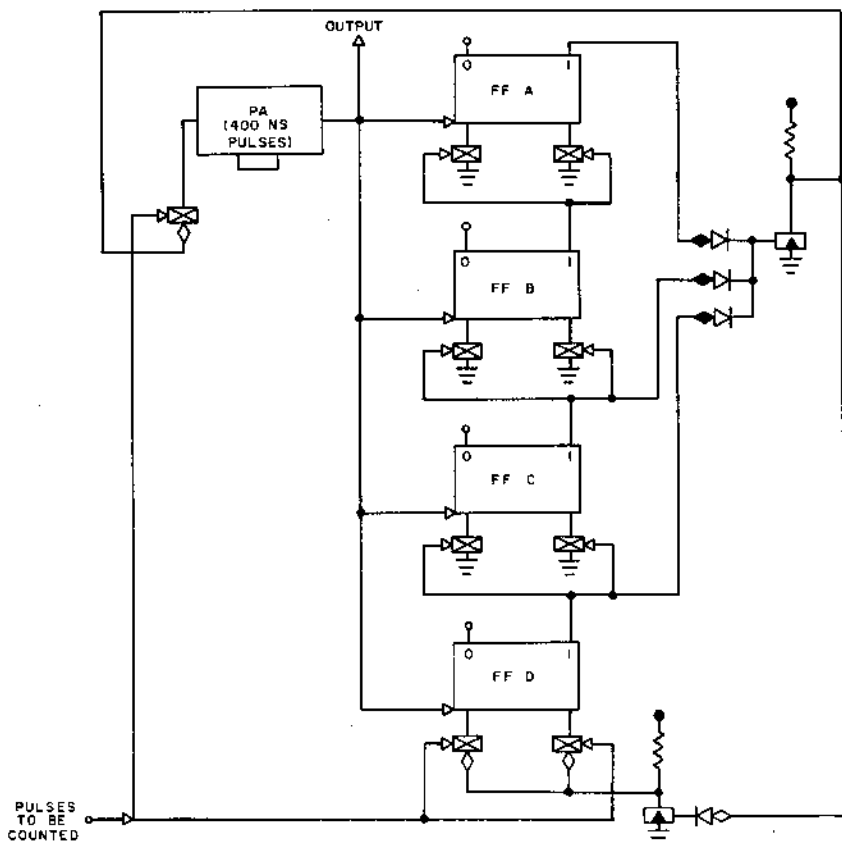


Figure 22 Arbitrary Count—Count of 12 Illustrated
(R201, R202, or R205 Flip-Flops, R601 P.A.)

Because of the carry propagation time through the counter, the maximum input frequency depends on the number of bits. For M bits, the maximum frequency is

$$f = \frac{1000}{70M + 500} \text{ mc}$$

This allows 400 nsec to enable the DCD gate and 100 nsec delay through the diode gate and inverter.

Special counts of $N = 2^p + 1$ (that is, 3, 5, 9, 17 . . .) are simple to build using R201, R202, or R205 modules. Figure 23 illustrates how a count-of-5 counter is implemented. The 0 input of flip-flop A is connected directly to the counter input rather than the output of flip-flop B. Thus the last flip-flop is cleared on the first pulse after it has been set; that is, the states of the last flip-flop will be . . . 0, 1, 0, 0, . . . , 0, 1, 0, The level inputs of flip-flop C are connected to the 1 output of flip-flop A. This prevents the counter from counting when flip-flop A is in the 1 state (has been set on the previous pulse). This counting sequence can easily be extended by adding several binary stages in place of flip-flop B. The 2^p th pulse which sets the last flip-flop clears all previous flip-flops (see "Binary Up Counters"). The next pulse ($2^p + 1$) will clear the last flip-flop, returning the counter to zero.

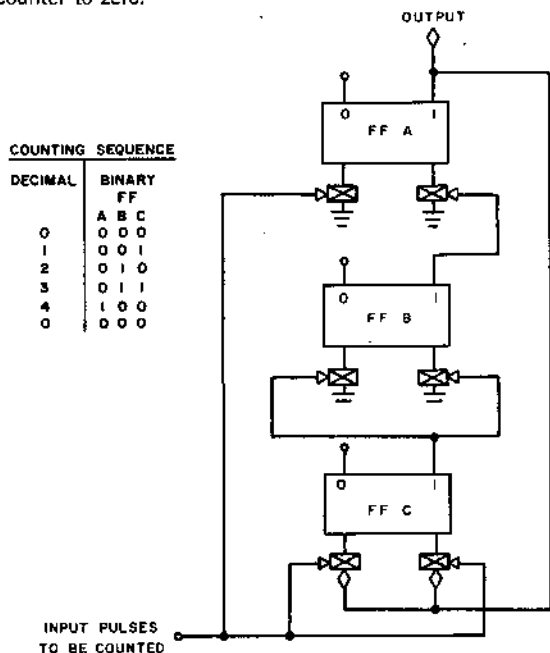


Figure 23 Count-of-Five Counter
(R201, R202, or R205 Flip-Flops)

The maximum input frequency for counts of 5 or more is

$$f = \frac{1000}{70(P+1) + 400} \text{ mc}$$

This allows 400 nsec set-up time for the DCD gates on the input stage, plus 70 nsec propagation time per stage.

Special counts of $N = 2^R (2^P + 1)$ are produced by adding a 2^R up counter in front of a $2^P + 1$ counter. The input of the $2^P + 1$ counter is the output of the 2^R counter. Thus the $2^P + 1$ counter counts every 2^R th pulse for a final count of $2^R (2^P + 1)$.

Binary-Coded Decimal Counter

A count of $10 = 2^1 (2^2 + 1)$ can be produced as illustrated in Figure 24. This BCD counter may be used wherever decimal results are desired. Longer duration decimal counters are made by using many BCD counters in series.

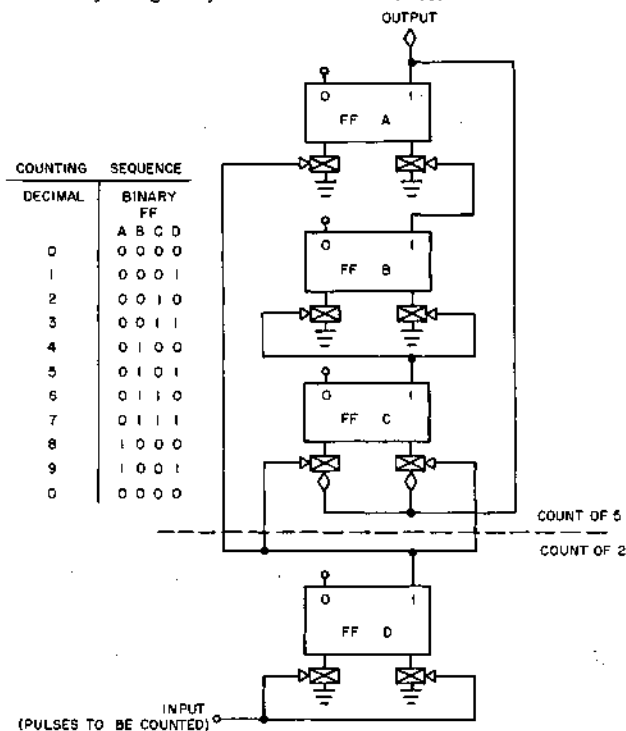


Figure 24 Count-of-Ten Counter
(R201, R202, or R205 Flip-Flops)

BUFFER AND SHIFT REGISTERS

Buffer Register

A buffer register is a flop-flop network used for temporary data storage. With no additional gating, the R201 accepts inputs from five external sources, the R202 from two sources, the R203 from one source, and the R205 from two sources.

Figure 25 illustrates a simple buffer register. To correctly read in a number, the register is first cleared. Then each flip-flop is set in accordance with the state of the level input to its DCD gate. This operation can also be performed by setting all flip-flops and then reading in through clear gates.

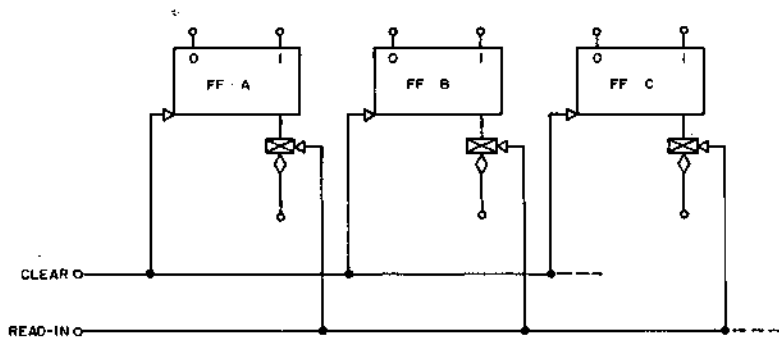


Figure 25 Three-Bit Buffer Register
(R201, R202, R203, or R205 Flip-Flops)

Shift Register

A shift register (Figure 26) shifts the contents of each flip-flop in a series into the next flip-flop in the series. If any flip-flop is in the 1 state, its 0 output is at ground enabling the 1 input of the next flip-flop. Hence the application of a shift pulse puts the second flip-flop into the 1 state. Similarly, a shift pulse puts the flip-flop into the 0 state when the previous flip-flop has been in the 0 state. At the time of the shift pulse, flip-flop C is cleared if the read-in level has been at ground. If the read-in level has been at $-3v$, flip-flop C is set to 1.

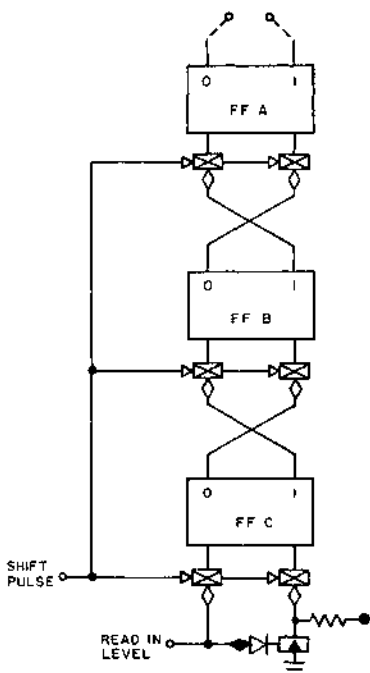


Figure 26 Three-Bit Shift Register
(R201, R202, or R205 Flip-Flops)

Ring Counter

A ring counter can be made from a shift register by connecting the 0 output of the last flip-flop to the 1 level input of the first flip-flop and the 1 output of the last flip-flop to the 0 level input of the first. Thus on each count pulse (shift pulse) the ring counter will shift the contents of the last flip-flop to the first flip-flop (Table 4).

Switch-Tail Ring Counter

A switch-tail ring counter can be made from a shift register by connecting the 1 output of the last flip-flop to the 1 level input of the first flip-flop and the 0 output of the last flip-flop to the 0 level input of the first. On each count pulse (shift pulse), the switch-tail ring counter will shift the inverse of the contents of the last flip-flop into the first flip-flop (Table 4).

TABLE 4 COUNTING SEQUENCE FOR RING COUNTERS
(A Shift Pulse Equals One Count)

| 3 Flip-Flop Ring Counter | 3 Flip-Flop Switch Tail Ring Counter |
|--------------------------|--------------------------------------|
| 001 (Initialized) | 000 (Initialized) |
| 010 | 001 |
| 100 | 011 |
| ----- | 111 |
| 001 | 110 |
| | 100 |
| | ----- |
| | 000 |

Jam-Transfer Buffer

The jam transfer buffer (Figure 27) is like a series of two-bit shift registers. When a shift pulse (or positive-going level change) occurs, the contents of A, B, and C will be shifted to E, G, and H. If A and B contain ones and C contains 0, a shift pulse sets E and G to ones and H to 0. A number is also read into flip-flops A, B, and C at the same time as the shift operation. When any of the three level inputs are at $-3v$, a 1 is read into the corresponding flip-flop. A 0 is read in if the corresponding terminal is at ground.

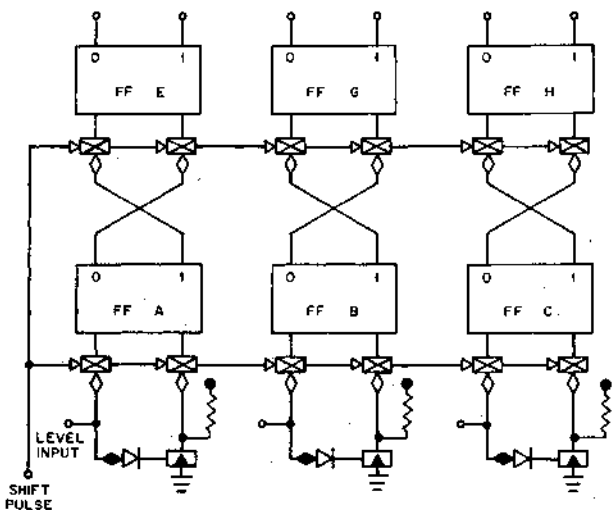


Figure 27 Three-Bit Jam Transfer Buffer
(R201, R202, or R205 Flip-Flops)

ARITHMETIC ELEMENTS

Parallel Adders

Parallel adders may be used to add two binary numbers. The augend is called the resident number and is stored in the accumulator register. The addend, or incident number, is stored in the incident register. The sum appears in the accumulator. R series Type R201, flip-flops can be used as shown in Figure 28.

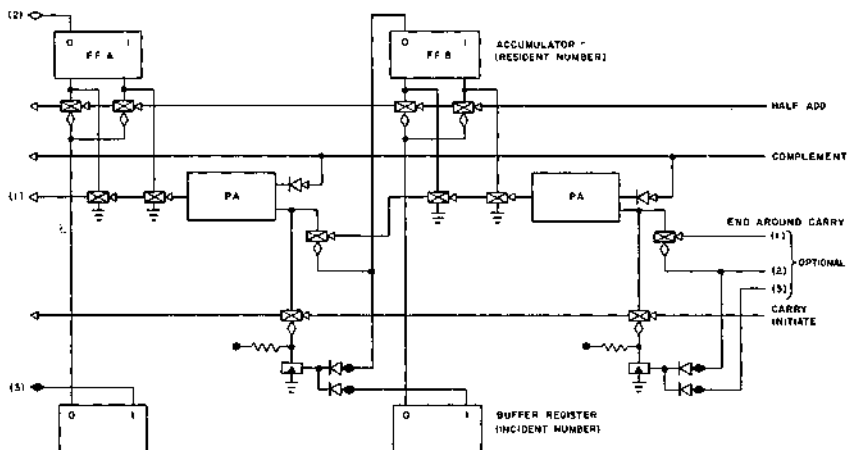


Figure 28 Parallel Adder
(R201 Flip-Flops in Accumulator and
Any Flip-Flops in Incident Register)

Addition is performed in two steps. The first step is a half-add . . . Each digit of the accumulator is complemented if the corresponding digit of the incident number is 1. The second step is a carry. A carry is generated if a digit in the accumulator is 0 and the corresponding incident number is 1. A carry is also propagated if an accumulator digit is 1 and it receives a carry pulse from the next less significant accumulator digit. Each stage will propagate one carry at most. After all carries have been propagated, addition is complete and the accumulator contains the sum of the incident and resident numbers.

Carry initiate must lag half add no less than 525 nsec to allow sufficient set up time. Next half add must lag carry initiate by at least $50M$ nsec (where M is word length in bits) to allow for M bits of carry propagation.

The final step in the addition produces a carry pulse if the sum is a larger number than the accumulator can hold. This pulse may be discarded, added to the first stage (by means of the end-around-carry), or stored externally by means of an additional flip-flop. Three examples are shown in Table 5.

TABLE 5 ADDITION STEPS

| Incident Number | Original Accumulator Number | Accumulator After Half-Add | — SUM — Accumulator After Carry | | |
|-----------------|-----------------------------|----------------------------|------------------------------------|-----------------|-------------------------|
| | | | End Around Carry | Discarded Carry | Externally Stored Carry |
| 001 | 010 | 011 | 011 | 011 | 0011 |
| 001 | 001 | 000 | 010 | 010 | 0010 |
| 101 | 011 | 110 | 001 | 000 | 1000 |

Subtractors

An adder may be also used for subtraction. To subtract a number from the accumulator, the number is made negative and added to the accumulator. The steps involved in performing a subtraction depend on whether the 1's complement or the 2's complement number system is used to represent a negative number.

The 1's complement number system is easiest to implement. To subtract a number from the accumulator, the steps are (1) complement the incident number, (2) half-add, and (3) carry. With this number system it is necessary to use the end-around-carry shown in Figure 28. One's complement subtraction may also be performed by (1) complementing the accumulator, (2) half-add, (3) carry, and (4) recomplementing the accumulator.

Serial Adder

Figure 29 illustrates a serial adder. The contents of register A are added to register B, and the sum is stored in register B. The two numbers to be added are read into registers A and B with the least significant bits stored in flip-flops AN and BN. The carry flip-flop may be cleared before addition is begun. $N + 1$ pulses are allowed to enter the shift pulse input. When a shift pulse is received, the number in each flip-flop is advanced one place. The least significant bits are added, together with the carry, and read into flip-flop B0. If there is a carry, it is stored in the carry flip-flop. After $N + 1$ shift pulses have occurred, register A has been cleared and register B contains the $N + 1$ least significant bits of the sum. The most significant, or overflow, bit is stored in flip-flop C.

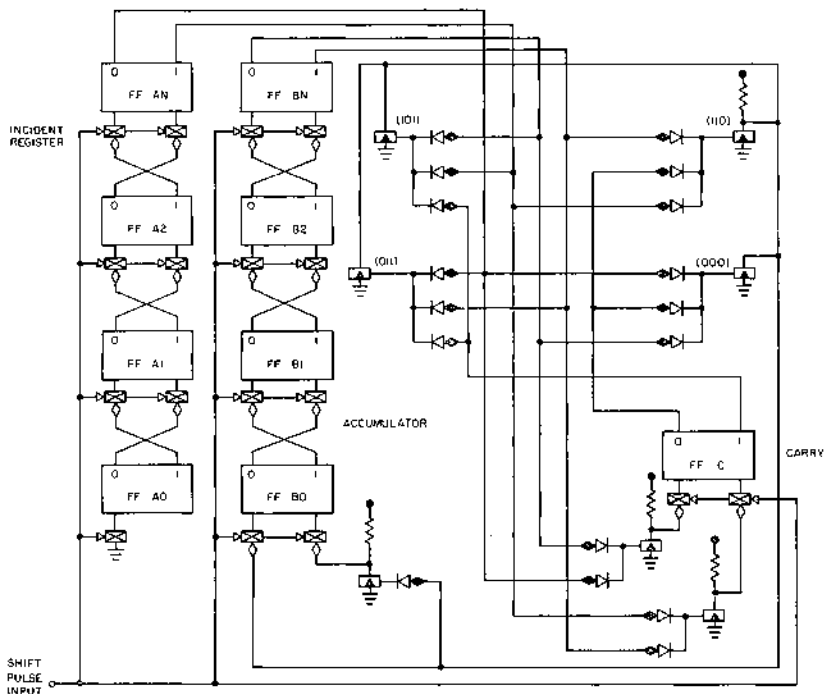


Figure 29 Serial Adders
(R201, R202, or R205 Flip-Flops)

NOTE: Parentheses on output gates indicate digits from flip-flops AN, BN, and C which each gate detects.

COMPARATORS

Comparing A Toggle Switch Register And A Flip-Flop Register

The simplest comparator is a counter that stops or resets itself after a preset number of counts. This type of comparator (Figure 30) has a multiple-input diode gate with each diode connected through a toggle switch to a flip-flop. Each toggle switch corresponds to a single bit; a closed switch represents a 1, an open switch represents a 0. In Figure 30, the counter goes from the binary number 0000 to the number 1011, then resets to 0000. Note that with the single-throw toggle switches, number 1111 could also generate an output. However, this number is never reached because the counter is reset after 1011.

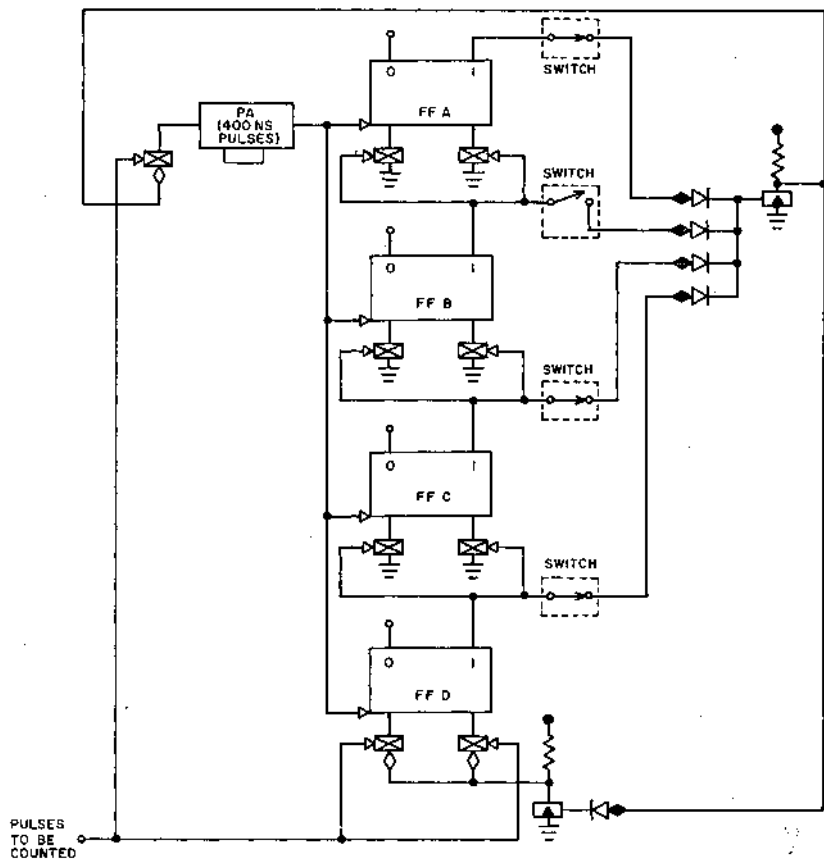


Figure 30 Count-of-Twelve Comparator
(R201, R202, or R205 Flip-Flops, R601 P.A.)

When the comparator output shuts off the counter input, it also reroutes the next count pulse to perform the clearing action. Since this action requires an additional input pulse to operate the pulse amplifier, the toggle switches must be adjusted to detect one less than the number of pulses to be counted, or the counter's least significant bit must be set while the rest of the counter is cleared. Table 6 shows the resulting counting sequences for each method.

TABLE 6 COUNTING SEQUENCES

| All Flip-Flops Cleared | | A, B, C Cleared, D Set | | | |
|------------------------|-----------|------------------------|-----------|--|--|
| Decimal | Binary | Decimal | Binary | | |
| | Flip-Flop | | Flip-Flop | | |
| | A B C D | | A B C D | | |
| 0 | 0 0 0 0 | 1 | 0 0 0 1 | | |
| 1 | 0 0 0 1 | 2 | 0 0 1 0 | | |
| 2 | 0 0 1 0 | 3 | 0 0 1 1 | | |
| 3 | 0 0 1 1 | 4 | 0 1 0 0 | | |
| 4 | 0 1 0 0 | 5 | 0 1 0 1 | | |
| 5 | 0 1 0 1 | 6 | 0 1 1 0 | | |
| 6 | 0 1 1 0 | 7 | 0 1 1 1 | | |
| 7 | 0 1 1 1 | 8 | 1 0 0 0 | | |
| 8 | 1 0 0 0 | 9 | 1 0 0 1 | | |
| 9 | 1 0 0 1 | 10 | 1 0 1 0 | | |
| 10 | 1 0 1 0 | 11 | 1 0 1 1 | | |
| 11 | 1 0 1 1 | 12 | 1 1 0 0 | | |
| 0 | 0 0 0 0 | 1 | 0 0 0 1 | | |

This technique can also be used with a down-counter. The diode gates are connected to the flip-flops so that a closed switch corresponds to a 0. The first comparator output is used to preset the counter to the all 1 state, or to turn off the counter input.

Comparing a toggle-switch register with a flip-flop register that does not necessarily start at 0 requires a single-pole, double-throw switch for each bit. One side of a switch is connected to the 1 output of a flip-flop, and the other side, to the 0 output. The rotor of the switch is connected to an input of the diode gate. When the 0 state of any bit is to be detected, the toggle switch is connected to the 0 terminal of that bit. Similarly, when the 1 state is to be detected, the toggle switch is connected to the 1 terminal of that bit. Thus, the diode gate detects the desired register state regardless of the register's counting sequence.

Because of the carry propagation time through the counter, the maximum input frequency depends on the number of bits. For M bits, the maximum frequency is

$$f = \frac{1000}{70M + 500} \text{ mc}$$

This allows 400 nsec to enable the DCD gate and 100 nsec delay through the diode gate and inverter.

Comparing Two Flip-Flop Registers

Comparison of two flip-flop registers, A and B, requires an exclusive OR for each corresponding pair of bits since two possible conditions produce an inequality: bit A1 equals 0 and bit B1 equals 1; or A1 equals 1 and B1 equals 0. The entire set of exclusive ORs must be ORed together to determine when any pair of bits is unequal. Figure 31 illustrates the use of the Type R141 Diode Gate for comparison of two 3-bit registers. When the two registers are equal, the output is negative; when the two registers are unequal, the output is ground.

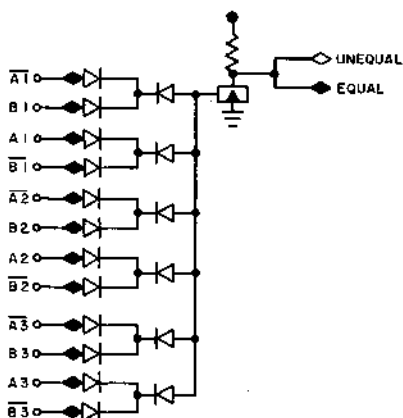


Figure 31 Comparing Two Flip-Flop Registers
(R141 AND-NOR Gate)

Type R131 Exclusive OR can also be used for this purpose, and requires only one input per bit.

Sign Of An Inequality

A more sophisticated comparator is used to compare the numerical value of two registers to determine equality or the sign of an inequality. Pairs of bits must be investigated in the order of their significance. Once an inequality has been discovered, all further investigation is stopped so that the differences in bits of lesser significance do not affect the output.

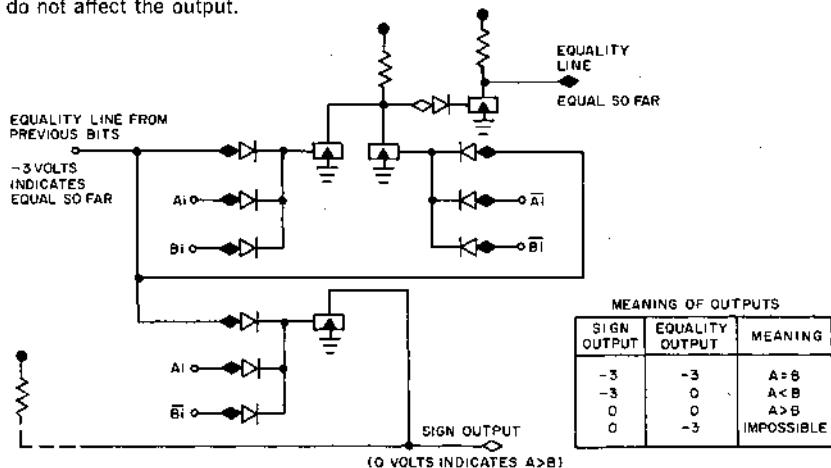


Figure 32 Comparator with Sign Output

Figure 32 shows the i^{th} stage of such a comparator chain. To begin investigation, the equality line is brought to $-3v$. This negative signal is ANDed with an exclusive OR for the first pair of bits. If there is equality, the negative signal is propagated down the equality line. If all corresponding pairs of both registers are equal, the negative signal appears at the end of the final stage. However, if an inequality is reached, further investigation is stopped and the equality line output remains at ground. If this inequality is such that register A is greater than register B, a ground signal is generated at the sign output. The comparator illustrated may contain up to 100 stages.

SYNCHRONIZERS

Synchronizers are important not only to determine what happens when asynchronous or incompatible signals occur, but also to protect against catastrophic errors resulting from such signals. Asynchronous signals are often commands such as start, stop, or clear. Incompatible signals must be guarded against whenever a single flip-flop register is connected for more than one possible mode of operation.

Synchronization is required in a shift register when it is being changed from parallel mode to serial mode (or vice versa). Care must be taken that a split or partial pulse is not allowed to enter the system, because it could result in a partial shift, partial read-in, or partial read-out. Likewise, a bidirectional shift register should never be commanded to shift left and shift right at the same time. In a bidirectional counter, particular care must be taken to assure that the add and subtract inputs are not pulsed simultaneously.

A synchronizer is built by ANDing a random input signal and a clock (or other primary pulse train) and using the results of this AND gate to set a single flip-flop. If the random signal partially enables the pulse gate of the synchronizer flip-flop, the single synchronizer flip-flop decides whether the signal will be accepted or rejected. Provision must also be made for the rejected signal to be accepted by the next clock pulse; thus, the input signal may be slightly delayed by the synchronizer flip-flop, but there will be no middle state to activate only a portion of the main circuit.

Level Synchronizer

Figure 33 shows a method of synchronizing a command level, such as a mode control, with a clock. When the input level is ground, the clock is gated through terminal A. When the input level is negative, the clock is gated through terminal B. If the input level has changed too recently to allow the DCD gates to fully set up before the clock pulse occurs, the decision to accept or reject the signal change is made by the synchronizer flip-flop only. Thus, no pulses are gated through both terminals A and B at the same time, and no split pulses are gated through either terminal. This method, or a variation, is often used in controlling the direction of count in an up-down counter.

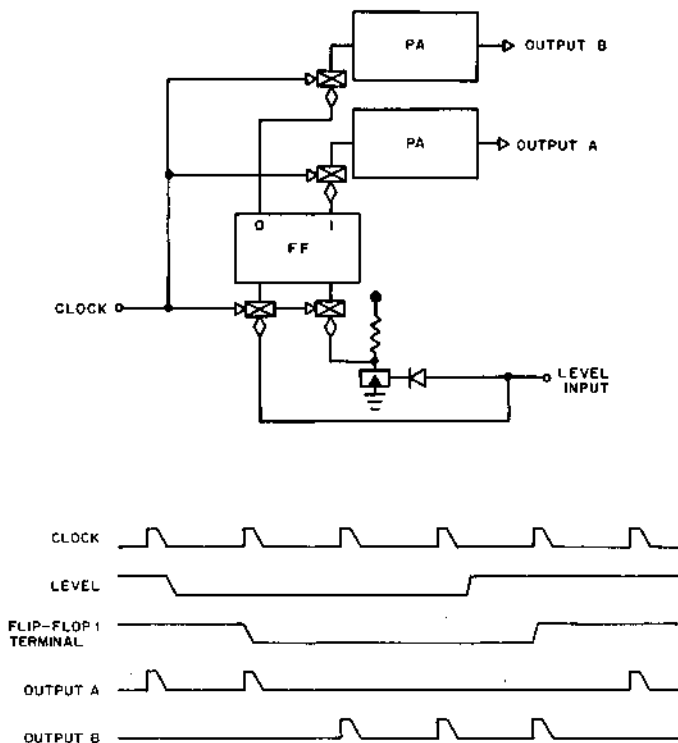


Figure 33 Level Synchronizer
(R201, R202, or R205 Flip-Flops)

Start-Stop Synchronizer

Figure 34 shows a method for synchronizing start and stop commands with a clock. The random start and stop pulses are converted to stop or start levels by flip-flop A. Flip-flop B converts this randomly changing level into a level that changes synchronously with the clock. This level, in turn, conditions the output pulses. The action may be delayed by one clock pulse; however, a split pulse will not be allowed to enter the main system.

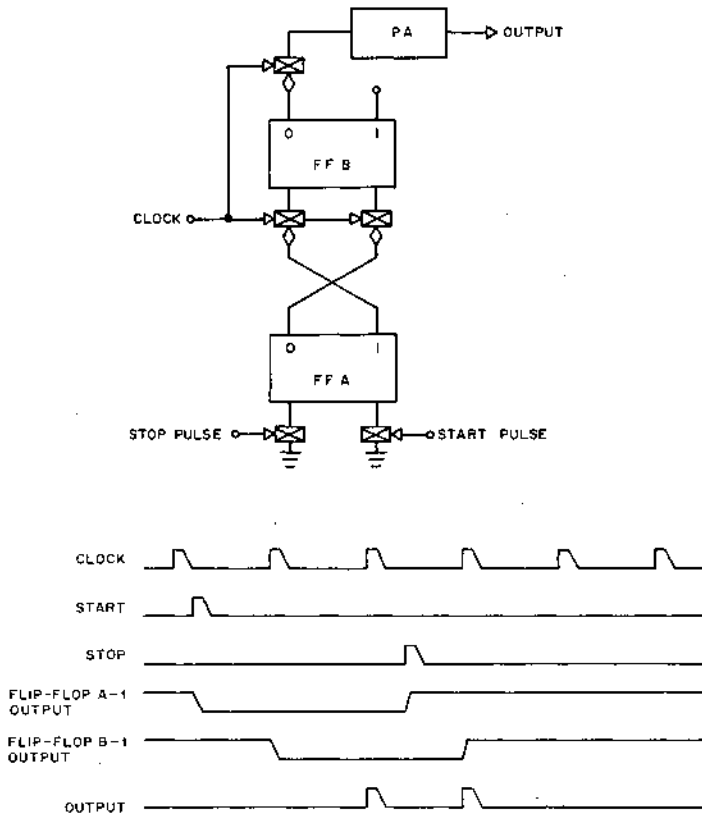


Figure 34 Start-Stop Synchronizer
(R201, R202, or R205 Flip-Flops)

Single-Pulse Synchronizer

Figure 35 shows a method of synchronizing a single pulse with a clock. The operation of the synchronizer is similar to that shown in Figure 34 except that the stop command is automatically generated by the first pulse to leave the synchronizer. Thus, only one pulse passes into the main system, and this pulse is synchronized with the clock.

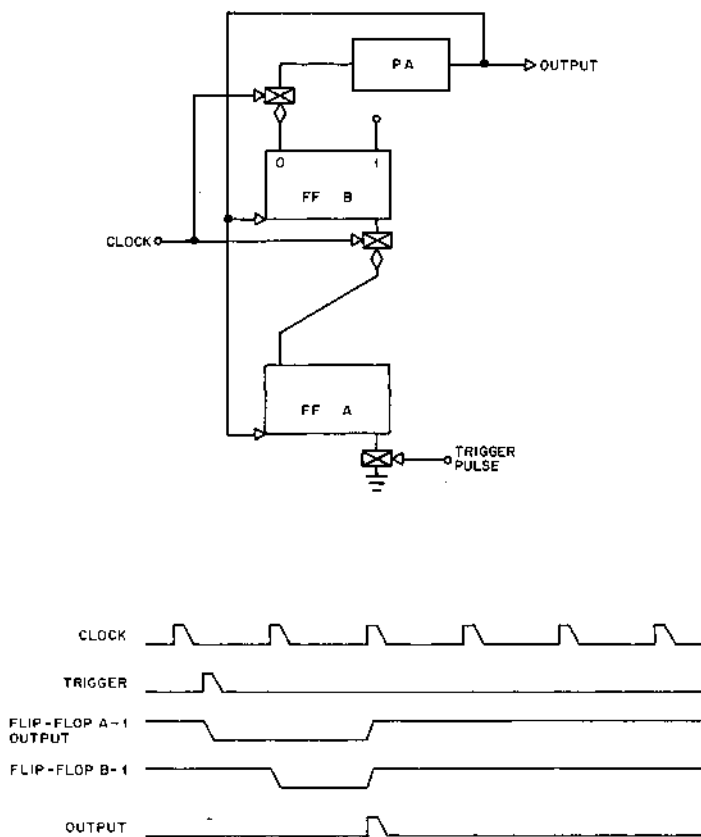


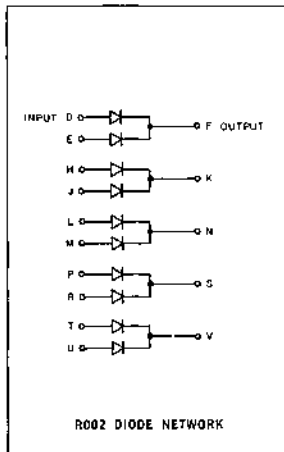
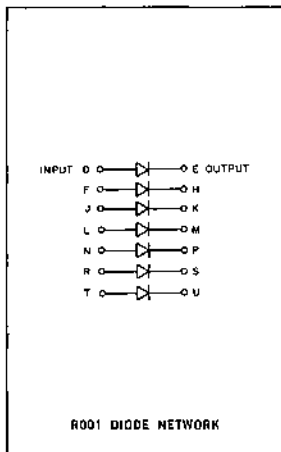
Figure 35 Single-Pulse Synchronizer
(R201, R202, or R205 Flip-Flops)

DIODE NETWORKS

TYPES R001, R002

R

SERIES



Diode networks can expand the logic capability of any R-Series, W-Series, or A-Series module which has one or more node inputs, such as the R111 diode gate. They can also make it possible to OR into an R-Series flip-flop output terminal for setting or clearing from several sources.

Diode networks cannot be cascaded to perform

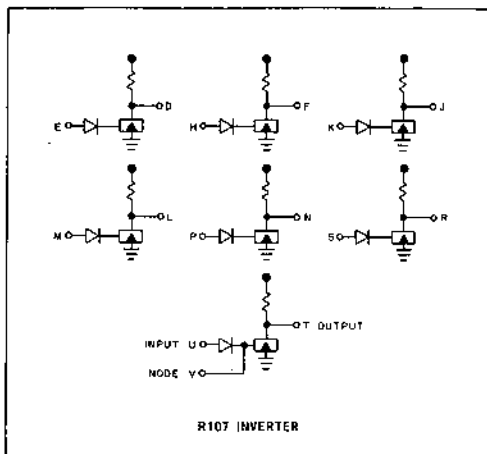
other logic operations.

Propagation delay of R-Series gates expanded by R001 or R002 diodes will increase typically 15-30 nsec when gate output rises from $-3v$ to $0v$, but will not change noticeably when gate output falls from $0v$ to $-3v$. Diodes used are similar to type IN3605.

R001 — \$4.00
R002 — \$5.00

INVERTER TYPE R107

R SERIES



The R107 Inverter contains seven inverter circuits with single-input diode gates. Six of the circuits are used for single-input inversion; the seventh circuit can be used for gating by tying additional diode input networks to its node terminal. Clamped load resistors of 2 ma are a permanent part of each inverter.

INPUT: Diode — Standard levels of $-3v$ and ground, 100-nsec minimum duration. Input load is 1 ma, shared among the inputs that are at ground. **Node Terminal** — Accepts only R001 or R002 Diode Networks or their equivalent. The combined length of all leads attached to the node terminal must not exceed 6 in. Input signal and load characteristics for diode networks are the same as those given for the diode input above.

OUTPUT: Standard levels of $-3v$ and ground. Each inverter can drive 18 ma of load at ground. Output terminals of inverters may be connected in parallel. Some typical propagation delays are shown below. High frequency logic designs may benefit from the application note "Estimating Propagation Delays."

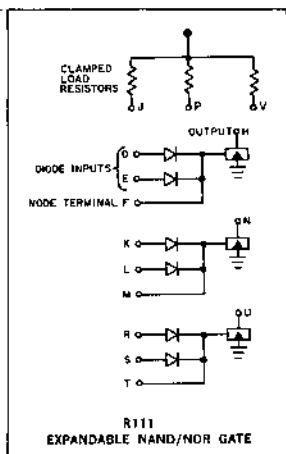
| Fan-out | 4 | 10 | 16 |
|-------------|---------|----------|----------|
| Output Rise | 30 nsec | 35 nsec | 40 nsec |
| Output Fall | 60 nsec | 100 nsec | 140 nsec |

POWER: $+10 v(A)/0.7 ma$, $-15 v(B)/30 ma$.

EXPANDABLE NAND/NOR GATE

TYPE R111

R
SERIES



The R111 contains three diode gates, each connected to a transistor inverter. The gate operates as a NAND for negative inputs, and as a NOR for ground inputs. Each gate has three input terminals: two are connected to diodes, a third is connected directly to the node point of the diode gate. The third terminal allows the number of input diodes to be increased by adding external diode networks such as the R001 or R002. External diodes must be connected in the same direction as the diodes in the R111. Unused inputs may be left open.

INPUT: Diodes—Standard levels of $-3v$ and ground, 100-nsec minimum duration. Input load is 1 ma, shared among the inputs that are at ground.
Node Terminal—Accepts only R001 or R002 networks or their equivalent. The combined length of all leads attached to the node terminal must not be greater than 5 in. Input signal and load characteristics for the diode networks are the same as those given for the diode above.

OUTPUT: Standard levels of $-3v$ and ground. Each output can drive 20 ma of load at ground. Clamped load resistors are included in the module. Each clamped load resistor represents 2 ma of load. The output terminals of diode gates may be connected in parallel. Two gates in parallel (driven by the same signal) can drive 38 ma at ground (20 ma each, less the 2-ma clamped load). If they are not driven by the same signal, gates in parallel drive 20 ma at ground minus 2 ma for each clamped load used. Some typical propagation delays are shown below. High frequency logic designs may benefit from the application note "Estimating Propagation Delays."

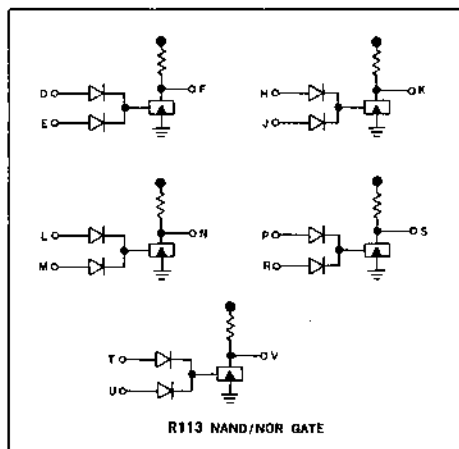
| Fan-out | 4 | 10 | 16 |
|-------------|---------|----------|----------|
| Output Rise | 30 nsec | 35 nsec | 40 nsec |
| Output Fall | 60 nsec | 100 nsec | 140 nsec |

POWER: $+10 v(A)/0.3 ma$, $-15 v(B)/18 ma$.

R111 — \$14.00

NAND/NOR GATE TYPE R113

R SERIES



The R113 contains five diode gates, each connected to a transistor inverter. The gate operates as a NAND for negative inputs, and as a NOR for ground levels.

INPUTS: Standard levels of -3v and ground, 100-nsec minimum duration. Input load is 1 ma, shared among the inputs at ground. Unused inputs may be left open.

OUTPUT: Standard levels of -3v and ground. Each output can drive 18 ma of load at ground. Output terminals may be connected in parallel. Clamped

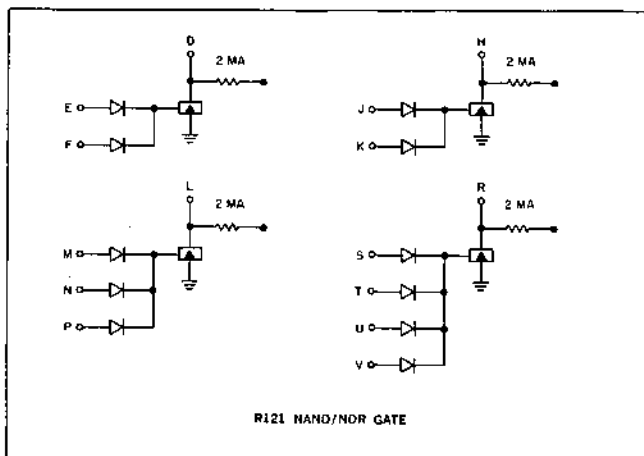
loads included in the module are 2 ma each. Some typical propagation delays are shown below. High frequency logic designs may benefit from the application note "Estimating Propagation Delays."

| Fan-out | 4 | 10 | 16 |
|-------------|---------|----------|----------|
| Output Rise | 30 nsec | 35 nsec | 40 nsec |
| Output Fall | 60 nsec | 100 nsec | 140 nsec |

POWER REQUIREMENTS: $+10\text{V}$ (A) 0.5 ma. -15V (B) 23 ma.

NAND/NOR GATE TYPE R121

R SERIES



The R121 contains four R111-type circuits with 2-ma loads internally connected to each output. This module increases density at the expense of flexibility, since gate expanders R001 and R002 cannot be used.

INPUT: Standard levels of $-3v$ and ground, 100 nsec, minimum duration. Input load is 1 ma, shared among the inputs that are at ground.

OUTPUT: Standard levels of $-3v$ and ground. Each output has a permanently attached 2 ma clamped load resistor. Each output can drive 18 ma of load at ground. Delays are similar to R111 delays. See application note "Estimating Propagation Delay" for more information.

POWER: $+10v(A)/0.4$ ma, $-15v/20$ ma.

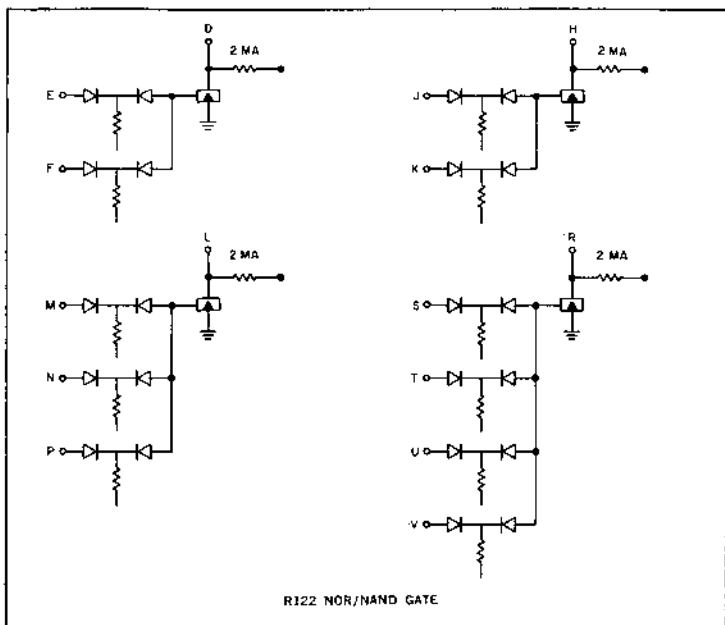
R121 — \$17.00

NOR / NAND GATE

TYPE R122

R

SERIES



Provides the logical complement to the R121 NAND Gate at some sacrifice of speed and economy.

INPUT: Standard levels of $-3v$ and ground. Minimum duration: 400 nsec at ground, 100 nsec at $-3v$. Input load is 1 ma at each input.

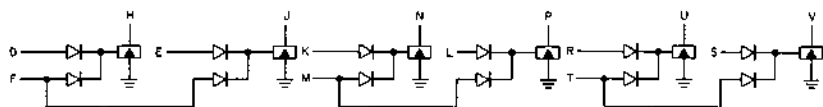
OUTPUT: Standard levels of $-3v$ and ground. Each

output has a permanently attached 2 ma clamped load resistor. Each output can drive 18 ma of load at ground. Propagation delays for output rise are similar to R111 delays. Propagation delays for output fall are typically 75 nsec longer than R111 delays.

POWER: $+10v(A)/3$ ma. $-15v/31$ ma.

INPUT BUS GATE TYPE R123

R SERIES



R123 INPUT BUS GATE

This module contains six R111-type diode gates arrayed for convenient driving of the PDP-8 computer input bus, and for other matrix-like applications. Clamped loads are not provided on this module, and must be obtained from some module in the associated logic.

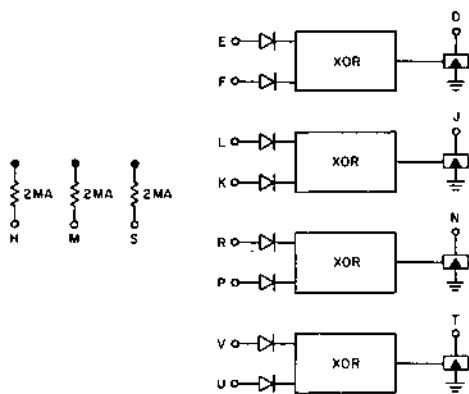
INPUT: Standard levels of $-3v$ and ground, 100-nsec, minimum duration. Each of the six gates is a 1 ma load shared among its grounded inputs; thus inputs F, M, and T may be loaded with up to 2 ma at ground.

OUTPUT: Standard levels of $-3v$ and ground. Each output can drive up to 20 ma at ground. A 2 ma or heavier clamped load must be used at each group of paralleled collector outputs, chosen to provide fall times fast enough for the use intended. Delays are similar to R111 delays. See application note "Estimating Propagation Delay" for more information.

POWER: $+10v(A)/.6$ ma, $-15v/15$ ma.

EXCLUSIVE OR TYPE R131

R SERIES



R131 EXCLUSIVE OR

This module provides a convenient way to compare two binary numbers or patterns. The output of each circuit is negative if its inputs are the same, and ground if they are different. If the outputs of several circuits are tied together, the common output line will be negative if every input pair matches, ground if any pair doesn't match.

During the transition from one input pattern to another with the same output, there is an interval during which the R131 output may be wrong for both patterns. Transitions between unequal inputs have a relatively short settling time, but transitions between equal inputs may produce transients to ground lasting 250 nsec or more.

INPUTS: Standard levels of $-3v$ and ground. Each input is a 2 ma load at ground.

OUTPUTS: Standard levels of $-3v$ and ground. Each output can drive 18 ma at ground. Propagation delay for output rise is similar to R111 delay. Propagation delay for output fall is typically 300 nsec longer than R111 delay.

POWER: $+10v(A)/0.8$ ma; $-15v(B)/36$ ma.

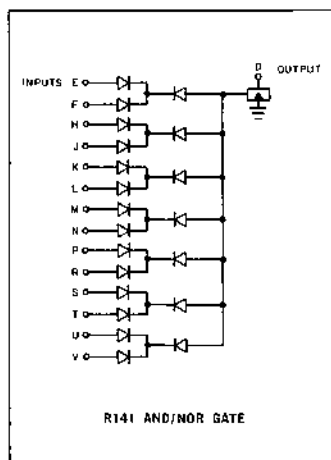
TRUTH TABLE

| Input E(K, P, U) | Output D(J, N, T) | Input F(L, R, V) |
|---------------------|----------------------|---------------------|
| 0v | 0v | $-3v$ |
| $-3v$ | 0v | 0v |
| 0v | $-3v$ | 0v |
| $-3v$ | $-3v$ | $-3v$ |

R131 — \$35.00

AND/NOR GATE TYPE R141

R
SERIES



The R141 AND/NOR Gate performs two levels of gating. The module contains a multiple-input diode gate with a transistor inverter for signal amplification. For negative input signals the R141 is seven 2-input AND gates which are NORed together. For ground inputs, it is seven 2-input OR gates NANDed together. This module is frequently used to mix multiple inputs to a pulse amplifier, or to compare the contents of two flip-flop registers.

The back-to-back diode circuits are possible because of an internal bias resistor connected to the input of each second stage diode. The bias holds the input of the second stage at $-3v$ unless one of the first stage inputs is grounded. Propagation delay for output rise is similar to R111 delay. For output fall, delay is typically 100 nsec longer than R111 delay

under similar loading conditions, assuring sufficient pulse stretching to allow 70 nsec inputs. Output is typically too wide, however, to allow 2 mc rates. Maximum rate depends upon R141 loading, and may be as low as 1 mc.

INPUT: Standard 100-nsec pulses, standard levels of $-3v$ and ground, or 70-nsec negative pulses such as those generated by the W607 Pulse Amplifier. Input load is 1 ma per input pair shared by the grounded inputs. When any pair of inputs is not being used, at least one of the two must be grounded.

OUTPUT: Standard levels of $-3v$ and ground. The output can drive 20 ma of external load at ground. It has no internal load.

POWER: $+10 v(A)/0.5 ma$, $-15 v(B)/19 ma$.

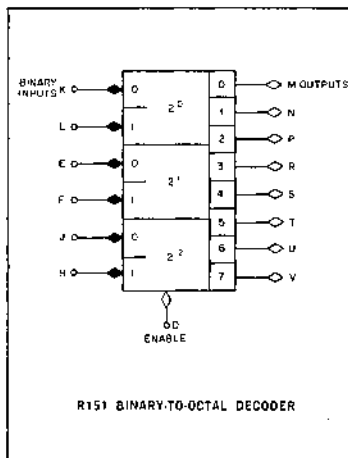
R141 — \$13.00

BINARY-TO-OCTAL DECODER

TYPE R151

R

SERIES



TRUTH TABLE

| INPUTS | | | | | | | OUTPUTS | | | | | | | |
|--------|-----|-----|-----|-----|-----|----|---------|-----|-----|-----|-----|-----|-----|-----|
| J | H | E | F | K | L | D | M | N | P | R | S | T | U | V |
| -3v | 0v | -3v | 0v | -3v | 0v | 0v | 0v | -3v | -3v | -3v | -3v | -3v | -3v | -3v |
| -3v | 0v | -3v | 0v | 0v | -3v | 0v | -3v | 0v | -3v | -3v | -3v | -3v | -3v | -3v |
| -3v | 0v | 0v | -3v | -3v | 0v | 0v | -3v | -3v | 0v | -3v | -3v | -3v | -3v | -3v |
| -3v | 0v | 0v | -3v | 0v | -3v | 0v | -3v | -3v | -3v | 0v | -3v | -3v | -3v | -3v |
| 0v | -3v | -3v | 0v | -3v | 0v | 0v | -3v | -3v | -3v | -3v | 0v | -3v | -3v | -3v |
| 0v | -3v | -3v | 0v | 0v | -3v | 0v | -3v | -3v | -3v | -3v | -3v | 0v | -3v | -3v |
| 0v | -3v | 0v | -3v | -3v | 0v | 0v | -3v | -3v | -3v | -3v | -3v | -3v | 0v | -3v |
| 0v | -3v | 0v | -3v | 0v | -3v | 0v | -3v | -3v | -3v | -3v | -3v | -3v | 0v | -3v |
| 0v | -3v | 0v | -3v | 0v | -3v | 0v | -3v | -3v | -3v | -3v | -3v | -3v | 0v | -3v |
| -3v | -3v | -3v | -3v | 0v | -3v | 0v | -3v | -3v | -3v | -3v | -3v | 0v | -3v | 0v |
| -3v | -3v | -3v | -3v | 0v | -3v | 0v | 0v | -3v | 0v | -3v | 0v | -3v | 0v | -3v |
| -3v | -3v | 0v | -3v | -3v | -3v | 0v | -3v | -3v | 0v | 0v | -3v | -3v | 0v | 0v |
| -3v | -3v | 0v | -3v | 0v | -3v | 0v | 0v | 0v | -3v | -3v | 0v | 0v | -3v | -3v |
| 0v | -3v | -3v | -3v | -3v | -3v | 0v | -3v | -3v | -3v | -3v | 0v | 0v | 0v | 0v |
| -3v | 0v | -3v | -3v | -3v | -3v | 0v | 0v | 0v | 0v | 0v | 0v | -3v | -3v | -3v |

The R151 decodes binary information from three flip-flops into octal form. When the enable input is at ground, the selected output line is at ground and the other seven outputs are at $-3v$. When the enable input is at $-3v$, all outputs are at $-3v$. The internal gates are similar to those in the R111. The enable input is the common emitter connection of the output inverters. Typical total transition times are 75 nsec for output rise and 60 nsec for output fall.

INPUT: Binary — Standard levels of $-3v$ and ground, 100 nsec minimum duration. Input load is

2.3 ma per grounded input when the inputs are binary, as in the first 8 lines of the truth table. The input current is 4 ma at ground when only one input is grounded, as in the last 6 lines of the truth table.

Enable — Standard levels of $-3v$ and ground, 100 nsec minimum duration. Input load at ground is 3 ma plus the current required by the load on the selected output when the inputs are binary, as in the

first 8 lines of the truth table. For other inputs, the load is 3 ma per selected output plus the loads on those selected outputs. The maximum input current is 10 ma when driven from an inverter collector. No more than one inverter can be placed in series with this pin and ground. If any external circuit brings an R151 output to ground, any gate being used to enable pin D must not drive anything else.

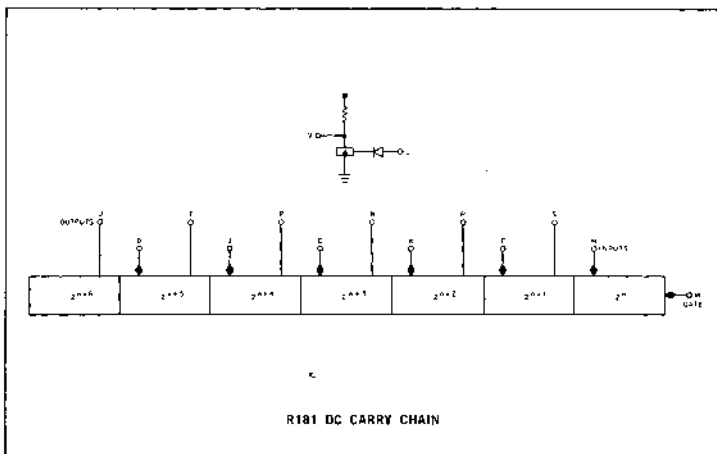
OUTPUT: Standard levels. Each octal output has a permanently attached 2-ma clamped load resistor. Each output can drive 7 ma of load at ground. If the enable input is permanently grounded, each output can drive 18 ma of load at ground. The length of the wire used to ground the enable input (pin D) should be kept as short as possible. Note: Simultaneous switching of R151 outputs is not assured. If adjacent R151 outputs are ORed together for example, the gate output may contain spikes.

POWER: $-10 v(A)/0.9 ma$, $-15 v/32 ma$.

R151 — \$33.00

DC CARRY CHAIN TYPE R181

R
SERIES



The R181 DC Carry module is designed for building counters with no carry propagate delay. A 2-mc counter of any size, with all flip-flops switching simultaneously, can be constructed using the dc carry modules interconnected as in Figures 1 and 2 on the next page. The pulse amplifier interconnection of Figure 1 should be used between the first pair of dc carry modules. The dc carry interconnection of Figure 2 may be used between all following pairs of stages.

If the time between input count pulses is greater than $400 + 100(N-1)$ nsec (where N is the number of dc carry modules), the pulse amplifier connection is not necessary and the dc interconnection may be used between all dc carry modules.

The carry module contains an independent 1-input diode gate and six interconnected diode gates with

two, three, four, five, six, and seven inputs respectively. The outputs are all similar to the Type R107.

INPUT: Inputs are DEC standard levels. The input loads on Pins M and H are 6 ma each. The load on Pin F is 5 ma; on Pin K it is 4 ma; on Pin E, 3 ma, etc. The loads presented by Pins D and L are 1 ma each. All loads are at ground, there is no load at $-3v$.

OUTPUTS: Each output is at ground only when the input to the common gate and all inputs to gates of lesser significance are at $-3v$. Each output circuit can supply 18 ma at ground and has an internal load of 2 ma.

POWER: +10 v(A)/0.7 ma, $-15v(B)$ /26.2 ma.

R181 — \$35.00

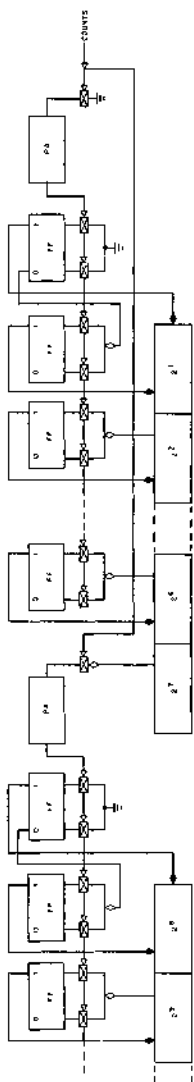


Figure 1 Pulse Amplifier Interconnection

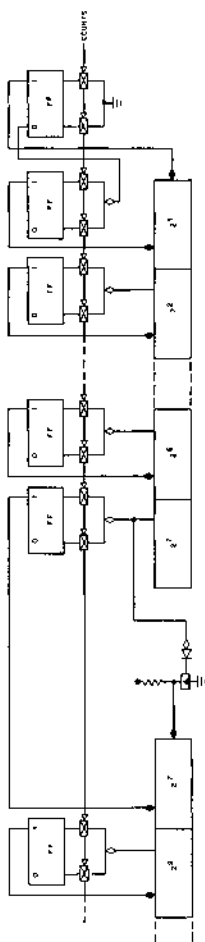
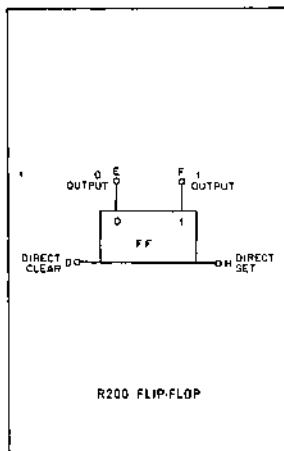


Figure 2 DC Interconnection

FLIP-FLOP TYPE R200

R SERIES



The R200 is a basic flip-flop for use in set-reset applications. It can be set and cleared at any frequency up to 2 mc. A set input makes the 1 output go to $-3v$ and the 0 output to ground; a clear input makes the 0 output go to $-3v$ and the 1 output to ground.

INPUT: Direct Set and Clear—A standard 100-nsec pulse or a ground level of 100 nsec minimum duration activates the input; the load at ground is 1 ma. When not in use, the direct set and clear terminals must be at $-3v$. If both inputs are held at ground, both outputs are at $-3v$. **Collector Triggering**—The flip-flop can also be set or cleared through its output by a diode gate or a diode network. The triggering circuit load is the external load on the output terminal being driven plus the internal load.

OUTPUT: Standard levels. Each output can drive 17 ma of external load at ground. The internal load is 4 ma. If more than 18 in. of wire is attached to an output, additional clamped loads (see the W002, W005) should be connected to decrease the output fall time. The load is sufficient if the positive transition at the opposite terminal reaches $-1v$ within 80 nsec after the flip-flop is pulsed.

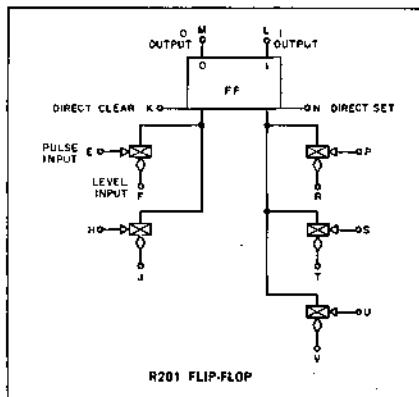
Note: Additional driving capability at $-3v$ is required by some circuits outside the R series. Auxiliary clamped loads W002 and W005 are available for this purpose.

POWER: $+10v(A)/0.3ma$, $-15v(B)/16ma$.

R200 — \$9.50

FLIP-FLOP TYPE R201

R
SERIES



The R201 Flip-Flop has direct set and clear inputs and five diode-capacitor-diode (DCD) gates. Because of this large number of inputs, the R201 can be used in any of the following applications without additional gating:

1. Any two of the following as well as conditional read-in from an external source: up counter, shift register, jam transfer buffer, ring counter, and switch tail ring counter. Down counters or up-down counters can also be implemented if conditional read-in is not required.
2. BCD counter with read-in from two sources.
3. Buffer register or control flip-flop with read-in from five sources.
4. Special Counts of $2^k (2^r + 1)$

INPUT: Direct Set and Clear—A standard 100-nsec pulse or a ground level of 100 nsec minimum duration activates the input; the load at ground is 1 ma. When not in use, the direct set and clear terminals must be at $-3v$. If both inputs are held at ground, both outputs will be at $-3v$. If the flip-flop is used in an up counter with carry gates enabled, the direct clear pulse must be at least 400 nsec long to suppress carry propagation. Similarly, if the down counter gates are enabled, the direct set pulse must be 400 nsec long. **DCD Gates, Level**—Standard levels of $-3v$ and ground. Because DCD gates are internally conditioned by the state of the flip-flop, complement inputs may be formed by tying 1 and 0 DCD gate inputs together. A DCD gate is enabled by a ground level and disabled by a $-3v$ level. The conditioning level must be present for at least 400 nsec before the gate is pulsed. The level input represents

2 ma of load at ground. When 1 and 0 DCD gates are connected in parallel to form a complement input, the total level load is 3 ma at ground. **Pulse**—Standard 100-nsec pulses ($-3v$ to ground) at any frequency up to 2 mc. It can also be driven by positive-going level changes ($-3v$ to ground) with rise times of 60 nsec max and duration of 100 nsec min. Prior to operation the input must have been at $-3v$ for at least 400 nsec. The pulse input represents 3 ma of load at ground. When a pair of 1 and 0 DCD gates have a common pulse input, as in complementing or shifting, the total pulse load is 4 ma at ground. **Collector Triggering**—The flip-flop can also be set or cleared from its outputs by a diode gate circuit or a diode network. The triggering circuit load is the external load on the terminal being driven by the circuit plus the internal load on that terminal.

OUTPUT: Standard levels of $-3v$ and ground. The carry propagate time is 70 nsec. The 0 terminal can drive 11 ma of external load at ground. The internal load is 10 ma. The 1 terminal can drive 13 ma of external load at ground. The internal load is 8 ma. If more than 18 in. of wire is attached to an output, additional clamped loads (see the W002, W005) should be connected to decrease the output fall time. The load is sufficient if the positive transition at the opposite terminal reaches $-1v$ within 80 nsec after the flip-flop is pulsed.

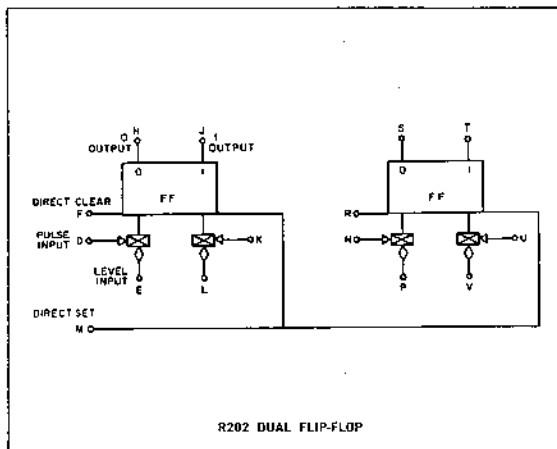
Note: Additional driving capability at $-3v$ is required by some circuits outside the R series. Auxiliary clamped loads W002 and W005 are available for this purpose.

POWER: $+10 v(A)/0.2$ ma, $-15 v(B)/27$ ma.

R201 — \$22.00

DUAL FLIP-FLOP TYPE R202

R
SERIES



The R202 Dual Flip-Flop contains two identical flip-flops. Each has a direct clear input, a common set input, and two DCD gates. The R202 can perform in any one of the following applications without additional gating: up counter, down counter, shift register, ring counter, jam transfer buffer, and switch tail ring counter.

INPUT: Direct Set and Clear — A standard 100 nsec pulse or a ground level of 100 nsec minimum duration activates the input; the load at ground is 1 ma for each clear input, and 2 ma for the set input. When not in use, the direct terminals must be at $-3v$. If the flip-flop is in an up counter with carry gates enabled, direct clear pulses must be at least 400 nsec long to suppress carry propagation. In like manner, a 400 ns set pulse must be used when the flip-flops are arranged as a down counter. If both inputs are held at ground, both outputs are at $-3v$. **DCD Gates, Level** — Standard levels of $-3v$ and ground. Because DCD gates are internally conditioned by the state of the flip-flop, a complement input may be formed by tying the 1 and 0 DCD gate inputs together. A DCD gate is enabled by a ground level and disabled by a $-3v$ level. The conditioning level must be present for at least 400 nsec before the gate is pulsed. The level input represents 2 ma of load at ground. When 1 and 0 DCD gates are connected in parallel to form a complement input, the total level load is 3 ma at ground. **Pulse** — Standard 100-nsec pulses ($-3v$ to ground) at any

frequency up to 2 mc. It can also be driven by positive-going level changes ($-3v$ to ground) with rise times of 60 nsec max and duration of 100 nsec min. Prior to operation the input must have been at $-3v$ for at least 400 nsec. The pulse input represents 3 ma of load at ground. When a pair of 1 and 0 DCD gates have a common pulse input, as in complementing or shifting, the total pulse load is 4 ma at ground. **Collector Triggering** — The flip-flop can also be set or cleared through its outputs by a diode gate circuit or a diode network. The triggering circuit load is the external load on the terminal being driven by the circuit plus the internal load on that terminal (6 ma each).

OUTPUT: Standard levels. The carry propagate time is 70 nsec. Each terminal can drive 15 ma of external load at ground and has an internal load of 6 ma. If more than 18 in. of wire is attached to an output, additional clamped loads (see the W002, W005) should be connected to decrease the output fall time. The load is sufficient if the positive transition at the opposite terminal reaches $-1 v$ within 80 nsec after the flip-flop is pulsed.

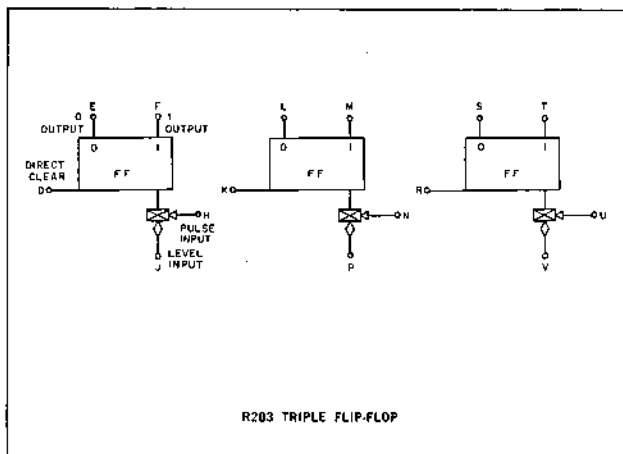
Note: Additional driving capability at $-3v$ is required by some circuits outside the R series. Auxiliary clamped loads W002 and W005 are available for this purpose.

POWER: $+10 v(A)/0.5 ma$, $-15 v(B)/34 ma$.

R202 — \$25.00

TRIPLE FLIP-FLOP TYPE R203

R SERIES



The R203 Triple Flip-Flop contains three identical flip-flops. Each flip-flop has a direct clear input and a DCD gate for conditional read-in.

INPUT: Direct Clear—A standard 100-nsec pulse or a ground level of 100 nsec minimum duration activates the input; the load at ground is 1 ma. When not in use, the direct clear terminal must be at $-3v$.
DCD Gates, Level—Standard levels of $-3v$ and ground. A DCD gate is enabled by a ground level and disabled by a $-3v$ level. The conditioning level must be present for at least 400 nsec before the gate is pulsed. The level input represents 2 ma of load at ground.
Pulse—Standard 100-nsec pulses ($-3v$ to ground) at any frequency up to 2 mc. The flip-flop can also be driven by positive-going level changes ($-3v$ to ground) with rise times of 60 nsec max and duration of 100 nsec min. Prior to operation the input must have been at $-3v$ for at least 400

nsec. The pulse input represents 3 ma of load at ground.
Collector Triggering—The flip-flop may also be set or cleared from its outputs by a diode gate circuit or a diode network. The triggering circuit load is the external load on the terminal being driven by the circuit plus the internal load on that terminal.

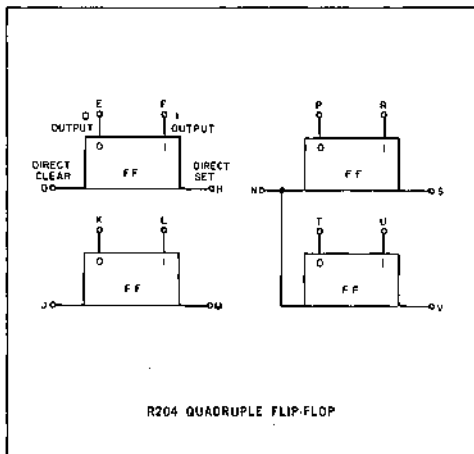
OUTPUT: Standard levels of $-3v$ and ground. The 0 terminal can drive 15 ma of external load at ground. The internal load is 6 ma. The 1 terminal can drive 17 ma of external load at ground. The internal load is 4 ma. If more than 18 in. of wire is attached to an output, additional clamped loads (see the W002, W005) should be connected to decrease the output fall time. The load is sufficient if the positive transition at the opposite terminal reaches $-1v$ within 80 nsec after the flip-flop is pulsed.

POWER: $+10 v(A)/0.7 ma$, $-15 v(B)/40 ma$.

R203 — \$28.00

QUADRUPLE FLIP-FLOP TYPE R204

R
SERIES



The R204 Quadruple Flip-Flop contains four flip-flops. Each has direct set and direct clear inputs. Two of the flip-flops share a common direct clear input. The R204 is used in general control applications. A set input makes the 1 output $-3v$ and the 0 output ground; a clear input makes the 1 output $-3v$ and the 0 output ground.

INPUT: Direct Set and Clear — A standard 100-nsec pulse or a ground level of 100 nsec minimum duration activates the input; the load at ground is 1 ma per flip-flop. When not in use, the direct set and clear terminals must be at $-3v$. If both inputs are held at ground, both outputs will be at $-3v$. **Collector Triggering** — The flip-flop can also be set or cleared through its outputs by a diode gate circuit or a diode network. The triggering circuit load is the external load on the terminal being driven by the circuit

plus the internal load on that terminal. The internal load is 4 ma for each terminal.

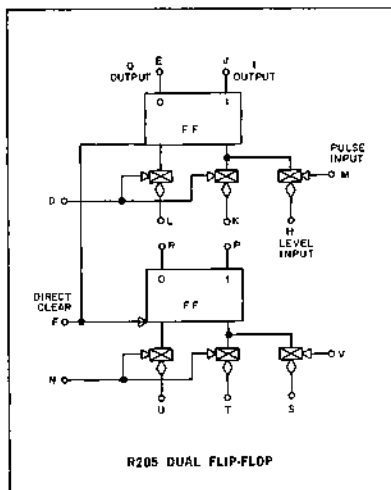
OUTPUT: Standard levels of $-3v$ and ground. Each terminal can drive 17 ma of external load at ground, and has an internal load of 4 ma. If more than 18 in. of wire is attached to an output, additional clamped loads (see the W002, W005) should be connected to decrease the output fall time. The load is sufficient if the positive transition at the opposite terminal reaches $-1v$ within 80 nsec after the flip-flop is pulsed.

Note: Additional driving capability at $-3v$ is required by some circuits outside the R series. Auxiliary clamped loads W002 and W005 are available for this purpose.

POWER: | 10 v(A)/0.9 ma, 15 v(B)/42 ma.

DUAL FLIP-FLOP TYPE R205

R SERIES



The R205 contains two identical flip-flops with a common direct clear input. Each has three DCD gates, and can be collector-triggered at either output by a diode-transistor gate or a diode network. The R205 can be used in any of the following applications without additional gating: up counter, down counter, shift register, ring counter, or jam transfer register.

INPUT: Direct Clear—A standard 100-nsec pulse or a ground level of 100 nsec minimum duration activates the input; the load at ground is 1 ma. When not in use, the direct clear terminal must be at $-3v$. If the flip-flop is used in an up counter with carry gates enabled, direct clear pulses must be at least 400 nsec long to suppress carry propagation. **DCD Gates, Level**—Standard levels of $-3v$ and ground. Because DCD gates are internally conditioned by the state of the flip-flop, complement inputs may be formed by tying 1 and 0 DCD gate inputs together. A DCD gate is enabled by a ground level and disabled by a $-3v$ level. The conditioning level must be present for at least 400 nsec before the gate is pulsed. The level input represents 2 ma of load at ground. When 1 and 0 DCD gates are connected in parallel to form a complement input, the total load is 3 ma at ground. **Pulse**—Standard 100-nsec pulses ($-3v$ to ground) at any frequency up to 2 mc. It can also be driven by positive-going level changes ($-3v$ to ground) with rise times of 60 nsec

max and duration of 100 nsec min. Prior to operation the input must have been at $-3v$ for at least 400 nsec. The pulse input represents 3 ma of load at ground. When a pair of 1 and 0 DCD gates have a common pulse input as in complementing or shifting, the total pulse load is 4 ma at ground. **Collector Triggering**—Triggering circuit load is the external load on the terminal being driven plus the internal load on that terminal. Internal load for the 1 terminal is 6 ma; for the 0 terminal, 8 ma.

OUTPUT: Standard levels. Carry propagation time is 70 nsec. The 0 terminal can drive a 13-ma external load at ground; the 1 terminal, 15 ma at ground. Internal load on the 1 terminal is 6 ma; for the 0 terminal, 8 ma. If more than 18 in. of wire is attached to an output, additional clamped loads (see the W002, W005) should be connected to decrease the output fall time. The load is sufficient if the positive transition at the opposite terminal reaches $-1v$ within 80 nsec after the flip-flop is pulsed.

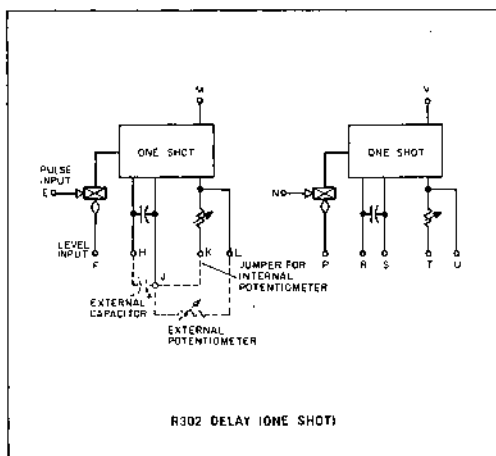
Note: Additional driving capability at $-3v$ is required by some circuits outside the R series. Auxiliary clamped loads W002 and W005 are available for this purpose.

POWER: +10 v(A)/0.5 ma, $-15 v(B)$ /36 ma.

R205 — \$29.00

DELAY (ONE SHOT) TYPE R302

R SERIES



The R302 contains two delays (one-shot multivibrators) which are triggered by DCD gates. Each delay is independent and can be externally or internally controlled. When the input is triggered, the output changes from its normal ground level to

3v for a predetermined, adjustable period of time and then returns to ground. The length of the delay is determined by the capacitor and potentiometer. External capacitors can be attached between terminals H and J (or R and S), J (S) being the more positive terminal. The 20-kilohm internal potentiometer can be used by putting a jumper between terminals J and K (or S and T). External potentiometers can be attached between terminals J and L (S and U). The total resistance between these terminals must not exceed 20 kilohm. A 20% change in power supply voltage will change the delay less than 2%. Delay jitter due to power supply ripple is less than 0.2%.

The expected delay of any combination (with more than a 500-pf capacitance) can be estimated by the following formula:

$$\text{Delay} = RC$$

where the delay time is in nsec, R in kilohm and C in pf. The total capacitance, C, equals 220 pf of internal capacitance plus any external capacitance used. The resistance, R, is equal to the resistance of the potentiometer plus 1 kilohm of internal resistance. The minimum delay is 400 nsec. The min-

imum delay in nsec for a given external capacitor is C where C is equal to the external capacitance in pf plus a 220-pf internal capacitance. The recovery time is twice the minimum delay.

The delay range for typical capacitors used with the internal potentiometer is given in the table that follows:

DELAY RANGES

| Total Capacitance Used (External + 220 pf internal) | Minimum Delay Range | Recovery Time |
|-----------------------------------------------------|---------------------|---------------|
| Internal 220 pf only | 400-4000 nsec | 800 nsec |
| 2000 pf | 4-40 μ sec | 8 μ sec |
| 20 nf | 40-400 μ sec | 80 μ sec |
| 200 nf | 0.4-4 msec | 0.8 msec |
| 2000 nf | 4-40 msec | 8 msec |
| 20 μ f | 40-400 msec | 80 msec |
| 200 μ f | 400-4000 msec | 800 msec |

R302 — \$44.00

Large electrolytic capacitors can have internal leakage enough to substantially modify time delay. For best results, use wet-slug tantalum electrolytics for delays of several seconds or more. Four volt ratings are adequate in most cases, but 6 or 8 volt ratings may be desirable to further reduce leakage in some cases.

Remote Control Wiring: Noise picked up on wires leading to remote timing capacitors or rheostats tends to synchronize the end of the delay period (or it could cause false triggering in extreme cases). Even for 1 ft control wires, a grounded shield may be advisable if smooth control and freedom from jitter are essential.

INPUT: Level — Standard levels of -3v and ground. A DCD gate is enabled by ground level and disabled by a -3v level. The conditioning level must be

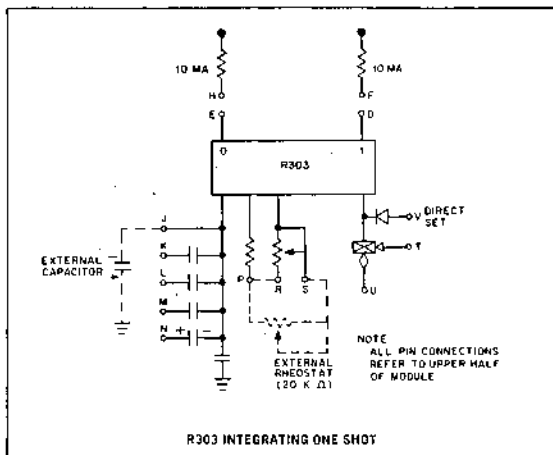
present for at least 400 nsec before the gate is pulsed. The level input represents 2 ma of load at ground. **Pulse** — Standard 100-nsec pulses (-3v to ground). It can also be driven by positive-going level changes (-3v to ground) with rise times of 60 nsec max and duration of 100 nsec min. Prior to operation the input must have been at -3v for at least 400 nsec. The pulse input represents 3 ma of load at ground. The delay cannot be set from its output terminal.

OUTPUT: Standard Level of -3v for the duration of the delay time. The output can drive 18 ma of external load at ground. The internal load is 2 ma.

POWER: $+10\text{ v(A)}/0.6\text{ ma}$; $-15\text{ v(B)}/88\text{ ma}$.

INTEGRATING ONE SHOT TYPE R303

R SERIES



The R303 contains a zero recovery time multivibrator and complementary output buffers. Its unusual characteristics include the ability to respond to inputs even while in the ONE state, so that successive inputs above a preset frequency can postpone the return to ZERO indefinitely. This characteristic can be used, for example, to detect gaps in an otherwise continuous pulse train, or to determine whether an input pulse rate is above or below a preset frequency threshold. The module can also be used to establish initial conditions after system power is interrupted, since it always goes to the ONE state when the power is first applied.

Delay is 3.5 microseconds to 0.9 second. Jitter is less than 1.4% peak-to-peak. Precision: Delay time will change less than 2% for a change of 20% in supply voltage.

INPUTS: Direct Set — A standard 100 nsec pulse or a ground level of at least 100 nsec duration starts the delay. The load at ground is 1 ma. At least 90% to 99.5% of total delay (for 0 and 20 kilohm rheostat setting, respectively) will not be measured out until $-3v$ is restored, a fact which may be important if this input is grounded for longer than 300 nsec.
DCD Gate — Same as R302.

OUTPUTS: Each output can drive 18 ma at ground, 0 ma at $-3v$. Extra 10 ma clamped loads may be connected to change the driving capability at each output to 8 ma at ground, 7 ma at $-3v$. The ONE output will be at $-3v$ during the delay period and ground otherwise. The ZERO output is grounded during the delay period and $-3v$ otherwise.

POWER: + 10v(A)/6 ma; $-15v/75$ ma.

CONTROLS: To choose desired range of delay, ground the appropriate capacitor pin K through N (for minimum delay range, ground none of these). Ranges are separated by approximately a factor of ten. For extra long delays, connect an external capacitor from pin J to ground. To use the internal rheostat, connect pin P to pin R. For external control, connect a variable resistance no larger than 20,000 ohms from pin P to pin S.

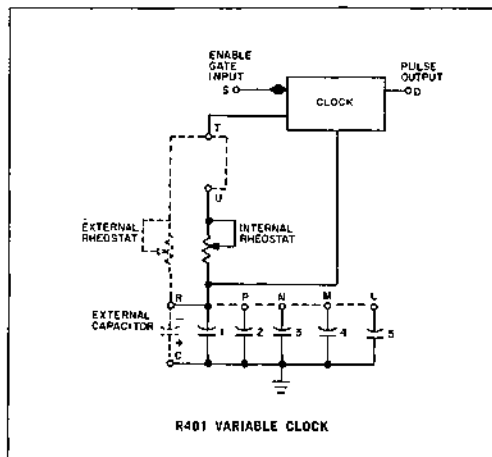
EXTERNAL CONTROL: Delay times may be controlled by external R and C in the same manner as described for R302. Substantially the same R and C are required in the R303 as in the R302 for a given delay, taking into account the ten times larger minimum capacitance built into the R303. If electrolytic capacitors are used, at least a 6-volt rating is required.

Capacitor Values (MFD): Internal — 0.0022, Pin K — 0.027, Pin L — 0.39, Pin M — 3.9, Pin N — 39.0.

R303 — \$45.00

VARIABLE CLOCK TYPE R401

R SERIES



The R401 Variable Clock is a gateable clock that produces standard 100-nsec pulses from a stable RC-coupled oscillator. The variable clock is often used as a primary source of timing for large systems.

The frequency of the R401 Clock is variable from 30 cps to 2.0 mc. Five capacitors provide coarse frequency control, and a built-in 20,000-ohm potentiometer permits fine adjustment. Terminals for an external potentiometer or capacitor are available. The maximum size of the external potentiometer to be used is 20,000 ohms.

FREQUENCY SELECTION

| | | |
|--------------|---------------------------|-------------------|
| Select Pin R | $C_1 = 82 \text{ pf}$ | 300 kc to 2.0 mc |
| Pin P | $C_2 = 1200 \text{ pf}$ | 30 kc to 375 kc |
| Pin N | $C_3 = 0.015 \text{ MFD}$ | 3.5 kc to 40 kc |
| Pin M | $C_4 = 0.15 \text{ MFD}$ | 300 cps to 4.5 kc |
| Pin L | $C_5 = 2.2 \text{ MFD}$ | 30 cps to 340 cps |

Lower frequencies may be obtained by adding an external capacitor between pins R and C. A 20%

change in power supply voltage will change the prf less than 1%. The pulse-to-pulse jitter is less than 0.2%.

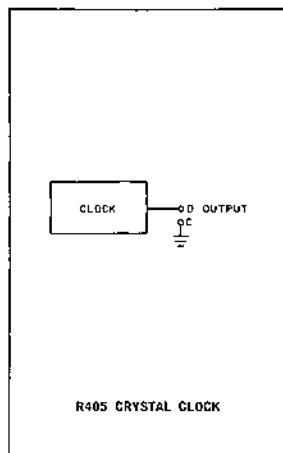
INPUT: The clock is enabled by a -3 v level or an open circuit at its enable gate input. The total transition time from the time the gate is enabled until the first pulse reaches 90% of its amplitude is approximately 45 nsec. The pulses that follow appear at the frequency selected. The clock may be disabled by applying a ground level at the enable gate pin 5. The enable gate loading is 4 ma at ground. Disable duration must exceed the period to which the clock is set.

OUTPUT: The output is a standard 100 nsec pulse, -3 v to ground. The output can drive 70 ma of external load at ground. The internal load is 3 ma.

POWER: $+10 \text{ v(A)}/1.3 \text{ ma}$; $-15 \text{ v(B)}/19 \text{ ma}$.

CRYSTAL CLOCK TYPE R405

R
SERIES



The Type R405 employs a series resonant crystal oscillator, squaring circuit, and output pulse amplifier. The crystal clock's output frequency remains within 0.01% of specified value between 0°C and +55° C. The clock frequency is specified anywhere in the 5 kc to 2 mc range by the customer

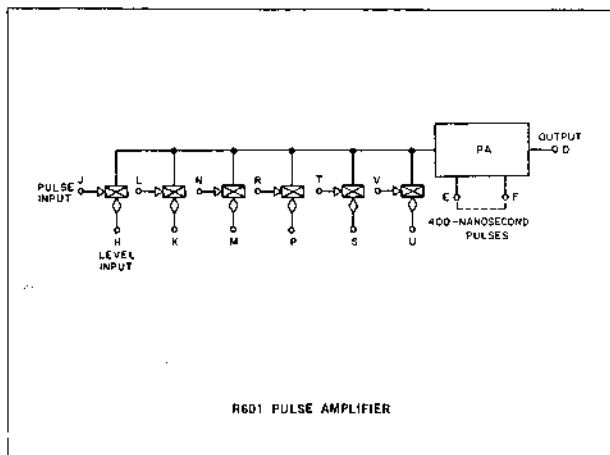
and is stamped on the crystal can.

OUTPUT: 100-nsec pulse, -3v to ground. The output can drive 70 ma of external load at ground. Internal load is 3 ma.

POWER: +10 v(A)/5.4 ma; -15 v(B)/50 ma.

PULSE AMPLIFIER TYPE R601

R SERIES



The R601 is a pulse amplifier that standardizes pulses in amplitude and width. Outputs may be either standard 100- or 400-nsec pulses ($-3v$ to ground). It has six DCD gates so that inputs from as many as six sources may be mixed. Input pulses can occur at any frequency up to 2 mc for 100-nsec pulse outputs and up to 1 mc for 400-nsec outputs. Delay through the pulse amplifier is approximately 50 nsec.

DCD GATE INPUTS: Level — Standard levels of $-3v$ and ground. A DCD gate is enabled by a ground level and disabled by a $-3v$ level. The conditioning level must be present for at least 400 nsec before the gate is pulsed. The level input represents 2 ma of load at ground. Pulse — 40-nsec or longer pulses, $-3v$ to ground, at any frequency up to 2 mc. It can also be driven by positive-going level changes ($-3v$ to ground) with rise times of 60 nsec max, and dura-

tion of 40 nsec min. The input must have been at $-3v$ for at least 400 nsec prior to operation of any input. The pulse input represents 3 ma of load at ground.

OUTPUT: With terminals E and F connected together, the output is a standard 400-nsec pulse ($-3v$ to ground). With E and F open, the output is a standard 100-nsec pulse, $-3v$ to ground. The output (for either 100- or 400-nsec pulses) can drive 70 ma of external load at ground. The internal load is 3 ma.

Pulse amplifier outputs may be paralleled for a logical OR.

Pulse lines and ground lines should be kept as short as possible.

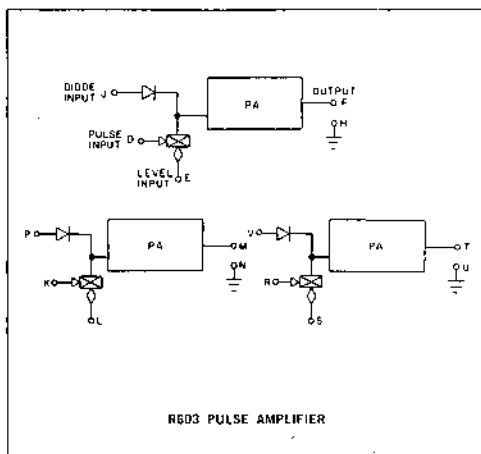
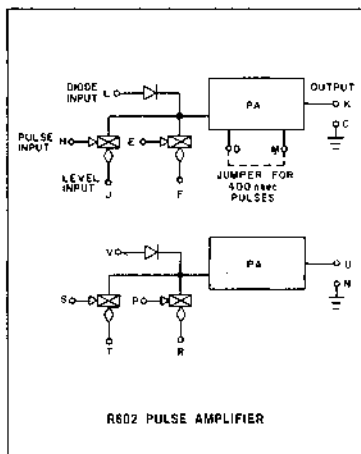
POWER: $+10 v(A)/1.1$ ma; $-15 v(B)/33$ ma.

PULSE AMPLIFIERS

TYPES R602, R603

R

SERIES



The R602 and R603 contain pulse amplifiers for power amplification and for standardizing pulses in amplitude and width. Each amplifier produces standard 100-nsec pulses and one section of the R602 can also produce 400 nsec pulses. DCD gates and a single diode input permit inputs from many sources to be mixed. Input pulses can occur at any frequency up to 2 mc for 100 nsec pulses, and up to 1 mc for 400 nsec pulses. Delay through the pulse amplifier is approximately 50 nsec.

INPUTS: Level and Pulse — Same as R601. **Diode** — Standard 100-nsec pulses ($-3v$ to ground) or

positive-going level changes ($-3v$ to ground) with a rise time of 60 nsec max. The input level must be

returned to $-3v$ for at least 400 nsec before another input may occur at either the diode or the DCD gate input. The diode input represents a 1-ma load at ground.

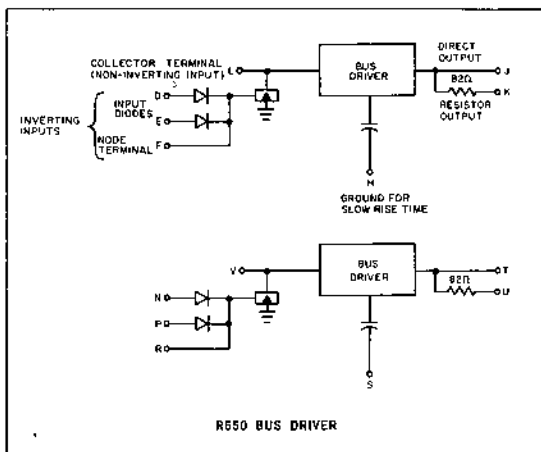
OUTPUTS: Outputs are standard 100 nsec pulse, $-3v$ to ground (except pin K of R602, which may be changed to 400 nsec pulses by connecting pin D to pin M). Each output can drive up to 70 ma load at ground. The internal load is 3 ma. Pulse amplifier outputs may be paralleled to obtain a logical OR. Pulse lines and grounds should be kept as short as possible.

POWER: R602: +10 v(A)/2.2 ma; -15 v(B)/45 ma.
R603: +10 v(A)/3.3 ma; -15 v(B)/57 ma.

R602 — \$22.00
 R603 — \$28.00

BUS DRIVER TYPE R650

R SERIES



The R650 contains two inverting bus drivers for driving heavy current loads to either ground or negative voltages. The four input terminals make the R650 a versatile logic element as well. The diode inputs D and E (N and P) are the principal inputs. They form a NAND gate for negative inputs or a NOR gate for ground inputs. Gate inputs, such as the R001 or R002, can be added through the node terminal F (R). Other gating sources may be mixed with the gate inputs by using collector terminal L (V).

The bus drivers operate at frequencies up to 2 mc with typical rise and fall times of 25 nsec. The typical total transition times are 60 nsec for output rise and 65 nsec for output fall.

By grounding pin H (S) the rise and fall time can be increased to avoid ringing on exceptionally long lines. The driver then operates at frequencies up to 500 kc with typical rise delay of 50 nsec, fall delay of 50 nsec, and total transition time of 800 nsec for

output rise and 700 nsec for output fall. Terminal K (U) can be used for driving coaxial cable.

INPUT: Standard levels at frequencies up to 2 mc (up to 500 kc with H or S grounded). The diode inputs, including any diodes attached to the node terminal, represent 1 ma of load, shared by all grounded inputs. Collector terminal L (V) represents 10 ma of load at ground. External clamped loads should not be connected to this terminal. The combined length of all leads attached to the node terminal should not exceed 6 in. The combined length of all leads attached to the collector terminal should not exceed 18 in.

OUTPUT: Direct— Standard levels. The output can drive 20 ma of external load at either ground or -3v . **Resistor**— Standard levels. The resistor output drives 90-ohm coaxial cable such as RG-62-U. The output can drive 5 ma of external load at either ground or -3v .

POWER: $+10\text{ v(A)}/50\text{ ma}$; $-15\text{ v(B)}/81\text{ ma}$.

B SERIES



B-SERIES BASIC CIRCUITS

INTRODUCTION

B-series FLIP CHIP modules operate at frequencies from dc to 10 mc. They are electrically and mechanically compatible with all other FLIP CHIP modules, including the W-series accessories described in the previous section.

The B-series circuits described below are somewhat different from the R-series circuits described in earlier sections of this catalog.

The Transistor Inverter

Many logical operations with B-series modules are performed with saturating PNP transistor inverters. When a transistor is turned completely on or saturated, the collector is practically a short circuit to the emitter of the transistor. If the emitter is at ground in this condition, the output from the collector will also be at ground.

When a transistor is turned completely off (opened) the collector-to-emitter path is practically an open circuit. If the collector is connected to a clamped load resistor, the collector will be at -3 v.

Figure 1 depicts a B-series inverter and clamped load resistor. The capacitor shunting the input resistor provides overdriving current to the transistor during input level changes, thus switching the transistor much more rapidly. The load resistor is clamped at -3 v with a diode so that when the transistor is off, the output signal is always at -3 v, regardless of the loading on the inverter output.

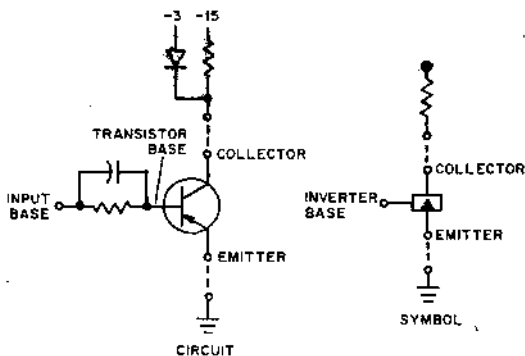


Figure 1 Inverter Circuit and Symbol

To simplify logic drawings, symbols are used, as shown on the righthand side of Figure 1. When the input is negative, the output is shorted to ground. When the input is at ground, the transistor is open-circuited and the output, if connected to a clamped load resistor, is at -3 v.

The inverter switch is analogous to the mechanical switch, as shown in Figure 2. The logical designer can often build networks of inverters in the same manner as he would if he were using mechanical relays or simple switches.

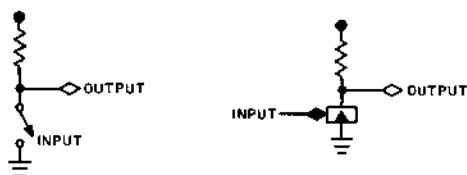


Figure 2 Switch-Inverter Analogy

Figure 3 shows two switches connected in series to form a NAND circuit. Mechanical switches A and B must be closed in order to ground the output. Similarly, in the series inverter network, transistor inputs A and B must be negative in order to short the output to ground. If either input is ground, that transistor will be an open circuit, and the output will be -3 v. Therefore, the network also acts as a NOR circuit for ground levels.

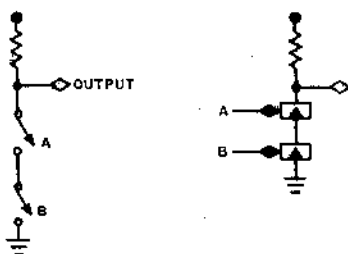


Figure 3 Series Circuit

A similar analogy can be made with a parallel circuit, as shown in Figure 4. If any of the switches close, the output will be shorted to ground. If A or B or C is negative, the output will be shorted to ground. Only if all inputs are at ground will the network output be negative. The parallel arrangement is a NOR gate for negative levels and a NAND gate for ground levels.

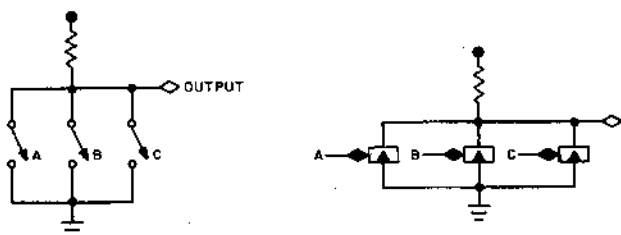


Figure 4 Parallel Circuit

Inverters can be stacked in complicated series-parallel combinations, like that of Figure 5, to perform sophisticated logical operations. There are some rules, however, since the inverters are not quite ideal switches. These rules are discussed under "Special Instructions for B-series Logic Design."

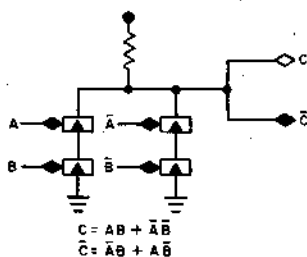


Figure 5 Series-Parallel Circuit

Diode Logic

All logical systems could be constructed with only parallel and series combinations of transistors in inverter networks. However, as the number of inputs to a particular gate increases, it becomes more economical to perform the gating action with diode gates. The outputs of diode gates, which are permanently connected to a transistor inverter, have the reference level re-established after every gate. Thus, such diode gates may be connected in tandem indefinitely.

The circuit in Figure 6 illustrates a diode gate which can serve as a NAND gate for negative signals and a NOR gate for ground signals. When both input pin A and input pin B are negative, the current in the resistor to -15 v will overwhelm the small positive bias and turn on the transistor, bringing the collector to ground. When either input A or input B is held at ground, the positive bias on the base assures that the transistor will be cut off and that the collector of the inverter will be at a negative voltage. If either pin A or pin B is not connected, the circuit will act as a simple inverter. These diode gates have the same circuit geometry as R series gates.

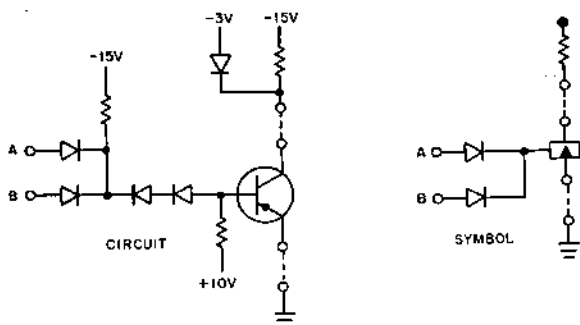


Figure 6 Diode Gate

Unbuffered Flip-Flops

If two grounded inverters are interconnected as shown in Figure 7, a bistable flip-flop is obtained, whose symbol is shown on the right. When one side is cut off, its output is negative. This condition holds the other side on, which, in turn, holds the first side off.

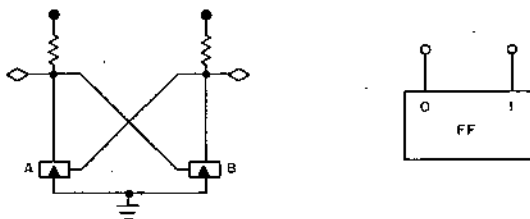


Figure 7 Flip-Flop

If a grounded inverter, C, is connected to the off side, A, of the flip-flop in Figure 8, the state of the flip-flop can be changed by pulsing the base of transistor C with a negative signal. This extra transistor will short the collector of transistor A to ground and will cut off transistor B, which will turn on transistor A. The flip-flop will then stay in that state even after the signal is removed from C.

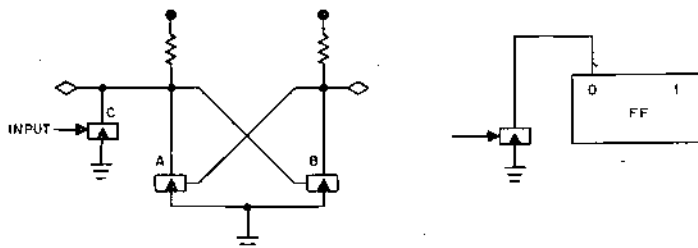


Figure 8 Setting A Flip-Flop

The flip-flop is said to be in the 0 state when the 0 output terminal is at -3 v and the 1 output terminal is at ground. It is in the 1 state if the 1 output terminal is at -3 v and the 0 output terminal is at ground.

A flip-flop input can be gated as shown in Figure 9. If the level input is negative when the pulse arrives, the flip-flop will be set. If the level input is at ground, the flip-flop will not be set. Negative pulses may be used in this way only if they are at least 70 nsec wide. To set or clear B series unbuffered flip-flops with 40 nsec pulses, a single inverter must be used, as in Figure 8. On any inverter or diode gate connected to a flip-flop output, the emitter terminal must be tied directly to ground. It must not be gated.

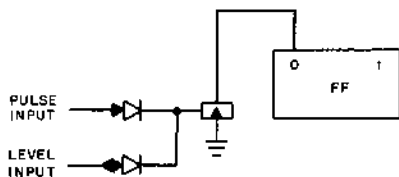


Figure 9 Gated Setting of a Flip-Flop

Buffered Flip-Flops

In logic configurations described near the beginning of this catalog for R-series FLIP CHIP modules, a diode-capacitor-diode (DCD) gate is always used to read into a flip-flop if the conditioning level is changing. The delay in the DCD gate allows the gate to be sampled while its conditioning level is changing.

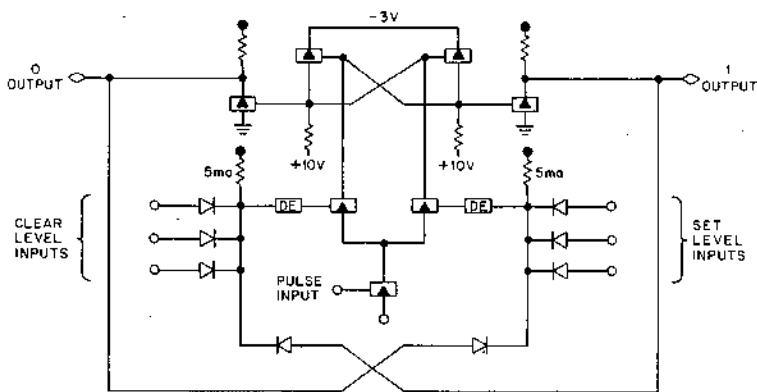


Figure 10 B200 Buffered Flip-Flop

A similar principle is used in one type of 10 mc flip-flop. At the higher frequency, however, the implementation of gate delay has to be modified to avoid excessive loading. Figure 10 shows how the B200 general-purpose 10 mc flip-flop is arranged, with two diode gates controlling the delayed inputs.

The connection from each output to the opposite input gate makes the level inputs conditional. This means that if both set and clear inputs are at $-3v$ together, the flip-flop will be complemented by a pulse input. Flip-flops with this characteristic are sometimes called "JK" flip-flops. All complementing FLIP CHIP flip-flops are "JK" flip-flops.

In addition to conditional inputs, direct set and direct clear inputs are provided. The direct set input of the B200 permits read-in from several sources, as shown in Figure 11. The direct clear input allows a negative 40 nsec pulse to clear several flip-flops simultaneously.

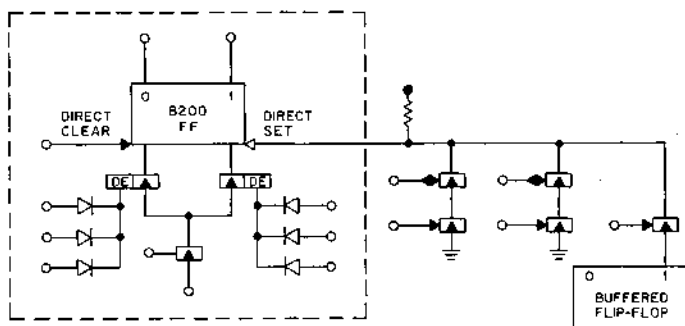


Figure 11 B200 Read-In

Since flip-flops with buffers have isolation between their outputs and the internal circuitry, their outputs can be used as the lower of two series inverters. One of the sources shown from which ONES are read in makes use of this property.

Some applications of 10 mc flip-flops would involve using the B200 input gates for two purposes. For example, it may be necessary to shift and count, or to receive a jam transfer and shift. If one flip-flop must do two such operations the B201 is called for.

The internal structure of the B201 flip-flop differs from that of the B200, to allow access directly at the flip-flop inputs themselves. While this permits gate expansion by ordinary 10 mc inverters, it also requires the addition of delay to the output buffers. The resulting arrangement still allows the flip-flop to be pulsed and sampled simultaneously.

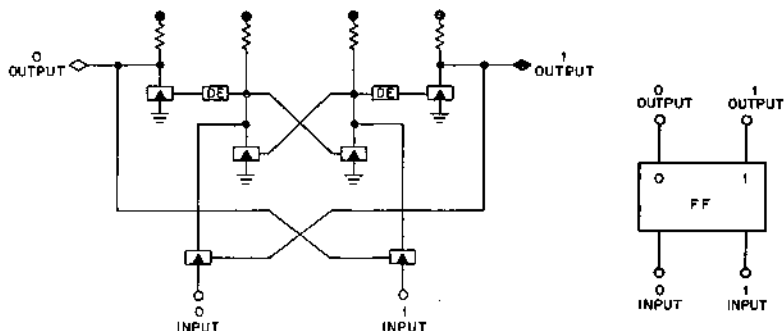


Figure 12 B201 Buffered Flip-Flop

The B201 flip-flop and the B620 carry pulse amplifier sometimes used with it are limited to two input inverters in series, and they require the upper inverter to be pulsed. In Figure 13, read-in configurations are shown using the normal 1 input, rather than the direct set input used for read-in on the B200.

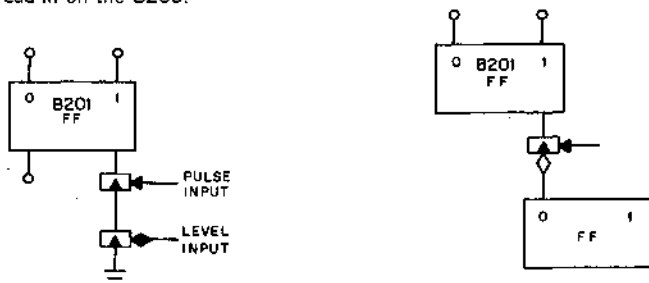


Figure 13 B201 Read-In

Pulse Amplifiers

Flip-flop action is usually initiated by pulses. These pulses may be generated within the system by a clock (see below) or brought in from an external source and standardized by a pulse amplifier.

The pulses which initiate the action in B series modules are 2.5 v volts in amplitude. In most cases they are negative-going with a positive overshoot similar in amplitude to the basic pulse. The duration of the pulse is 40 nsec.

Pulse amplifiers are powerful logical elements because they not only amplify and standardize the shape of the pulses but also gate pulses. When the same logical gating is to be done on a whole register of flip-flops, it can often be done once before the pulse amplifier which drives the register.

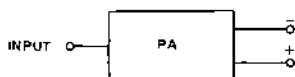


Figure 14 Pulse Amplifier

B602 pulse amplifier outputs are pulse transformers that are capable of driving many units of load. Normally both terminals of the transformer are available so that pulses may be transmitted over twisted pairs, with a ground connection at the receiving end only. Negative pulses are used for clearing, setting, and complementing through inverters.

Delays

The B301 Delay contains a flip-flop which has only one stable state. When the input terminal is shorted to ground by a pulsed inverter, the level output terminal will switch from the normal ground level to the -3 v level for a fixed period of time.

At the same time the level output returns to its normal ground condition, a standard pulse is produced at the pulse output terminals. Pulse outputs are transformer coupled and have both terminals available at the module connector, like a B602 Pulse Amplifier. The duration of the delay is adjustable with both coarse and fine controls. Typical wave forms for a delay unit are shown.

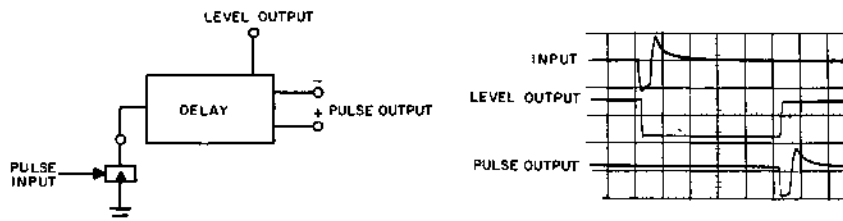


Figure 15 One-Shot Delay

The B301 requires a short amount of time to recover after the delay is over. For applications in which this recovery time is inconvenient, or where only a short delay is needed, the B360 Delay Line is also available. It accepts a pulse input or level transition input and produces a corresponding pulse output or level transition output a short time later. The pulse amplifier built into the module allows pulse timing chains to be built conveniently, as shown in Figure 16

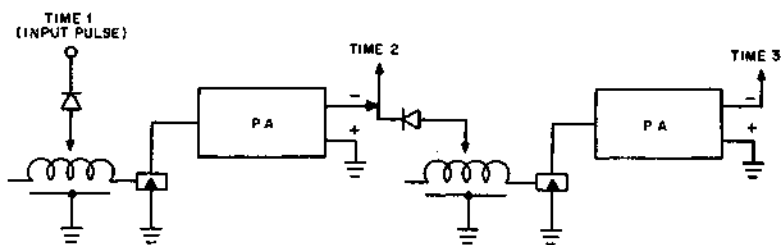


Figure 16 Delay Line Timing Chain

Clocks

If pulses are to be generated internally, a variable clock may be used. These units produce standard pulses from RC-coupled oscillators. The clocks have a coarse and fine control for setting the desired frequency up to the maximum of the speed line. If precise timing is required, crystal clocks which contain a single frequency crystal oscillator are available.

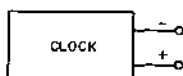


Figure 17 Clock

B-SERIES LOGIC CONFIGURATIONS

10 Mc Shift Registers

Figure 18 shows two shift registers, both equally capable of 10 mc operation. Aside from their use in serial-parallel converters, shift registers can be used as down-counters when fed back to form ring counters or switch-tail ring counters. This possibility takes on special importance at frequencies approaching 10 mc because loop delays can easily exceed 100 nsec in conventional binary counters modified to count at unusual radices.

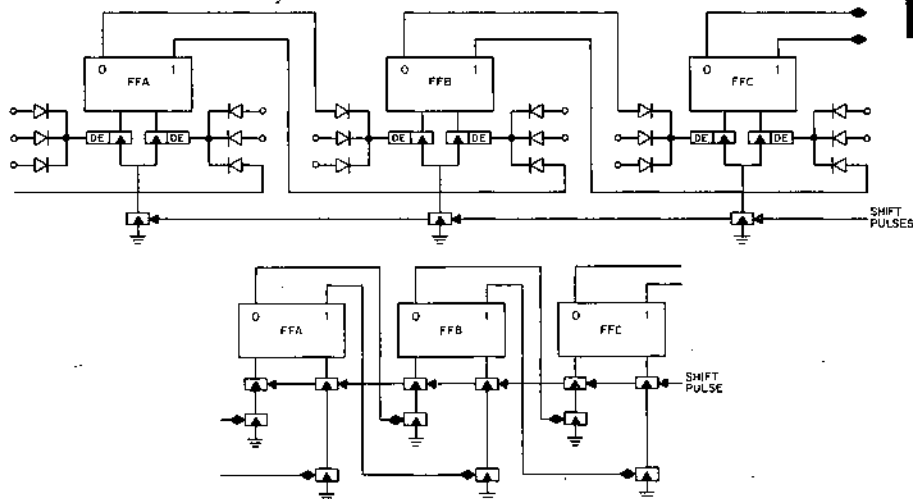


Figure 18 Two 10 Mc Shift Registers
(upper register: B200 Flip-Flops; lower register: B201 Flip-Flops)

The counter shown in Figure 19 forms the first three bits of a 10 mc scaler whose low-order stages are R series flip-flops such as type R202. This is the simplest 10 mc counter.

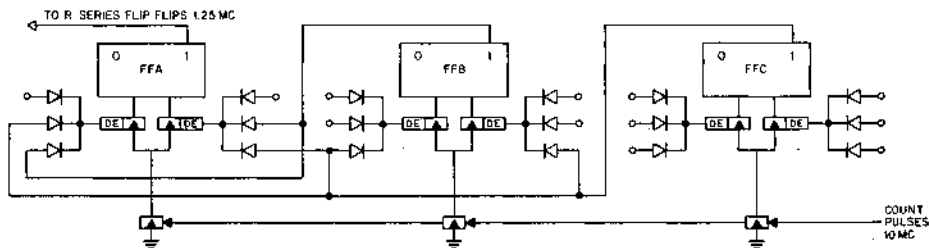


Figure 19 10 Mc Scaler
(B200 Flip-Flops)

Pulse-Carry 10 Mc Counter

Sometimes it is desirable to make each stage the same way in a long counter. The counter in Figure 20 uses one B201 and one-half of a B620 for each stage. The nine input inverters built into the B201 are not used in this application, and are therefore available for other operations such as shift, jam transfer, set, clear, or complement. The carry propagation delay in this counter will be about 10 nsec per bit.

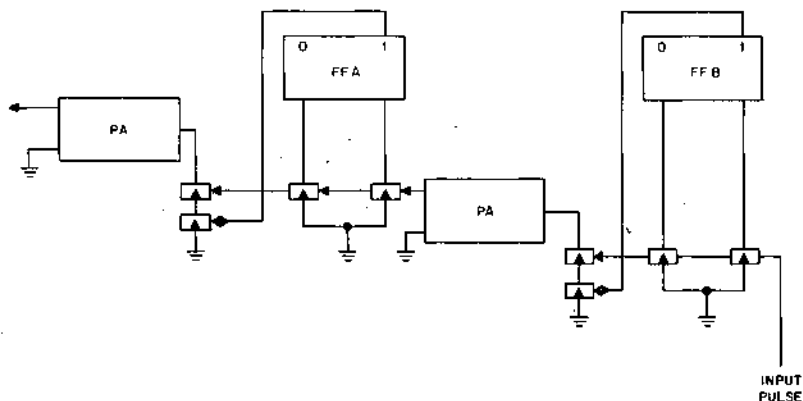


Figure 20 Fast-Carry 10 Mc Counter
(B201 Flip-Flops, B620 Pulse Amplifiers)

Counter with Simultaneous Transitions

Counters with simultaneous transitions are sometimes required for on-the-fly read-out or scanning applications. When the input pulse rate is low, the counter circuit of Figure 21 may be used. In this counter, a dc carry network is made with high speed diode gates and inverters. Immediately after an input pulse has been received, a dc carry begins to propagate from the least significant bit. When the carry is completely propagated, all of the gates will be set up so that the next input pulse can simultaneously jam all flip-flops to the proper state. Of course, it is important that input counts do not come in before the carry has propagated all the way down the counter.

In the counter illustrated, the set-up time must include the transition time of the flip-flop as well as the transition times of an inverter and diode gate for each group of three flip-flops except the last group. Thus, the time between input pulses must be at least as great as $50 + N(60 + 15)$, where N is the number of diode gates used for carry.

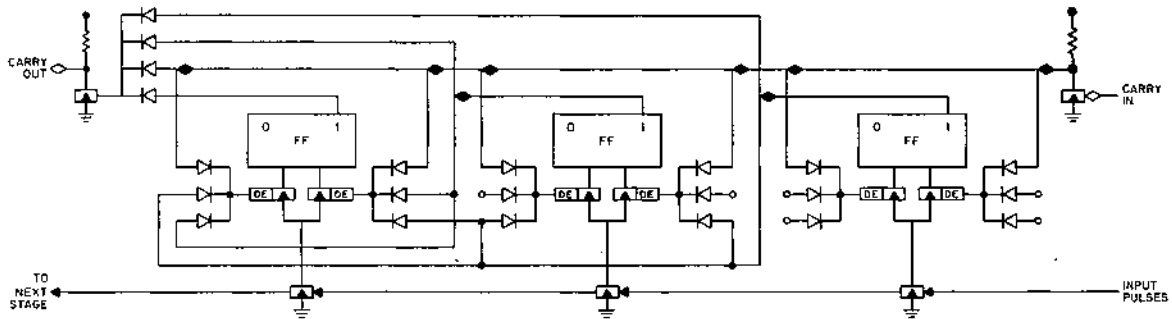


Figure 21 Counter With Simultaneous Transitions
(B200 Flip-Flops)

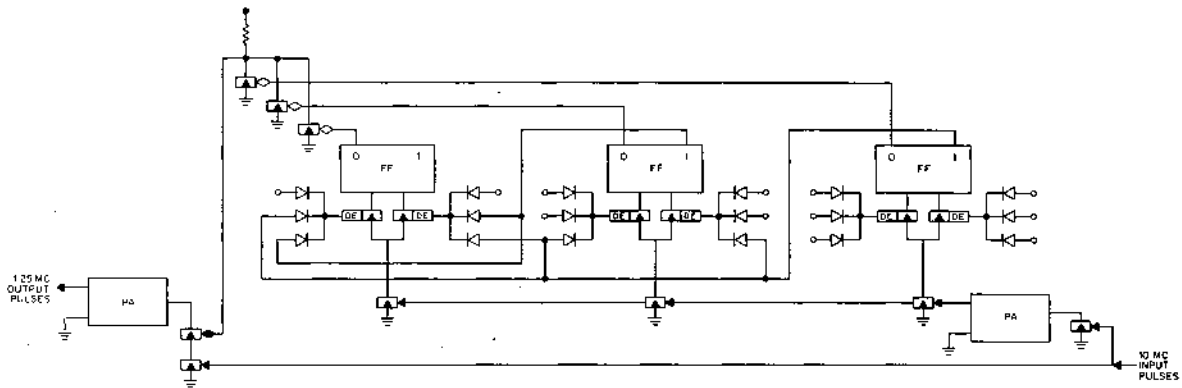


Figure 22 10 Mc Counter With Simultaneous Transitions
(B200 Flip-Flops, B602 Pulse Amplifiers)

Counters with Both High Input Rates and Simultaneous Transition

A sophisticated counter is required for high resolution of the time between fast input signals or for high speed scanning. When only a few states are needed, it is practical to use a ring counter or switch tail ring counter such as described in the R series Logic Configurations section at the beginning of this catalog. These two techniques are approximately equal in complexity. The ring counter has the advantage that it is already decoded to single line outputs. The switch tail ring counter has the advantage that it requires fewer flip-flops.

For high resolution counters, the techniques outlined in Figures 19 and 21 can be combined. The least significant bits should use the technique shown in Figure 19. If a pulse amplifier is at the input stage and another is added for carry pulses out, as shown in Figure 22, the delays of the two pulse amplifiers will approximately cancel each other. The lower frequency stages still need to have simultaneous transitions but the input is now only 1.25 mc. Thus, the method of Figure 21 can be used for later stages.

A 10-mc counter with a total of 15 stages can be made this way, and more if the 1.25 mc P.A. is duplicated. The time difference between the earliest and the latest flip-flop output transitions for any one input pulse will be simply the variation in delays of the flip-flops and pulse amplifiers, about 30 nsec or less.

Overflow Detector

The simplest, most common counters have non-simultaneous output as would be obtained with the counter of Figure 19 followed by R series flip-flops. Sometimes it is necessary to detect the all ones state and initiate action such as disconnecting the input source or setting an alarm flip-flop when this state is reached. The arrangement shown in Figure 23 can be used for this purpose. By treating the fastest bit of the counter separately, this system attains sufficient speed to allow input pulse rates up to 10 mc.

The first input to come to its final 1 state will be the most significant bit, which receives carry pulses after the greatest delay. After each of the other flip-flops comes to its final 1 state, eventually the first bit in the counter does so. This least significant flip-flop receives input pulses directly, without delay. The next input pulse, which clears the counter, also produces a pulse output from the overflow detector. This pulse can be used to clear a control flip-flop, cutting off pulses into the counter.

With proper regard for timing considerations it is possible to use a similar technique as the basis of counters and scalars for arbitrary numbers and ratios at high speeds.

Synchronizer

B-series FLIP CHIP modules form synchronizers in much the same way as R-series modules do. A start-stop synchronizer is shown in Figure 24. Notice that a B201 flip-flop must be used, since it is being sampled by an inverter gate rather than by a B200 delaying input gate.

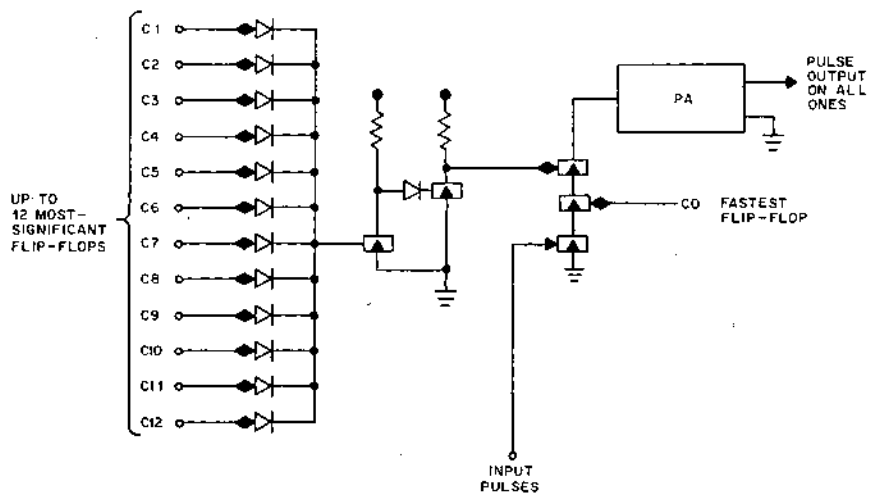


Figure 23 Overflow Detector
(B171 Diode Gate, B602 Pulse Amplifier)

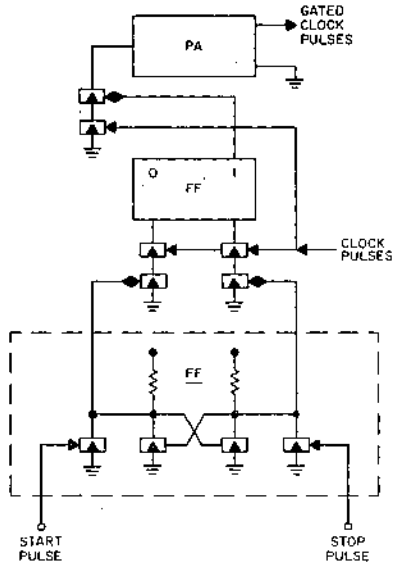


Figure 24 Synchronizer
(B201 Flip-Flop, B602 Pulse Amplifier)

Gateable Clock

Below is shown a method of producing a stable gateable clock from a B360 Delay Line and two external inverters. The clock is capable of operating at frequencies from 10 mc down to approximately 4 mc. The enabling level must be at -3 v for the duration of operation. Clock pulses are begun by a 40 nanosecond negative pulse at the "start" input. Lower frequencies may be obtained by inserting one or more additional B360 sections in the loop.

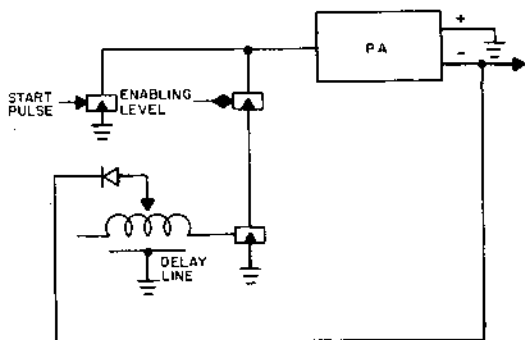


Figure 25 Gateable Clock
(B360 Delay Line)

SPECIAL INSTRUCTIONS FOR B SERIES LOGIC DESIGN

Inverter Usage

A maximum of two inverters may be put in series if the output is to drive another inverter (Figure 26). If a flip-flop output is driving an inverter emitter, this flip-flop must be counted as an inverter (Figure 27).

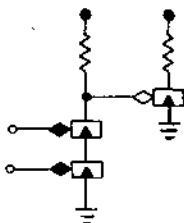


Figure 26 Level Gating

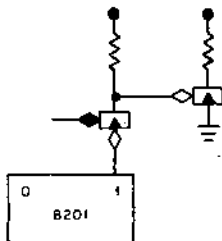


Figure 27 Flip-Flop Buffer as an Inverter

When the output of a series of transistor inverters is driving the input of a pulsed unit, as in Figure 28, an inverter pulse gate may be added in series with the two level gates. This pulsed inverter must be placed at the bottom of the series string; i.e., the end farthest from the load. The emitter may be driven by a flip-flop instead of being grounded as shown, replacing one of the inverters.

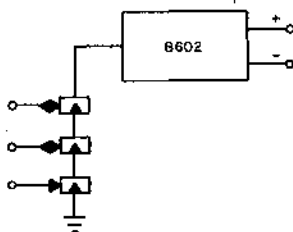


Figure 28 Pulse Gating

The Flip-Flop B201 is a special case. No more than two inverters in series may be used to drive the B201, and the inverter at the top must be pulsed with a standard 40-nsec pulse as shown in Figure 29. The same applies to the B620, which is used with the B201 for counting applications.

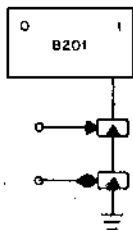


Figure 29 B201 Gating (B620 also)

The collector of an inverter driving an emitter in a network of transistors must also supply the base current leaving the inverters higher in the chain. This number is normally small, but in complex networks it must be considered.

An inverter can drive no more than one clamped load resistor and six bases of on-inverters. Since transistors are almost symmetrical, this on base current can also flow through the collector of a transistor whose emitter is open, as shown in Figure 30. In this case, the collector of the bottom on-transistor must carry the current A from the load resistor and the base currents from B, C, and D. Nominally, the current required is 10 ma to a negative voltage return; however, this is increased by the base current required.

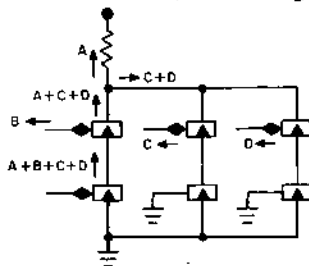


Figure 30 Loading

Because inverters are not really ideal switches, each collector of a series string of dc inverters supplying a pulse inverter will go somewhat negative during the pulse. This means that if a series of inverters is supplying both pulse current and a dc signal, care must be taken because a signal will occur in the dc output during the pulse.

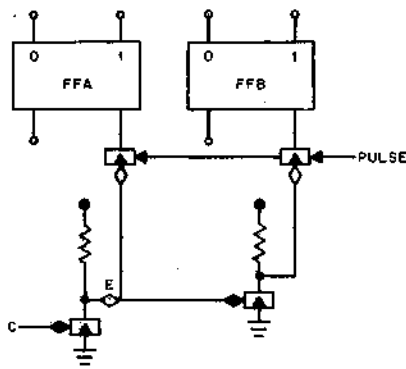


Figure 31 Illegal Inverter Use

In Figure 31, when the input C is negative, flip-flop A should be set by the pulse, but flip-flop B should not be set. However, during the pulse, collector E of the dc inverter feeding flip-flop A will go slightly negative. It will partly turn on the dc inverter feeding flip-flop B, and sometimes it will set flip-flop B as well as flip-flop A. This network will work only if the two pulsed inverters are driven by separate, non-simultaneous signals.

The total current path from the pulse gate emitter to ground (including the path through any level gate) should be as short as possible. The recommended maximum length is 6 in. If this path is closed to ground by a mechanical switch the lead length may be longer, provided a 0.001 to 0.01 μ f capacitor is connected from the emitter to ground to isolate the lead inductance. The switch should be single-pole, double-throw with one side to ground and the other to an unused clamped load.

Pulse transmission is optimized by using a twisted pair of wires, one grounded at the first load. Resonance effects may cause the pulse amplitude to increase, especially with heavy loads and long wires. A carbon damping resistor of about 100 ohms may be required at the receiving end to reduce the amplitude to 2.5 v. Lightly loaded pulses may be transmitted about 6 in. on a single wire.

Noise in Emitter Gating

The benefits in logic speed and simplicity obtained by the use of gated emitter logic can be lost if interconnections are not adequately planned. Figure 33 illustrates how a wire which is conditioning two pulsed inverter emitters can act as part of a resonant circuit. When one inverter is turned off, resonance may produce a positive pulse on the emitter of the other inverter, turning it on at the wrong time. To avoid this, each emitter must be driven by a separate wire, unless the total wire length is 4 in. or less.

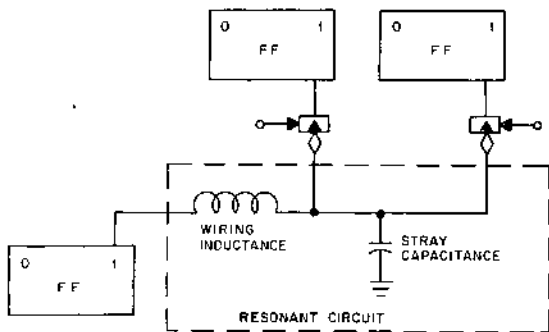


Figure 33 Effects of Wiring Reactances

Another consideration is shown in Figure 34. Here the hazard is that stray capacitance may provide an effective ground for the pulsed emitter, even though no logical path to ground is provided. To avoid trouble of this sort, a W002 or W005 clamped load should be connected to the gated emitter to discharge the stray capacitance if the total of such capacitance will exceed 35 pf (see data under "Fall Time" below). Not only flip-flops, but delays and pulse amplifiers too are susceptible to noise generated by these mechanisms.

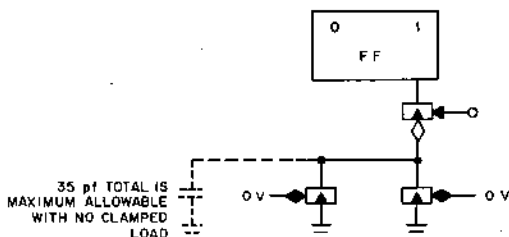


Figure 34 Stray Capacitance

Delay

On certain occasions a logical design requires a minimum delay around a loop. However none of the standard logic circuits except the B201 buffered flip-flop are built to maintain a minimum delay. Actually, efforts are regularly made to reduce inherent logic delays in existing circuits. Wherever a small logical delay is needed, a B360 Delay Line should be used.

Rise Time

B series modules are designed so that rise times (not including delay before rise) at any output will be at least as fast as fall times (not including delay before fall) at the same output, under most conditions. Thus an estimate of fall time is also an estimate of worst-case rise time, so that rise times need not be considered in design.

Fall Time

Slow fall times of logic levels sometimes may limit the repetition rate of systems made with B series modules to less than 10 mc. The diagram below shows how the fall time of a B series logic level can be estimated from a knowledge of the size of the clamped load and the total resistive and capacitive loading. Since a standard clamped load can drive up to 7 ma at -3 v, the fall time when a standard clamped load is doing the driving will be roughly half as many nsec as there are pf of capacitance to be driven. The calculation is given in Figure 35.

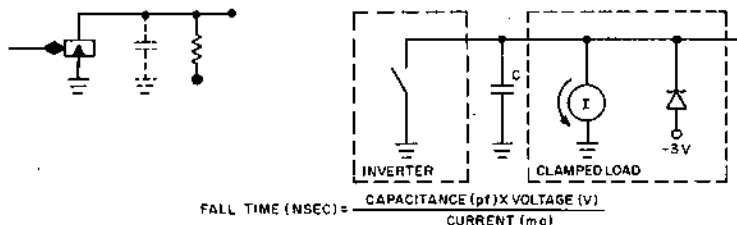


Figure 35 Calculation of Fall Time

This rule will predict fall times with adequate accuracy for many conditions, but as the number of inverter base inputs driven by the clamped load approaches the limit of seven, the predicted results become optimistic due to the static 1 ma drive absorbed by each inverter input. To restore accuracy to the calculation for heavy loading by inverter base inputs, the table below provides several bench marks for estimating.

FALL TIME FACTORS vs. INVERTER LOADING

| Clamped Load Drive Current Available at -3 v | Drive Current Absorbed by Static Loading at -3 v | Factor by Which Total Capacitance Should be Multiplied To Estimate Fall Time in Nsec |
|----------------------------------------------|--------------------------------------------------|--------------------------------------------------------------------------------------|
| 7 ma | 0 - 2 ma | 0.4 |
| | 4 ma | 0.5 |
| | 6 ma | 0.7 |
| 14 ma | 0 - 4 ma | 0.2 |
| | 8 ma | 0.25 |
| | 12 ma | 0.35 |

To obtain reliable predictions from this table, it is important to add together all the capacitances being driven by a given clamped load. Below is a summary of pertinent capacitances in B series modules:

Standard Inverters (B104, B105, B123, B124, B620)

- Base Input: 60 pf if either the emitter or collector is grounded.
4 pf if neither the emitter nor the collector is grounded.
- Emitter Input: 75 pf if the base is at -3 v.
8 pf if the base is at ground.
- Collector Output: 8 pf regardless of input conditions.

Diode Gates (B113, B115, B117, B130, B155, B171)

- Diode Inputs (except B155): 8 pf if any other diode input is grounded.
12 pf if no other diode input is grounded.
- Diode Inputs (B155 only): 20 pf at each of the six inputs, regardless of the conditions at the other five inputs.
- Emitter Input (B117 only): 8 pf regardless of diode input conditions.
- Emitter Input (B155 only): 20 pf regardless of diode input conditions.
- Collector Outputs: 8 pf regardless of input conditions, except pin D of B171: 12 pf.
- Emitter Outputs (B130 only): 8 pf regardless of input conditions.

Buffered Flip-Flops (B200, B201)

| | |
|-----------------------------|-------------------------------------------------------------------------------------------------------------|
| Inverter Base Inputs: | 60 pf for inverters with emitters grounded. |
| Input Inverter Collectors: | 8 pf each. |
| Buffered Flip-Flop Outputs: | 8 pf each. Estimate output fall times on the basis of 7 ma available drive at -3v for B200, 14 ma for B201. |

Unbuffered Flip-Flops (B204 or other flip-flops constructed from two B105-type inverters)

| | |
|--------------------|-------------|
| Flip-Flop Outputs: | 68 pf each. |
|--------------------|-------------|

Pulse Amplifiers (B602)

| | |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pulse Amplifier Input: | 8 pf. Estimate input fall time on the basis of 7 ma available drive at -3 v when calculation is necessary to assure 50 nsec dwell before going to ground. |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|

Power Inverters (B681)

| | |
|-------------------|---------|
| Base Input: | 100 pf. |
| Collector Output: | 12 pf. |

Bus Drivers (B684)

| | |
|--------|-------|
| Input: | 8 pf. |
|--------|-------|

Clamped Load (W002, W005, or any 10-ma standard clamped load with its own pin connection)

| | |
|--------------------|-------|
| Each Clamped Load: | 8 pf. |
|--------------------|-------|

Hookup Wire

| | |
|------------------------------------------------------------------------|-----------------|
| Single Wire: | 1 pf per inch. |
| Twisted pair with one wire grounded, or single wire in a loose bundle: | 1½ pf per inch. |
| Single wire or twisted pair, in laced cable: | 2 pf per inch. |

Example: Calculate the maximum number of inverter collectors at a B602 input for 10 mc operation.

| | |
|-------------------------|----------|
| Pulse-to-pulse interval | 100 nsec |
| Dwell required at $-3v$ | 50 nsec |
| Input pulse width | 40 nsec |
| Time left for fall | 10 nsec |

Factor by which capacitance should be multiplied to obtain fall time (from table): 0.4

Total allowable capacitance: $10/0.4 = 25$ pf

Number of 8 pf connections: $25/8 = 3 +$

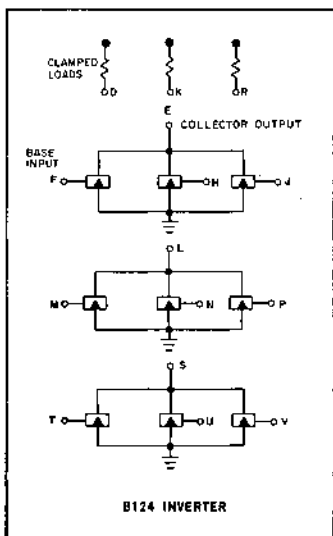
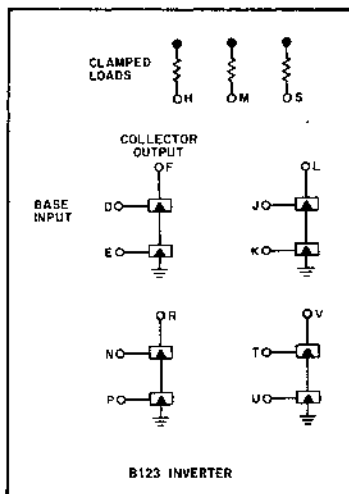
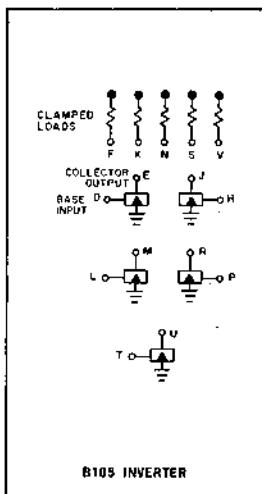
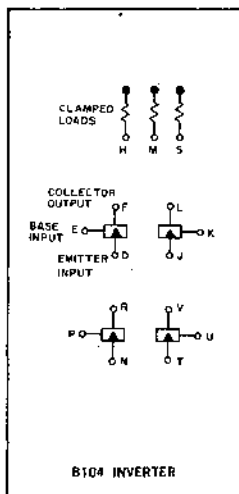
Thus in addition to the input capacitance of the P.A. itself, 2 inverter collectors may be connected.

INVERTERS

TYPES B104, B105, B123, B124

B

SERIES



The B104 contains three standard 10-ma clamped loads and four transistor inverters, each with its base, emitter, and collector brought to connector pins.

The B105 has five standard 10-ma clamped loads and five transistor inverters, each with emitter grounded, and with each base and collector brought out.

The B123 has three standard 10-ma clamped loads and eight transistor inverters. The inverters are tied together in series groups of two.

The B124 has three standard 10-ma clamped loads and nine transistor inverters, each with emitter grounded, and with each base and collector brought to terminals. The collectors are tied together in groups of three.

Each inverter is analogous to a switch. If the inverter base is at -3 v and the inverter emitter is at ground, the transistor is saturated and a conducting path is established between the emitter and collector of the inverter. If the base is at ground, or if

both base and emitter are at -3 v, the emitter-collector path is open circuited (i.e., will not allow current to flow).

Delay through the inverter is approximately 12 nsec for lightly loaded inverters driven by a pulse.

INPUT: inverter-Base — Whenever the base input is at -3 v and the emitter input is at ground, the static input load is 1 ma. In any other case (i.e., emitter at -3 v or both base and emitter at ground) there is no static load. The base can reject 0.5 v of noise. **Pulse** — Pulse inputs are standard 40-nsec pulses at any frequency up to 10 mc. (Pulses of longer duration may also be used.) **Level** — Level inputs are standard levels of ground and -3 v. **Emitter** — An inverter whose base input is at -3 v will saturate if its emitter is brought to ground by any conducting path. The circuit that establishes this path (another inverter, flip-flop, direct connection to ground, etc.) will be loaded with whatever external load may be present at the inverter collector, plus the internal load of 1 ma. If the base is at ground or both base and emitter are at -3 v, there will be no static load. **Clamped**

Load — Each clamped load draws 10 ma from any circuit that brings it to ground.

OUTPUT: Inverter — The maximum output driving capability at ground is 16 ma. This current is available if the emitter is connected directly to ground (as is always the case with the B105 and B124). If the emitter is not directly grounded, the maximum output load is 1 ma less than the maximum input available to the emitter. A 10-ma clamped load attached to the output (collector) will provide a maximum output driving capability at -3 v of 7 ma. **Clamped Load** — Each clamped load can supply up to 7 ma at -3 v.

Note: The saturation voltage drop of the inverter places a limit on the number of inverters which may be connected in series. For more information see "Inverter Usage."

POWER: B104: $+10$ v(A)/0 ma; -15 v(B)/38 ma.
B105: $+10$ v(A)/0 ma; -15 v(B)/58 ma.
B123: $+10$ v(A)/0 ma; -15 v(B)/38 ma.
B124: $+10$ v(A)/0 ma; -15 v(B)/38 ma.

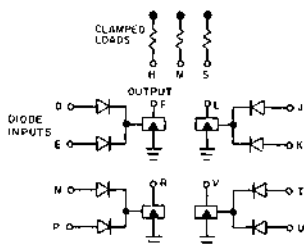
| | | |
|------|---|---------|
| B104 | — | \$17.00 |
| B105 | — | \$21.00 |
| B123 | — | \$31.00 |
| B124 | — | \$31.00 |

NAND/NOR GATES

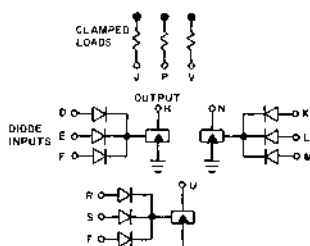
TYPES B113, B115, B117, B171

B

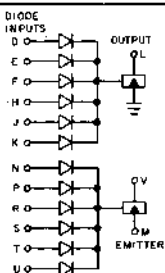
SERIES



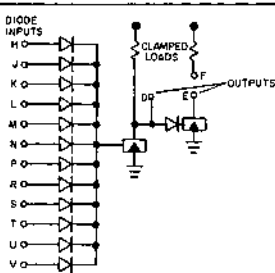
B113 NAND/NOR GATE



B115 NAND/NOR GATE



B117 NAND/NOR GATE



B171 NAND/NOR GATE

The B113, B115, B117, and B171 are positive NOR diode gates; they form NOR gates for ground inputs and NAND gates for -3 v inputs. The outputs of the diode gates drive inverters similar to the B105, for power amplification. The typical total transition time is 40 nsec for output fall and 60 nsec for output rise. (Because the rise and fall delays differ, these diode gates may shorten negative input pulses markedly; see below.)

The B113 provides three standard 10-ma clamped loads and four diode gates, each with two diode inputs and the collector brought out.

The B115 has three standard 10-ma clamped loads

and three diode gates, each with three diode inputs and the collector brought out.

The B117 has two diode gates, each with six diode inputs and the collector brought out. In addition, the emitter of one of the inverters is available.

The B171 is a single gate with twelve diode inputs. In addition to the positive NOR output, another inverter has been added at the output; using the inverted output makes the B171 an OR gate for ground inputs and an AND gate for -3 v inputs.

INPUT: Diode Inputs—The static load is $1\frac{1}{4}$ ma, shared by all inputs which are at ground. **Pulse**—Standard 70-nsec negative input pulses may be used for setting or clearing flip-flops only. Due to

pulse shortening by the gate, 40-nsec negative pulses may not be used as inputs. **Level**—Level inputs are standard levels of ground and -3 v. R series 100-nsec pulses must be regarded as levels when used with B series modules. **Emitter (B117 only)**—If all the base inputs are at -3 v, the B117 will saturate if its emitter is brought to ground by any conducting path. The circuit that establishes this path (another inverter, flip-flop, direct connection to ground, etc.) is loaded with whatever external load may be present at the inverter collector, plus the internal load of $1\frac{1}{4}$ ma. If the base is at ground (any 1 diode input at ground) or the base and emitter are at -3 v, there is no static load. **Clamped Load**—Each clamped load draws 10 ma from any circuit that brings it to ground.

OUTPUT: Collector Outputs—The collector outputs have a maximum output drive of 16 ma at ground. This current is available if the emitter is connected directly to ground. If the B117 emitter is not directly grounded, the maximum output load is $1\frac{1}{4}$ ma less than the maximum input available to the emitter. A 10-ma clamped load attached to the output (collector) drives 7 ma at -3 v. **B171 Only**—For the B171, terminal D drives 5 ma at ground and 7 ma at -3 v. Terminal E can drive 16 ma at ground. **Clamped Load**—Each clamped load can supply up to 7 ma at -3 v.

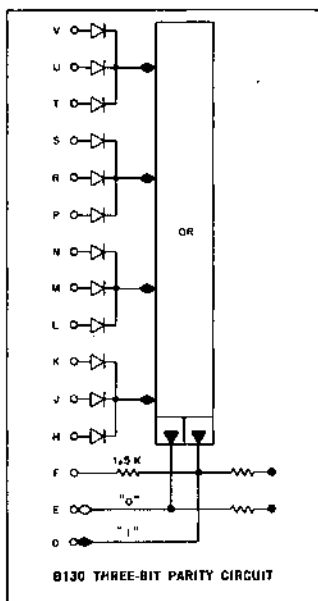
POWER: B113: $+10$ v(A)/0.7 ma; -15 v(B)/43 ma. **B115:** $+10$ v(A)/0.5 ma; -15 v(B)/42 ma. **B117:** $+10$ v(A)/0.3 ma; -15 v(B)/2.5 ma. **B171** $+10$ v(A)/0.3 ma; -15 v(B)/31 ma.

| | | |
|------|---|---------|
| B113 | — | \$23.00 |
| B115 | — | \$21.00 |
| B117 | — | \$14.00 |
| B171 | — | \$18.00 |

THREE-BIT PARITY CIRCUIT

TYPE B130

B
SERIES



This special logic module has two levels of high speed logic and complementary outputs. It is designed to compute the parity (odd or even) of the contents of a flip-flop register with a minimum of time delay, but it can be used wherever there is a need for four 3-input negative diode AND gates feeding a 4-input OR gate.

Delay is typically 15 nsec from 50% of the input transition to 50% of the output transitions when output capacitive loading is very small.

INPUT: Each of the gates has a 2-ma load shared among the ground inputs of that gate. When the

inputs are connected to compute parity, the total load on each of the input lines at ground is 2½ ma.

OUTPUT: Each of the complementary outputs can drive 10 ma at ground in addition to the built-in clamped load. The clamped loads each can drive 7 ma at -3 v. Due to the special nature of this circuit, inverter emitters may not be driven.

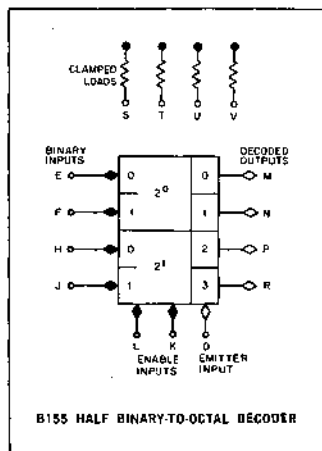
An indicator output is provided for applications where parity is to be displayed by an indicator-with-amplifier (4902, 4903) through an Indicator Connector Board W020.

POWER: +10 v(A)/49 ma; -15 v (B)/92 ma.

HALF BINARY-TO-OCTAL DECODER

TYPE B155

B
SERIES



TRUTH TABLE

| INPUTS | | | | | | OUTPUTS | | | | |
|--------|-----|-----|-----|-----|-----|---------|-----|-----|-----|-----|
| H | J | E | F | D | K | L | M | N | P | R |
| -3v | 0v | -3v | 0v | -3v | -3v | 0v | 0v | -3v | -3v | -3v |
| -3v | 0v | 0v | -3v | 0v | -3v | -3v | -3v | 0v | -3v | -3v |
| 0v | -3v | -3v | 0v | 0v | -3v | -3v | -3v | -3v | 0v | -3v |
| 0v | -3v | 0v | -3v | -3v | -3v | -3v | -3v | -3v | -3v | 0v |
| | | | | | | | | | | |
| | | | | | | 0v | | | | |
| | | | | | | | -3v | -3v | -3v | -3v |
| -3v | -3v | 0v | -3v | 0v | -3v | -3v | -3v | 0v | -3v | 0v |
| -3v | -3v | -3v | 0v | 0v | -3v | -3v | 0v | -3v | 0v | -3v |
| 0v | -3v | -3v | -3v | 0v | -3v | -3v | -3v | -3v | 0v | 0v |
| -3v | 0v | -3v | -3v | 0v | -3v | -3v | 0v | 0v | -3v | -3v |

The B155 module is used alone as a 2-bit decoder with two enable inputs, or it is used with another B155 to form a full 3-bit (binary-to-octal) decoder, using one combined enable line. Either way, each binary input combination results in one selected output held at ground if the decoder is enabled. No output will be selected if an enable input is held at ground. The decoder consists of four 4-input diode gates with appropriate input interconnections. All of the output transistor emitters are connected to pin D, providing a third enabling point. Also included are four standard 10-ma clamped loads.

INPUT: Diode Inputs — The input load is $1\frac{1}{4}$ ma per negative output, shared among the grounded inputs. When the inputs are binary, as in the first 4 lines of the truth table, the current at ground is $2(1\frac{1}{4}) = 2$, or 2 ma. When a pair of B155s are connected as a binary-to-octal decoder the input load would be $7(1\frac{1}{4}) = 3$, or 3 ma per grounded input. When four B155s are connected as a sixteen-state decoder, the input load is $15(1\frac{1}{4}) = 4$, or $4\frac{3}{4}$ ma per grounded input. Similarly, the input load for the last 4 lines of the truth table is $3\frac{3}{4}$ ma for the grounded input. If the only grounded input is an enable input such as pin L or K, the load will be 5 ma.

Emitter Input — If both enable inputs are at -3v, one of the output transistors will saturate if the emitter input is brought to ground by any conducting

path. The circuit that establishes this path (an inverter, flip-flop, another diode gate, etc.) is loaded with whatever external load may be present at the selected output, plus the internal load of $1\frac{1}{4}$ ma.

Clamped Load — Each clamped load draws 10 ma from any circuit that brings it to ground.

When the two B155 modules are used together, each of the four binary inputs on one module is tied to the corresponding input on the other module and these four lines are driven by the least significant two bits. One enable input on each module is driven by the third bit so that only one of the two modules has an output selected. The second enable input allows four modules to be combined to form a 16-state decoder, and the emitter input allows further expansion to 32 states using 8 modules.

OUTPUT: Each decoder output can drive 16 ma at ground. Each clamped load can drive 7 ma at -3 v. If the emitter input is not directly grounded, the maximum output load is limited to $1\frac{1}{4}$ ma less than the maximum current available at the emitter input.

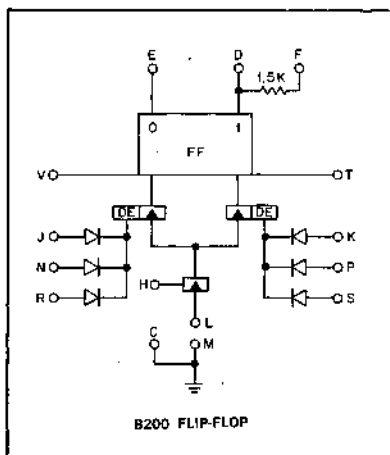
Note: Simultaneous switching of B155 outputs is not assured. If adjacent B155 outputs are ORed together, for example, the gate output may contain spikes.

POWER: +10(A)/0.6 ma; -15(B)/53 ma.

B155 — \$25.00

FLIP-FLOP TYPE B200

B SERIES



Most 10 mc registers can be built with B200 buffered flip-flops. The delay from pulse input to flip-flop output is short, suiting the B200 for unidirectional counting and shifting applications in which comparators are used to stop the action. Delayed level inputs are conditional, providing JK characteristics. Some typical operations the B200 can perform at 10 mc input rates are: gated shifting, parallel-serial conversion, jam transfer, and simultaneous-transition counting. Typical delay: 30 nsec. Typical output rise time: 35 nsec. See "B Series — Logic Configurations" for examples of B200 applications.

INPUTS: Pin V is a direct coupled clear input. Though it will force the zero output negative as long as it is held negative, its normal use is as a pulsed clear input. When driven from a 40 nsec pulse amplifier such as B602, pin V is equivalent to an inverter base input. If a clamped load used to bring it negative 2 milliamperes should be allotted to each pin V driven. Pin T is a direct coupled set input. Though it will force the one output negative as long as it is grounded, its normal use is as a pulsed preset. When used, pin T must be connected to an external clamped load; for 10 mc operation a 10 ma clamped load is required. This input requires the same drive as a 5 ma clamped load. Pulsewidth minimums are 40 nsec with inverters and 70 nsec with diode gates. Pins J, K, N, P, R, and S drive diode gates whose

outputs are delayed. The delayed gate outputs can be sampled by a 40 nsec pulse at pin H. Each gate is a 5 ma load shared among its grounded inputs including an internally connected input from the flip-flop output that makes it conditional. These diode inputs are normally driven by outputs from other B200 flip-flops sharing a common pulse source for pin H inputs. The internal delay is sufficient to permit full 10 mc operation connected this way, as long as fall time at gate inputs or flip-flop outputs does not overlap next input pulse at pin H. See table below. Pin H must be driven by negative 40 nsec pulses only. When pin H is pulsed, the flip-flop will respond to a "1" stored in either gate delay during the previous 100 nsec. Pin L is normally grounded to pin M. It is possible to use pin L as a gate for pin H inputs if no more than a 3 inch path to ground is provided by the gating inverter. Two inverters in series may not be used, but several parallel inverters may be used. This input constitutes a 15 milliampere load on the inverter (B104, B105, or B125) or buffered flip-flop (B201) that drives it.

OUTPUTS: 0 and 1 outputs — Each output can supply 16 ma at ground, or 7 ma at $-3v$. Each output is connected internally to one of the diode gate inputs. The 1 output (pin D) therefore shares a 5 ma gate load with any grounded inputs at pins J, N, or R. The 0 output (pin E) shares a 5 ma gate load

with any grounded inputs at pins K, P, or S. Thus in some cases flip-flop output driving ability may be reduced to as little as 11 ma at ground. At high frequencies fan-out from B200 outputs to 10 mc inverter bases is reduced. The table below gives some results from "Special Instruction for B Series Logic Design."

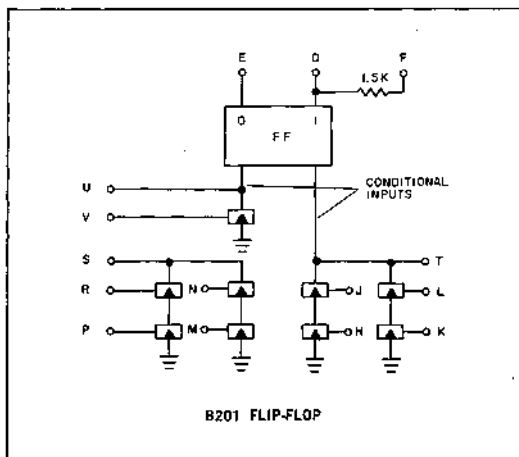
| B200 Flip-Flop Input Frequency | Maximum Inverter Base Inputs With Short Leads | Inverter Bases With Short Leads and 10 ma Clamped Load |
|--------------------------------|-----------------------------------------------|--------------------------------------------------------|
| 10 mc | 2 | 4 |
| 6 mc | 4 | 9 |
| 3 mc and below | 7 | 14 |

Indicator Output — a separate output at pin F drives a 4910 indicator through Connector Board W020 without loading the flip-flop output excessively with stray wiring capacitance. When used, this output reduces the 1 output drive by 1 ma when used with the W020, or by 2 ma when used to drive a 4910 indicator amplifier directly. Use direct outputs for driving W050 inputs.

POWER: -- 10v(A)/11 ma; - 15v(B)/45 ma.

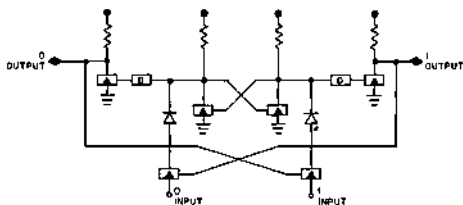
FLIP-FLOP TYPE B201

**B
SERIES**



Some 10 mc operations require a greater variety of pulse inputs than the B200 can provide. For example read in from several sources, bi-directional shifting, and arithmetic operations all require the greater flexibility of the B201.

In order to allow the outputs to be sampled by the same pulse that is changing the state of the internal flip-flop, the buffers include a controlled amount of delay. The diagram below shows the internal construction of the B201.



The B201 has nine built-in inverters for accomplishing such operations as set, clear, jam-transfer, shift, and complement without the need for additional gating. The B201 can also be used in counters. Logic diagrams for these operations are shown under "B Series Logic Configurations."

INPUT: All built-in inverters are similar to B104 and B105 circuits. Each conditional input is equivalent to a 15-ma clamped load. Counting internal and external inverter collectors as 8 pf each, not more than 40 pf capacitive loading is allowable at either input T or input U. Each input gate must consist either of one inverter, or of two series-connected inverters with the top inverter pulsed (see "Inverter Usage", page 99). If a level or pulse wider than 40 nsec is used to set or clear the flip-flop, 50 nsec must be allowed between the trailing edge of that signal and the leading edge of the next input that changes the state of the flip-flop. The B201 is complemented by simultaneously bringing both inputs to ground with pulse inverters (40-nsec pulses only). Since the inputs are conditioned by the state of the flip-flop, the total load is equivalent to one 15-ma clamped load.

OUTPUT: 0 and 1 Outputs — Each output can supply 16 ma at ground or 12 ma at -3 v. When the flip-flop input rate exceeds 3 mc, dynamic loading must be considered. The table below shows the maximum number of inverter bases that can be driven at selected frequencies, both with and without an extra 10 ma clamped load that increases drive at -3 volts while reducing to 6 ma the drive available at ground (See "Special Instructions for B series Logic Design" for more information about fall times and dynamic loading.)

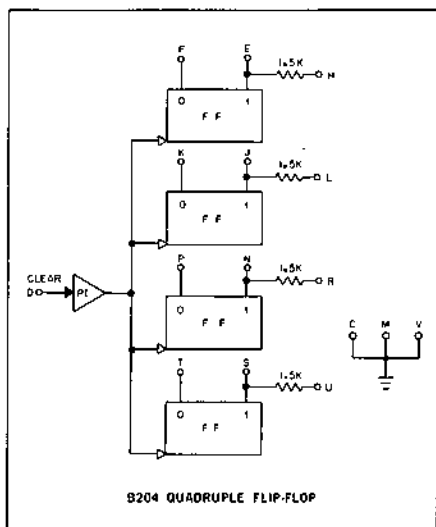
| B201 Flip-Flop Input Frequency | Maximum Inverter Base Inputs With Short Leads | Inverter Bases With Short Leads and 10 ma Clamped Load |
|-----------------------------------------|-----------------------------------------------------------|--------------------------------------------------------------------|
| 10 mc | 3 | 4 |
| 8 mc | 5 | 7 |
| 6 mc | 7 | 10 |
| 5 mc | 9 | 13 |
| 3 mc and below | 12 | 18 |

Indicator Output — A separate output at pin F drives an indicator-with-amplifier (4910) through Connector Board W020 without loading the flip-flop output excessively with stray wiring capacitance. When in use, this output reduces the I output drive at $-3v$ by 1 ma when used with W020, or by 2 ma when used to drive a 4910 directly.

POWER: +10(A)/5 ma; -15(B)/63 ma.

QUADRUPLE FLIP-FLOP TYPE B204

B SERIES



Module B204 contains four bits of unbuffered flip-flop memory. Each flip-flop comprises two B105-type inverters, two 10-ma clamped loads, a common clear input, and an indicator driver resistor.

INPUT: Each flip-flop may be individually set by grounding the 0 output and may be cleared by grounding the 1 output. The collector of an inverter, whose emitter is tied directly to ground, may be used to ground a flip-flop output. Diode gates such as B113, B115, B117, etc., may also be used, but due to their slower operation they must be conditioned "on" for at least 70 nsec to provide drive equivalent to an inverter driven by a 40-nsec pulse. A negative pulse at least 40 nsec wide applied to the input of the pulse inverter will clear all four flip-flops. Clear input loading is equivalent to one inverter base input.

OUTPUT: Each flip-flop output can drive 6 ma at

—3 v. Flip-flops driven by inverters with 40-nsec pulse inputs can have up to 200 pf of total dynamic loading at each output, counting internal loading of 68 pf, and up to 2 ma of static load at —3 v. When the input conditions are present for longer than 40 nsec, output loading may be increased until the estimated fall time is 1½ times as long as the grounded output is held at ground externally. (See "Fall Time" under "Special Instructions for 10 mc Logic Design"). No gated-emitter inverters may be driven.

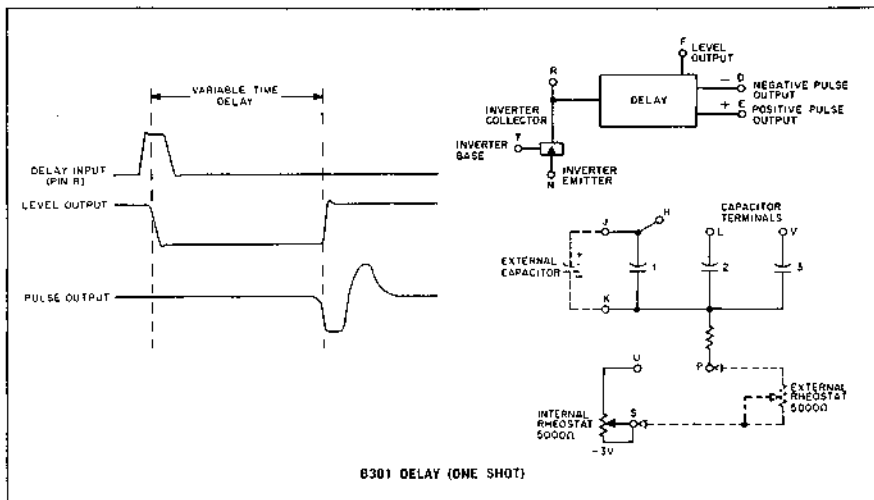
The 1500-ohm resistor outputs allow a control panel indicator with amplifier (4910) to be driven through Indicator Connector W020 without excessive loading of the flip-flop by the capacitance of the interconnecting wire. When used, this output may be counted as 1 ma of static base load on the appropriate 1 output, if the wire to the W020 is short.

POWER: +10(A)/0 ma; —15(B)/94 ma.

B204 — \$29.00

DELAY (ONE SHOT) TYPE B301

B SERIES



A delay (one shot) is a monostable multivibrator. When the input terminal is grounded, either through the inverter or externally, the level output switches from its normal ground level to -3 v for a pre-determined, but adjustable, period of time; then it switches back to ground. Simultaneously with the final transition, a standard 40-nsec pulse is generated at the pulse output.

The B301 contains three capacitors for delay range selection, and a screwdriver-adjustable rheostat for fine control. Typical level output duration ranges are 60 to 700 nsec, 0.5 to 10 μ sec, and 7 to 150 μ sec using pins J, L, and V respectively. To increase the range further, connect an external capacitor between pins J and K. When pins U and P are jumpered together, fine adjustments are made with the internal control. For external control, a rheostat of about 5000 ohms can be connected between pins S and P.

The circuit recovery time using a given timing capacitor is approximately 10% of the maximum delay available with that capacitor. This limits the maximum input frequency to about 6.5 mc.

A 20% change in power supply voltage will change the delay typically 1%. Delay jitter (due to power supply ripple) is less than 0.3%.

EXTERNAL CONTROL: The use of timing resistances larger than 5000 ohms is not recommended. A 5000-ohm rheostat will give approximately 20:1 variation with any but the smallest timing capacitors. In choosing external timing capacitors, allow about 1 nf for every 3 μ sec of delay desired at 5000 ohms. Noise on remote control wires tends to synchronize the end of the delay period (or it could cause false triggering in extreme cases); consequently, the control wires should be kept short. Even for 1-ft control wires, a grounded shield may be advisable if smooth control and freedom from jitter are essential.

INPUT: Pin R — The delay begins when this point is brought to ground by a pulsed inverter. Either the internal inverter or external inverters may be used. This input is equivalent to a 10-ma clamped load.

Pins T and N — These are the base and emitter terminals of a standard inverter. See description of B104.

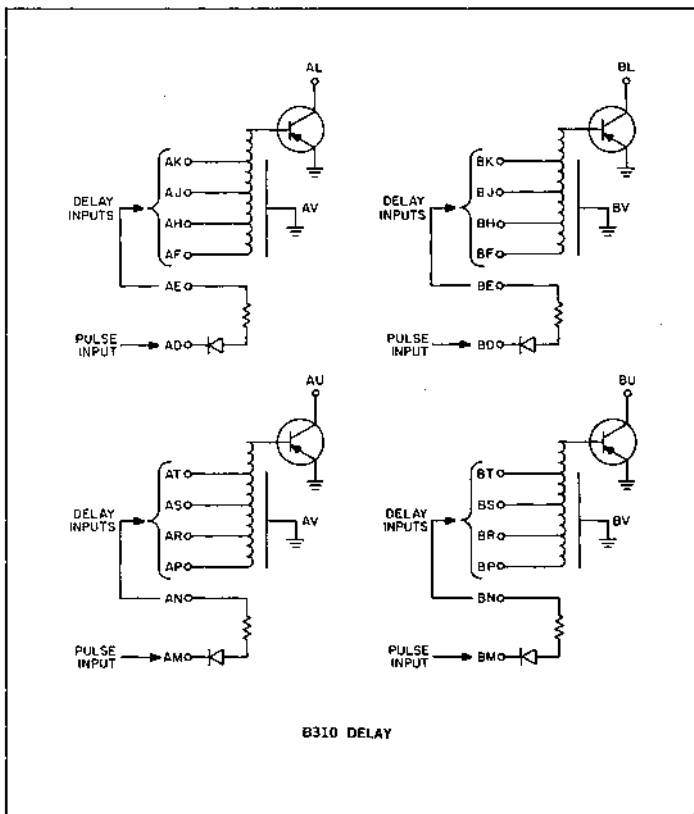
OUTPUT: Level — When the input is pulsed, a negative standard level occurs for the duration of the delay interval. The output supplies 12 ma at ground in addition to the 20-ma internal clamped load. The clamped load supplies 14 ma at -3 v. Dynamic load at the output is 8 pf. **Pulse** — At the end of the delay interval, a DEC standard 40-nsec pulse occurs. The

negative output will be active if the positive output terminal is grounded, and vice versa. This signal can drive up to eight inverter bases and an appropriate terminating resistor.

POWER: $+10$ v(A)/2 ma; -15 v(B)/110 ma.

**DELAY
TYPE B310**
Double Height Board

**B
SERIES**



The B310 contains four delay lines, each producing maximum delay of 50 nsec in 12.5 nsec steps. The output of each line is connected to a transistor inverter whose emitter is grounded. The collector terminal is available for logical gating. The 15 nsec delay through the inverter must be added to the delay of the line.

INPUTS: 40 nsec negative pulse or equivalent. One unit of load.

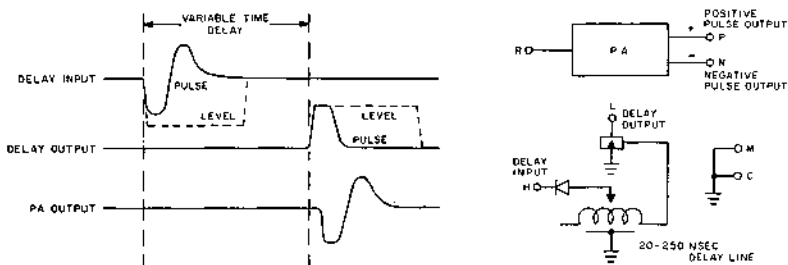
OUTPUTS: Collector should go to P.A. input of B602 or other unit being pulsed. However, up to two inverters may be placed in series between collector and P.A. input for additional logic gating.

POWER: None required.

B310 — \$66.00

DELAY WITH PULSE AMPLIFIER TYPE B360

B SERIES



B360 DELAY WITH PULSE AMPLIFIER

The B360 contains a delay line which may be varied from 25 nsec to 250 nsec, and a standardizing pulse amplifier similar to one half of a B602. The length of the delay is adjusted by means of a slotted screw accessible from the handle-end of the module. The high resolution of the delay line (approximately $\frac{1}{4}$ nsec) makes it ideal for high-speed timing chains. By connecting the delay and pulse amplifier together with suitable logic in a feedback loop, a stable gateable clock may be obtained (see Application Section).

INPUT: Delay — Pulse — The pulse input to the delay is a standard 40-nsec 2.5-v negative pulse. Loading is equivalent to four inverter bases. **Level** — The static input load is 12.50 ma at -3 v. Dynamic load is negligible. The input may be driven by three W005 Clamped Loads in parallel, or by one W005 Load in parallel with a standard 10-ma clamped load.

Pulse Amplifier — The input of the pulse amplifier is equivalent to a 10-ma clamped load, and is driven by an inverter. **Pulse** — At the base of the inverter the pulse input which drives the pulse amplifier, is normally a standard 40-nsec negative pulse. However, any negative pulse having an amplitude between 2 and 5 v, a rate of change greater than 1 v/12 nsec and width (at -2 v) greater than 25 nsec, can be used instead of the 40-nsec pulse. Inverter input

pulses of less than -0.5 v will not generate an output pulse. **Level** — The input to the pulse amplifier may also be a standard positive-going level change (-3 v to ground). A negative-going level change will not produce an output signal from the amplifier. The input must have been at -3 v for at least 50 nsec before going to ground.

OUTPUT: Delay — Pulse — When the input of the delay line is a 40-nsec pulse, the maximum output driving capacity at ground is 16 ma as with a standard inverter driven by a pulse. **Level** — When the input to the delay is at level, the maximum output driving capability at ground is 36 ma as with the output transistors of a buffered flip-flop. Each 10-ma clamped load attached to the output (collector) provides a maximum output driving capacity of 7 ma at -3 v. The dynamic load of the collector is 8 pf.

Pulse Amplifier — The output of the pulse amplifier (for either a negative pulse or a negative-going level change at the base of the inverter driving the amplifier) is a standard 2.5-v 40-nsec pulse which occurs at the output terminal every time the input signal meets the input requirements. The negative output will be activated if the positive output terminal is grounded. Each output drives twelve 10-mc bases and appropriate terminating resistors.

POWER: $+10$ v(A)/5 ma; -15 v(B)/50 ma.

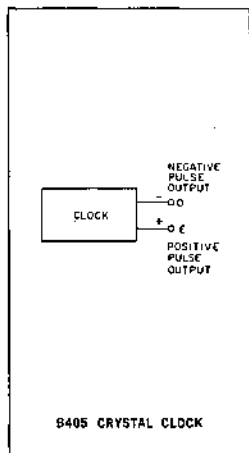
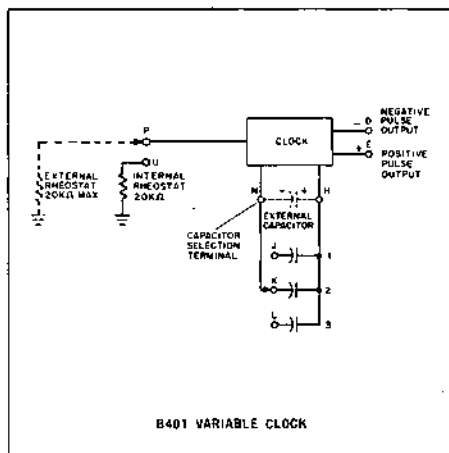
B360 — \$84.00

CLOCKS

TYPES B401, B405

B

SERIES



The B401 Variable Clock produces standard pulses from a stable, RC-coupled oscillator with a wide range of frequencies. The variable clock is often used as a primary source of timing for large systems. Where very precise timing is needed, the B405 Crystal Clock, which contains a single-frequency crystal oscillator, may be used.

B401 FREQUENCY RANGE

| PIN | Capacitance | Approx. Range |
|----------|-------------|---------------|
| J | 100 pf | 1 mc-10 mc |
| K | 1000 pf | 100 kc-1 mc |
| L | .01 mfd | 10 kc-100 kc |
| EXTERNAL | 0.1 mfd | 1 kc-10 kc |
| EXTERNAL | 1 mfd | 100 cps-1 kc |

The frequency of the B401 is variable from 10 kc to 10 mc. Three capacitors determine the frequency

range, and a potentiometer provides fine control. For lower frequencies, an external capacitor may be used. When terminals U and P are connected together, the internal rheostat provides fine control. If desired, an external rheostat can be connected between terminals P and C. A 20% change in power supply voltage will change the frequency less than 1%. Pulse-to-pulse jitter is less than 0.3%.

The B405 contains a series resonant crystal oscillator circuit and a pulse-shaping buffer amplifier which produces standard 40-nsec pulses. The frequency, specified by the customer, can be between 2 and 10 mc. The frequency is stamped on the crystal. Stability is 0.01% over the temperature range of -20 to $+55^{\circ}\text{C}$.

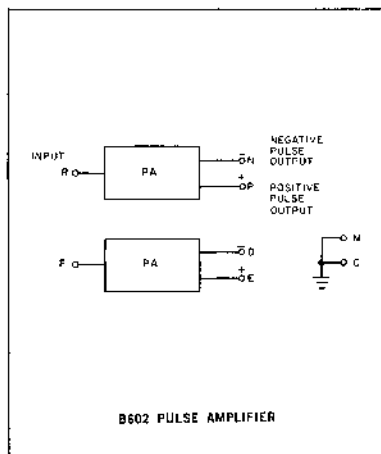
OUTPUT (EITHER CLOCK): Standard 40-nsec pulses at the preselected frequency. The negative output is active if the positive output terminal is grounded; the positive output is active if the negative output terminal is grounded. Each output can drive eight 10-mc inverter bases and an appropriate terminating resistor.

POWER: B401: +10 v(A)/0 ma; -15 v(B)/70 ma.
B405: +10 v(A)/51 ma; -15 v(B)/25 ma.

B401 — \$57.00
 B405 — \$100.00

PULSE AMPLIFIER TYPE B602

B
SERIES



The B602 contains two pulse amplifiers which are used for power amplification, for standardizing pulses in amplitude and width, and for transforming a level change to a pulse. Delay from the input of an inverter that drives the PA to the PA output is approximately 20 nsec. Input pulses may occur at any frequency up to 10 mc.

INPUT: The input of the pulse amplifier is equivalent to a 10-ma clamped load and may be driven from a transistor collector. **Pulse** — The pulse input to the base of the inverter whose collector drives the pulse amplifier is normally a standard 40-nsec negative pulse. However, any negative pulse having an amplitude between 2 and 5 v, a rate of change greater than 1 v/12 nsec and width (at -2 v) greater than 25 nsec, can be used. Input noise of 0.5 v or less will not generate a PA output pulse. Several pulse gate collectors can be connected together to mix pulse sources. The inverter emitter must be at

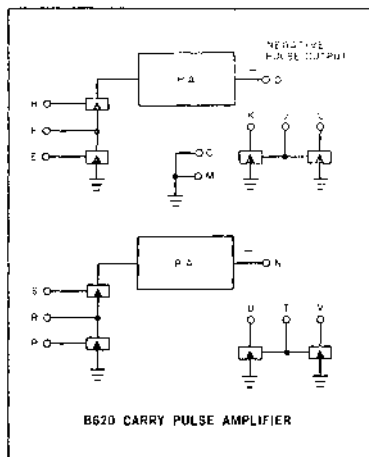
ground for assertion at the output. **Level** — The input to the pulse amplifier may also be a standard positive-going level change (-3 v to ground). A negative-going level change will not produce an output signal from the amplifier. The PA input must rest at -3 v for at least 50 nsec before going to ground.

OUTPUT: The output of the pulse amplifier, when either a pulse or a level brings the input to ground, is a standard 2.5-v, 40-nsec pulse which occurs at the output terminal every time the input requirements are met. The negative output is produced when the positive output terminal is grounded; the positive output is produced when the negative terminal is grounded. Each output can drive twelve 10-mc inverter bases or their equivalent and an appropriate terminating resistor.

POWER: $\pm 10 \text{ v(A)}/2 \text{ ma}$; $-15 \text{ v(B)}/75 \text{ ma}$.

CARRY PULSE AMPLIFIER TYPE B620

B
SERIES



Module B620 supplements the B201 for 10-mc counting applications. It supplies the circuitry to complement two B201 Flip-Flops and propagate their carry pulses. One B620 and one B201 can also be combined to form one bit of an up-down counter. The B620 contains two pairs of inverters for complementing 10-mc flip-flops with conditional set and clear inputs, and two standardizing pulse amplifiers each capable of driving three inverter bases. The propagation delay is approximately 10 nsec. Maximum pulse repetition frequency is 5 mc for pulse amplifiers.

INPUT: The eight inverters of the B620 are similar to other 10-mc inverters, for example, the inverters

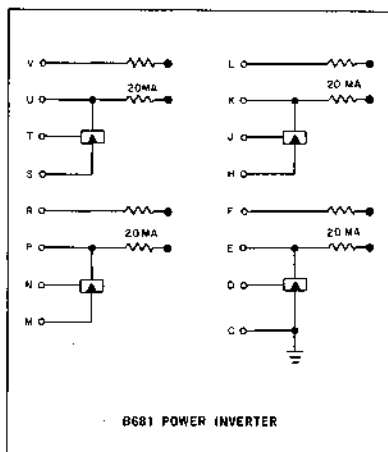
of the B104 and B105. To obtain minimum propagation delay, input H or S should be pulsed. Use inputs E, F, P, and R for gating inputs. Pulse amplifiers will not produce standard pulse outputs unless a standard 40-nsec pulse input is used.

OUTPUT: When 40-nsec pulses are used at their inputs, the pulse amplifiers produce 2.5-v, 40-nsec standard negative pulses capable of driving one to three inverter bases. Maximum length of wire used to connect pulse amplifiers to the inverters is 6 in. Noise pulses may occur if the ground pin next to each output pin is not connected directly to the local ground of the inverters that the output drives.

POWER: +10 v(A)/6 ma; -15 v(B)/20 ma.

POWER INVERTER TYPE B681

B SERIES



The B681 Power Inverter contains four high-current inverters, each with separate emitter connections. A 20-ma clamped load is permanently connected to each collector. Four additional 10-ma clamped loads are supplied. Input and output current ratings are double those of a standard inverter.

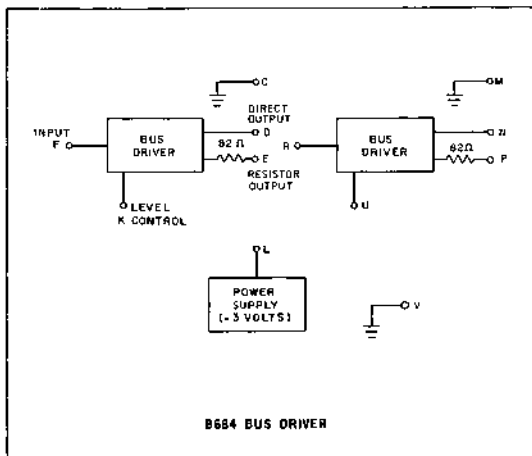
INPUT: Each input requires a steady-state 2-ma current at -3 v. Each independent clamped load requires 10 ma from a transistor collector to hold it at ground.

OUTPUT: Each power inverter transistor can supply 32 ma at ground. Each internal clamped load absorbs 20 ma, and 12 ma remain for an external emitter (level or pulse), or loads to -15 such as odd-numbered diode gates, etc. Each of the clamped loads that are internally connected to power inverter collectors can supply 14 ma at -3 v. Each of the additional clamped loads can supply 7 ma at -3 v.

POWER: $+10$ v(A)/0 ma; -15 v/130 ma.

BUS DRIVER TYPE B684

B SERIES



The B684 contains two dual-purpose, non-inverting bus drivers and a -3 v supply. Each bus driver provides standard levels either to a large number of inverter base and diode loads, or to a terminated 90-ohm cable. All logic terminals are available at the connector. Delay through a bus driver is approximately 30 nsec.

INPUT: Standard levels or equivalent; 1 ma of load when the input is at -3 v. Input capacitance is 8 pf. The input circuit will tend to oscillate if it is driven by a wire more than 3 feet long.

OUTPUT: Direct — Standard levels capable of driving ± 40 ma at 10 mc. Each bus driver level control pin must be connected to -3 v when using the direct output. The separate ground terminal provided for each circuit should be the ground point for loads driven by that circuit. This output is the one to use for driving heavy loads over short distances.

Resistor — Ground and -6 v levels at the resistor output provide standard levels at the end of a 93-ohm cable when it is terminated with a 100-ohm resistor to ground. The terminated cable will drive 10 ma at 10 mc. The level control pins must be left open when driving a terminated cable from the resistor output. The separate ground terminal provided for each circuit should be the ground return point for loads driven by that circuit.

For driving 5 ma loads or less, an unterminated cable or open wire may be driven from the resistor output using 3v levels. This connection allows heavy local loads to be combined with light distant loads on one circuit.

POWER UNLOADED: $+10$ v(A)/80 ma; -15 v(B)/120 ma.

POWER FOR LOAD: Current to bring loads to ground must be added to the total demanded from $+10$ (A); current to bring loads negative must be added to the total current from -15 (B).

W SERIES



W SERIES INTRODUCTION

The W series provides input-output compatibility between FLIP CHIP Modules and other digital devices. The range of W series inputs and outputs is wide. Inputs up to $\pm 48\text{v}$, outputs up to $\pm 135\text{v}$ or up to 10 amp, inputs from source impedances as high as 100 K Ω , floating systems, bouncing contacts, long transmission lines, all can be handled easily by one or more of these modules. A few of their uses are listed below.

Clamped Loads

The inputs of all R series circuits draw current only when the input voltage is at ground. Other DEC circuits may require input current to be supplied at the negative voltage level. The use of additional clamped load resistors allows an R series module to be preloaded so that it is able to supply higher currents at the -3v level.

It is also possible to obtain higher drive capability at ground from DEC circuits which normally supply current at -3v . In this case the normal clamped load resistor would be replaced by one which is a lighter load at ground. The Type W002 contains clamped load resistors of this type. Care should be exercised when such a lighter load is used since an increased fall time will result.

A clamped load can also be used as a short-circuit proof, -3v supply for toggle switches or patchboards.

Cable Connectors

Cable connectors provide a convenient means for going from one section of logic to another. They may also be used to hold series isolation resistors or shunt termination resistors. They allow large systems to be broken into pluggable subsystems for efficiency in checkout and field maintenance.

Drivers

The Types W050 and W051 provide signals for indicator lights, relays, and solenoids. W051 outputs go to ground and can therefore be used to drive R111 or similar diode inputs. W061 can drive NIXIE tubes, or other loads returned to positive voltages. W061 outputs supply sufficient current for most projection type numerical displays as well, and for relays and solenoids too large for W051 circuits. W040 is the next larger driver, and has sufficient output capability for most electromechanical devices. Stepping motors and other exceptionally high current devices may require the use of a W042. Line voltage can be controlled by the W080 module, and if a Triac is added to its output this module allows up to 1 kilowatt of AC power to be solid-state controlled by FLIP CHIP logic.

Input Converters

The W501 allows external low frequency or noisy signals to be converted to DEC standard levels. The Type W510 converts positive signals of a few volts amplitude into DEC levels. Other external levels that are noise-free and have a swing greater than 3v can usually be biased so that they can be brought directly into the logic modules. Pulses, which are noise-

free and fast, can usually come directly into the pulse amplifiers. Small signals, with amplitudes of a few millivolts or more, can be brought into the logic system using W520 or A501 comparators. Floating battery signals such as those in process controls can be converted by W502 modules. The W500 buffers inputs from photocells, vacuum-tube equipment, and other high-impedance sources. Some types of computer interface can use the W590 module. W700 filters bounce from contact signals not requiring W501 standardization.

Output Converters

The W600 and W601 provide a means of driving low power digital devices requiring signals in the range of -15 to 20v. Most drivers can be used as output converters under some circumstances. Some types of computer interface can use the W690 module. Many types of output pulse requirements can be met by W607 or W640 pulses.

Communications Interface Modules

The W706, W707, and W708 are functional modules which are used to provide Teletype communications system interfaces to computers and other parallel devices. These units contain serial to parallel and parallel to serial conversion for 5-bit and 8-bit communication systems.

Accessory Modules

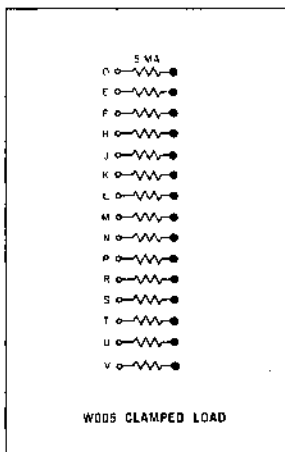
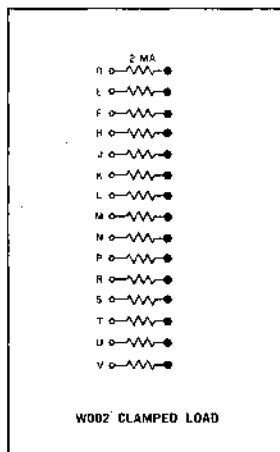
The accessory modules include blank boards for constructing special circuits, a module extender, which allows access to the module while it is connected to the mounting panel, and a system module adapter, which allows DEC system modules to be connected into a FLIP CHIP mounting panel. Related are the A series amplifier boards A990 and A992, for mounting operational amplifiers of various types.

Pulse Conversion

See the application note with the above heading for a table of pulse conversions between FLIP CHIP and earlier System Modules and Laboratory Modules made by DEC. All modules use logic levels of ground and $-3v$, so in many cases no conversion at all is required.

CLAMPED LOADS TYPES W002, W005

W
SERIES



The W002 contains 15, 2-ma clamped loads. These can be used for clamping voltages at the output of inverter collectors in R-series modules, or for converting B-series modules to work with R-series.

OUTPUT: When the clamped load output is grounded, it draws 2 ma. When it is at $-3v$, it can supply up to 1.4 ma.

POWER: $-15 v(B)/46$ ma.

The W005 contains 15, 5-ma clamped loads. These can be used for clamping voltages at the output of inverter collectors in B-series modules, or for converting R-series modules to work with B-series. Two of these clamped loads in parallel are equivalent to one B-series clamped load.

OUTPUT: When the clamped load terminal is grounded, it draws 5 ma. When at $-3v$, it can supply up to 3.5 ma.

POWER: $-15 v(B)/91$ ma.

W002 — \$13.00
W005 — \$15.00

CABLE CONNECTORS FOR INDICATOR AMPLIFIERS TYPES W018, W023

**W
SERIES**

The W018 and W023 provide 18 line ribbon cable connections to FLIP CHIP mounting panels. In the W018 connection to each pin is through a series low leakage silicon diode. The W023 provides unbroken signal lines from the cable to the connector pin.

When these cables are used with 4917 or 4918 indicators, the W018 must be located at the FLIP CHIP panel and the W023 inserted in the indicator socket connector. Cables may be ordered with connector modules on **both ends** or on **one end only**. Cable length may be specified in increments of 1 inch.

For ordering information, see W021, W022, and W028 on next page.

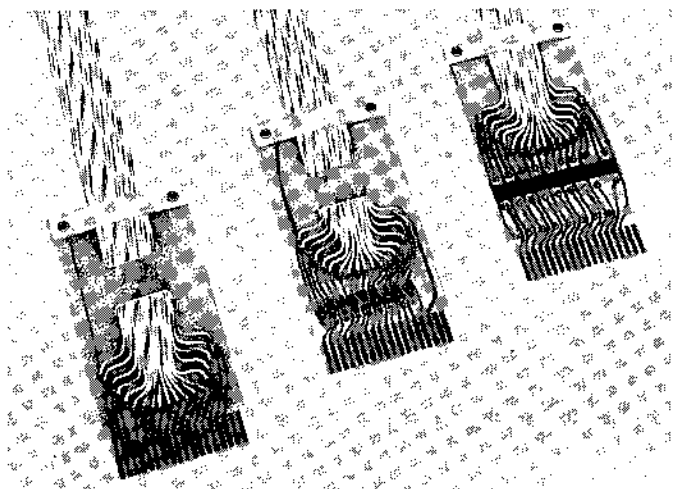
Care should be taken when using the W023 for other purposes, since the Power Pins (A, B) are unprotected.

| Type | Price with Cable Attached | Type | Price without Cable |
|------------------------------------------------|---------------------------|-------|---------------------|
| W018 | \$19.00* | W018U | \$18.00 |
| W023 | \$13.00* | W023U | \$ 4.00 |
| *Ribbon Cable: Add \$.60 per foot, or fraction | | | |

CABLE CONNECTORS FOR LEVELS AND PULSES

TYPES W021, W022, W028

W SERIES

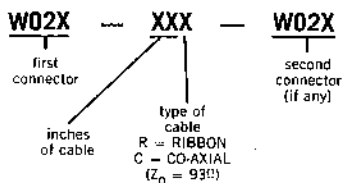


The W021, W022, and W028 provide cable connections to the FLIP CHIP mounting panel. The cable is a 19-conductor ribbon with nine signal leads and ten shields. The signal leads are connected to pins D, E, H, K, M, P, S, T and V. The shields are internally connected together and to pins C, F, J, L, N, R, and U.

In the W021, the signal leads are connected directly to the signal pins. In the W028, jumpers are available for series or shunt terminators. The Type W022 has a 100-ohm shunt terminator from each signal wire to the shield.

Connectors may be ordered in like or unlike pairs. They may also be ordered separately, in which case the other end of the cable is left free. Cable length may be specified in increments of 1 in.

ORDERING INFORMATION: To insure clear communication, use the format below.



EXAMPLE: W028-24C two feet of co-axial cable attached, no second connector

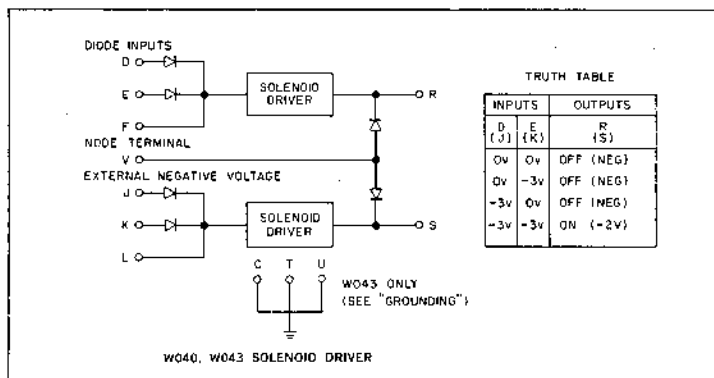
| Ribbon Cable Connectors | | | | Coaxial Cable Connectors† | | | |
|---------------------------------------------|----------------------|--------|----------|-----------------------------------------------|-----------------------|--------|----------|
| Type | Cable Attached | Type | No Cable | Type | Cable Attached | Type | No Cable |
| W021R | \$13.00 ^o | W021RU | \$4.00 | W021C | \$31.00 ^{o*} | W021CU | \$ 4.50 |
| W022R | \$13.50 ^o | W022RU | \$4.50 | W022C | \$33.00 ^{o*} | W022CU | \$6.50 |
| W028R | \$13.00 ^o | W028RU | \$4.00 | W028C | \$31.00 ^{o*} | W028CU | \$4.50 |
| ^o Ribbon Cable: Add \$.60/ foot. | | | | ^{o*} Coaxial Cable: Add \$1.50/foot. | | | |

SOLENOID DRIVERS

TYPES W040, W043

W

SERIES



These high current drivers can drive relays, solenoids, stepping motor windings, or other similar loads. The output levels are -2 volts and a more negative voltage determined by an external power supply. One terminal of the load device should be connected to the external power source, the other to the driver output. There are two drivers per module and both modules use the same pin connections.

Pin V of the driver module must be connected to the external supply so that the drivers will be protected from the back voltage generated by inductive loads. If the wire to the power supply is more than 3 feet long it may have to be by-passed at the module with an electrolytic capacitor to reduce the short overshoot caused by the inductance of the wire. If pin V is connected to the supply through a resistor, the recovery time of inductive loads can be decreased at a sacrifice in maximum drive voltage capability. Maximum rated supply voltage (see below) less actual supply voltage should be divided by load current to find the maximum safe resistance. When both circuits on a module are used, the load current for the above calculation is the sum of the currents.

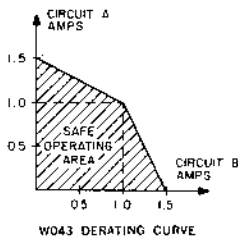
INPUTS: Standard DEC levels or equivalent. The maximum input load is 3 ma. per driver, shared by all grounded inputs. Additional diode inputs may be added by connecting diode networks such as R001 or R002 to the node terminal.

OUTPUTS: The table below shows maximum ratings for individual circuits. No more than two circuits should be paralleled to drive loads beyond the current capabilities of single circuits. For larger loads use the W042. When both circuits on a W043 are used with a duty cycle exceeding 35%, use the

current derating curve shown below.

GROUNDING: The W043 has three ground terminals C, T, U, which should be wired together externally to limit current through each connector pin to safe levels. (High current loads should be grounded at the W040 or W043 modules to avoid noise due to high pulse currents in ground conductors.)

| MODULE | MAXIMUM VOLTAGE | MAXIMUM CURRENT | TYPICAL DELAY |
|--------|-----------------|-----------------|---------------|
| W040 | - 70 V | 0.6 amp. | 5 μ sec |
| W043 | - 35 V | 2.0 amp. | 10 μ sec |



POWER: W040: + 10v (A)/ 0 MA, -15v (B)/24 MA. The external voltage supply must supply the output current of the two drivers (1.2 amp max.)

W043: +10v (a)/0.25 MA, -15v (B) /6 MA. The external voltage supply must supply the output current (2.0 amp max.)

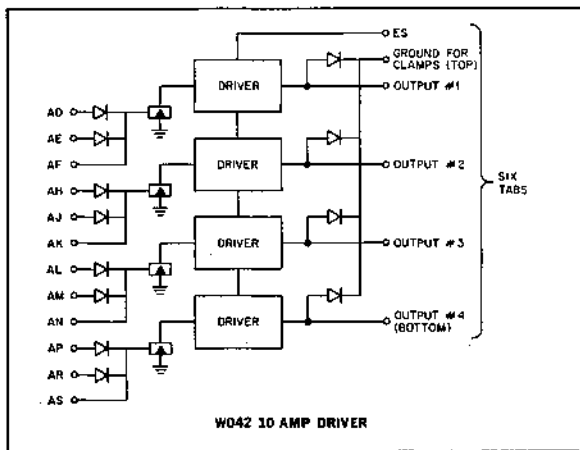
W040 — \$36.00
W043 — \$35.00

10 AMP DRIVER

TYPE W042

(DOUBLE-HEIGHT, DOUBLE-WIDTH MODULE)

W
SERIES



This module has four germanium transistor drivers each capable of providing up to ten amperes of DC drive at ambients up to 40°C for heavy loads such as paper tape punches, card punches, hydraulic servo valves, or high-torque stepping motors like Responsyn (T.M. United Shoe) or Slo-Syn (T.M. Superior Electric). In 55°C ambients, up to 8 amps total current may be obtained. AMP "Faston" tabs at the handle end of the module provide high current connections for ground, ES, and the four outputs. Loads are to be connected between the outputs and external ground. Due to the fact that this module may dissipate as much as 20 watts when operated at rated output, special consideration should be given to an unobstructed flow of cooling air. It is recommended that no modules be mounted directly above any W042 operating at more than 4 amps average current. Typical delay: 20 microseconds for the circuit alone. Load current decay time may be much longer, if its inductance is large.

INPUTS: Each input requires 2 ma at ground. Negative input brings corresponding output to ES. Input gates may be expanded with R001 or R002 diode modules, if no more than 6" of wire is connected to each node. All connections are made to the A half (upper) of the module.

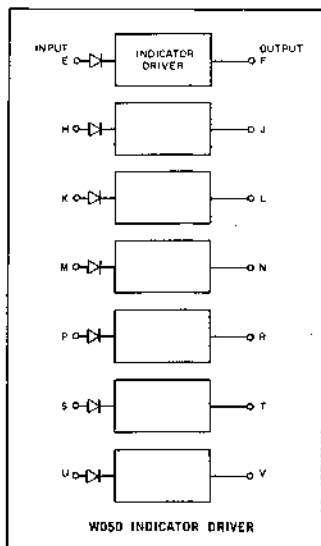
OUTPUTS: Total DC current from the W042 may be up to 10 amp, and may be distributed at will among the four outputs. Even higher currents may be obtained briefly by taking into account the 4 minute (approx.) time constant of the heat sink. For example, four 10 amp solenoids can be activated together, as long as they are on only a few seconds and at low duty factors. Outputs are not short circuit protected if shorted to ground. Shorts to output supply voltage are harmless. Clamp diodes are provided from each output to ground to damp transients when turning off inductive loads. Damping diode ground and all ES power is connected only by tab terminals. Logic ground and +10v power use standard connector pins. Output circuit power supply must be grounded to digital system power externally. Power jumpers Type 914 may be used to make connections. Outputs may not be paralleled to increase short duty peak current, unless 0.1 Ω current-sharing resistors are connected in series with each output.

The negative supply voltage (ES) must be between -12 and -15 volts.

POWER: +10v(A)/180ma; ES/270ma plus output current.

30 MA INDICATOR DRIVER TYPE W050

W
SERIES



The W050 contains seven transistor amplifiers that can drive miniature incandescent bulbs, such as those on an indicator panel. It is used to provide remote indicators for R- or B-Series flip-flops. If the input is at $-3v$, the output is at $-2v$.

INPUT: Standard levels of $-3v$ and ground. Each input represents 1 ma of load at ground.

OUTPUT: The output is capable of supplying 30 ma

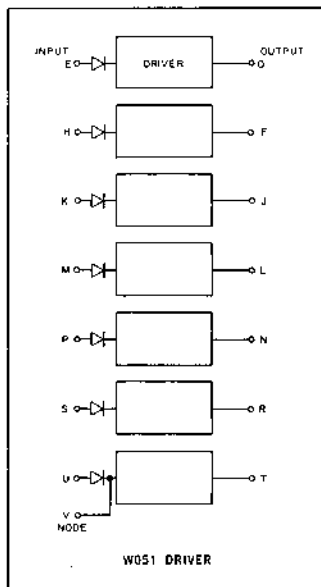
at $-2v$. The external load may be connected to any voltage between $-2 v$ and $-20 v$. The output is capable of driving an indicator light, such as Drake 11-504, Dialco 39-28-375, or Eldema CF2-WT-1762, returned to $-15 v$.

POWER: $+10 v(A)/1.1 ma$; $-15 v(B)/7 ma$.

NOTE: An additional 210 ma is drawn from the indicator supply when all remote lights are on. This power is not drawn from the module.

100MA INDICATOR AND RELAY DRIVER TYPE W051

W
SERIES



The W051 contains seven inverter amplifiers suitable for driving indicators, relays, and other medium power devices. The amplifiers can supply up to 100 ma at ground, and each output is diode clamped to -15v to prevent overvoltage when the current is interrupted in an inductive load. If the input is at -3v , the output is at ground.

INPUT: Diode — Standard levels of -3v and ground. The input load is 3 ma at ground. **Node** — Other inputs may be connected here through diodes such as those in the R002. The 3-ma load is shared among the grounded inputs.

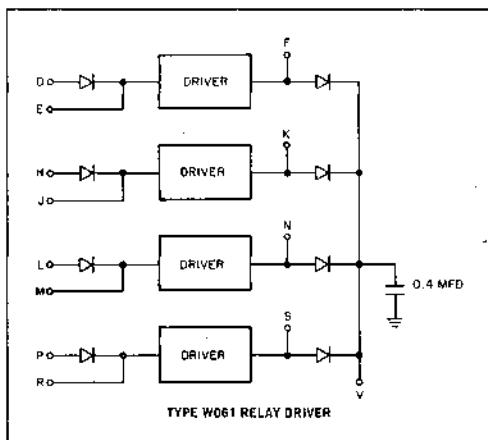
OUTPUT: The output is capable of supplying 100 ma at ground. The external load may be connected to any voltage between 0 and -15v . The negative output is diode clamped to prevent it from going more negative than -15v . Typical delay for circuit alone: 1 microsecond. Decay time of current in inductive loads may be much longer.

POWER: $+10\text{ v(A)}/3\text{ ma}$; $-15\text{ v(B)}/23\text{ ma}$.

NOTE: An additional 700 ma will be drawn from -15v when all circuits are on. This power is not drawn from the module.

RELAY DRIVER TYPE W061

W
SERIES



The W061 Relay Driver has four all-silicon 250 ma drivers with gateable inputs; it can drive relays and solenoids with positive voltage supplies up to 55v.

INPUTS: 2 ma at ground, no load at $-3v$. Use diodes for ungated input. Multiple-input AND gate may be obtained by connecting R001 or R002 diodes to node inputs.

OUTPUTS: The loads are to be connected between the outputs and an external positive supply. Each output can supply a quarter-amp load at

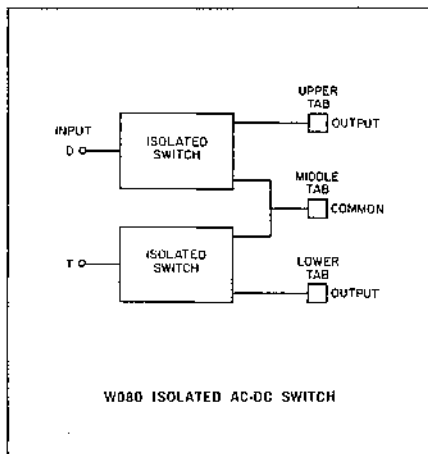
ground when the input(s) is (are) negative. Pin V must be connected to the positive voltage supply so inductive loads will not cause output transistor breakdown. Supply voltage should be between 2 and 55v positive. Typical delay for circuit alone: 1 μ sec. Decay time of current in inductive loads may be much longer.

POWER: $+10v(A)/70$ ma; $-15v/8$ ma.

OTHER POWER: Inductive loads cause clamp currents at pin V tending to drive supply voltage more positive when drivers are turned off.

ISOLATED AC-DC SWITCH TYPE W080

W
SERIES



This module contains two photon-coupled transistor switches with bridge rectifiers. Both turnon and turnoff are slow enough to minimize output noise. Output tabs are at handle end of module for maximum isolation. Drives relays, solenoids, panel lamps, small motors directly. Larger AC loads can be driven by the use of SCR or Triac* buffers. For example, one SC45B Triac with a W080 circuit tied from gate to anode 2 and a 100Ω resistor from gate to anode 1 can switch AC loads up to one kilowatt.

INPUT: Each input is a 30 ma load returned to -10v. A W061 driver is suitable. Switching rate must not exceed one hertz per second. Grounding an input turns on the switch, and an open circuit at the input turns off the switch.

OUTPUT: Each circuit can switch up to ¼ ampere from supplies up to 135 volts DC or AC (RMS) into resistive or inductive loads, or 30 va maximum at 120 volts. Can drive up to 40 va intermittently; up to 5 seconds on 50% duty factor. Derate by half for driving incandescent lamps. Typical "on" voltage drop: 8 volts. Typical switching time: 1/10 second.

*G.E. trademark

Not designed for series or parallel operation.

WIRING: Three AMP "Faston" tabs replace module handle. Type 914 Power Jumpers can be used to connect these to a nearby terminal block, etc. Use caution on high voltage.

NOISE: W080 is designed to generate little or no switching noise. However, power lines often carry noise from distant sources. Some types of loads generate noise, such as bush-type motors and power relays. Even SCR and Triac circuits generate fast transients on each turnon cycle. For these reasons, it is important to locate W080 modules and their output leads away from logic and logic wiring. If a W080 module must be used close to a logic module, put a W992 or W993 copper clad board with pins A and B cut away between them to form an electrostatic shield. In some cases line filters may also be necessary.

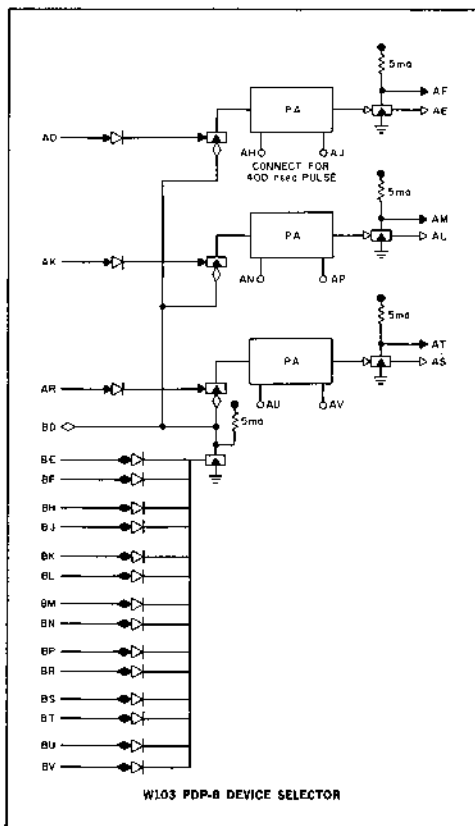
POWER: +10v(A)/60 ma; --15v(B)/0.

W080 — \$60.00

PDP-8 DEVICE SELECTOR

TYPE W103

W
SERIES



This module is used to decode the six device selector bits transmitted in complement pairs on the PDP-8 or PDP-8/S I/O bus, and it provides standard pulses to the selected device. The device code is selected by cutting one diode of each pair, BE or BF, etc., off the board. Device coding can also be accomplished by selective wiring of the bus inputs to the diode pairs.

INPUTS: Diodes — Standard levels of $-3v$ and ground. Input load is 1 ma shared among the inputs that are at ground. **Pulse Input** — Standard 100 nsec negative pulse or any pulse at least

100 nsec wide with an amplitude of 2.5 volts.

OUTPUTS: With terminals AH and AJ or the corresponding terminals on other sections connected together, the output is a standard 400 nsec pulse. With these terminals open the output is a standard 100 nsec pulse. Both positive ($-3v$ to ground) and negative pulses are available. Each positive output can drive 65 ma of external load at ground and each negative output 15 ma.

POWER: +10 v(A)/6.4 ma; $-15 v/57$ ma.

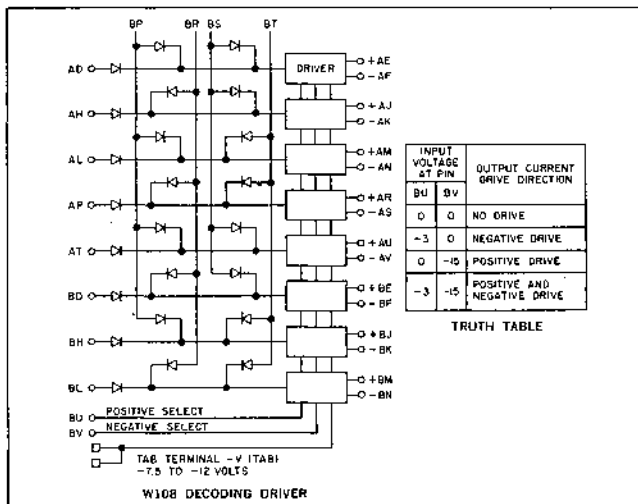
W103 — \$52.00

DECODING DRIVER

TYPE W108

(DOUBLE HEIGHT)

W
SERIES



| INPUT VOLTAGE AT PIN | | OUTPUT CURRENT DRIVE DIRECTION |
|----------------------|-----|--------------------------------|
| BU | BV | |
| 0 | 0 | NO DRIVE |
| -3 | 0 | NEGATIVE DRIVE |
| 0 | -15 | POSITIVE DRIVE |
| -3 | -15 | POSITIVE AND NEGATIVE DRIVE |

TRUTH TABLE

This driver provides up to 300 ma bipolar drive currents for use in memory systems including core memories, such as the H201, and magnetic tape systems. There are eight drivers on a module, each of which can be selected either by one of eight address lines or by using the built-in binary-to-octal decoding matrix. The drive current direction is selected by one of two input select lines and will be the same for all drivers on a module. Drive current can be varied from 160 ma to 300 ma by adjusting the external negative voltage reference connected to a tab terminal on the module handle.

INPUTS: Address selection diode inputs have a 2 ma at ground load shared between all inputs used on each driver. Positive output drive can be selected by a -3 volt signal at pin BU. When pin BU is brought to ground, the input driving source must supply 35 ma per addressed driver. The negative output drive current is selected by a -15 volt signal at Pin BV. This input requires a 25 ma drive at ground independent of driver addressing.

For a complete description of drive current direction selection see the truth table.

The negative voltage reference applied to the tab terminal input may have a voltage range of -7.5 to -15 volts with the current amplitude approximately

determined by the formula

$$I \text{ (ma)} = \frac{\text{Tab Voltage}}{0.048 + \text{External Series Resistance in Kilohms}}$$

This external source must be able to sink the maximum negative drive currents used in the W108. For tab voltages more negative than -12 volts the duty cycle of each negative driver should be such that the average drive current per driver is less than 200 ma. Momentary shorts to the negative drive outputs will cause no module damage.

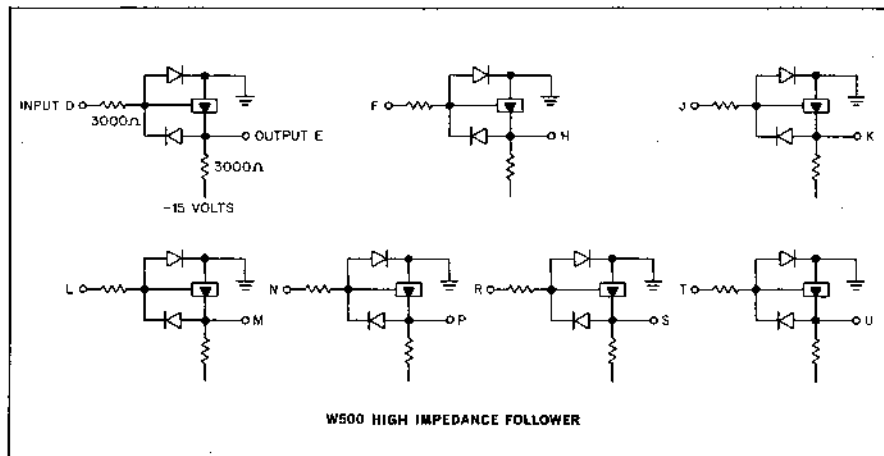
OUTPUTS: All negative current outputs sink current as controlled by the tab voltage. Typical turn-on and turn-off times for the negative current are, respectively, 100 nsec and 1.5 μ sec. The positive current driver output must be used in series with a negative current driver, the latter then controls the positive drive current. Each positive output is diode-protected to -15v against inductive backswing.

POWER: -15(B)/16 ma plus 35 ma per selected driver
-V(TAB)/maximum of 250 ma per negative current driver used.

W108 — \$75.00

HIGH IMPEDANCE FOLLOWER TYPE W500

**W
SERIES**



High impedance signal sources such as photo-cells and low-current instrumentation amplifiers can drive Schmitt Trigger W501 or logic gates through a W500 circuit. The module contains 7 fault-protected circuits, each comprising two cascaded emitter-follower amplifiers. Input voltage excursions up to $\pm 30\text{v}$ or short-circuits from output to ground are harmless. Outputs can go as negative as -15v with very light loading, but will not exceed -10v when driving a W501 input.

INPUTS: Excursions Between -0 and -3v : Input currents of $100\ \mu\text{a}$ or less (typically 50) flow toward the driving source, tending to bring it more positive. Low frequency equivalent input resistance exceeds $10\text{K}\Omega$ even while the output voltage is passing through the input threshold region of a Schmitt circuit or diode gate. Voltage offset between input and output: less than $\pm 1/3\text{v}$. **Larger Excursions:** A diode shorts the active components of the follower circuit if the input voltage goes more positive than ground or more negative

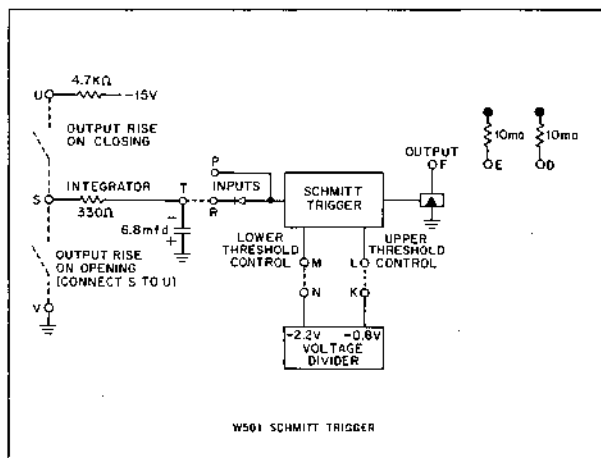
than -15v , and the input equivalent circuit changes to 3000Ω returned to the limiting voltage. If the output is connected to a clamped load for driving grounded loads such as B-series inverters, the limiting negative voltage changes from -15 to -3v .

OUTPUTS: Excursions Between 0 and -3v : Each circuit can drive up to 15 ma at ground. Driving capability at -3v is 3 ma more than that of any clamped load attached. If the output is brought to ground by a paralleled transistor collector, not only the internal 5 ma load and the external load must be driven, but also the current demanded by the input 3000Ω resistance returned to the negative input voltage present. 10 mc emitters may not be driven. **Larger Excursions:** If no clamped load is attached, each output will follow its input as far negative as its internal 3000Ω resistor to -15v will drive the load. Output voltage cannot go more positive than ground.

POWER: $+10\text{v(A)}/18\text{ ma}$; $-15\text{v}/35\text{ ma}$.

NEGATIVE INPUT CONVERTER AND SCHMITT TRIGGER TYPE W501

W
SERIES



The W501 contains a Schmitt trigger circuit which produces standard levels as a result of some outside activity such as the closure of a switch or relay. A ground level input produces a -3v level output, and a negative level input produces a ground level output. Nominal switching thresholds of -2.2v and -0.8v are obtained by connecting terminal L to terminal K and terminal M to terminal N. The switching thresholds can be varied over the range of 0 to -2.5v by applying external voltage levels to terminals M and L. Terminal M controls the lower level threshold, and terminal L controls the upper level threshold. The module also contains an integrating circuit to filter contact bounce when a switch or relay is used to generate the levels.

INPUTS: Diode — Any signal at pin R between $\pm 10\text{v}$ will not cause damage to the circuit. The input impedance is 7500 ohms to $+10\text{v}$ when the input is more negative than the lower threshold, and is an open circuit when the input is more positive than the upper threshold. The output will switch from -3v to ground if the input voltage goes more negative

than the lower threshold after having been more positive than the upper threshold. The output switches from ground to -3v if the input voltage goes more negative than the lower threshold after having been more positive than the upper threshold. Upper and lower thresholds must be at least $1/2\text{v}$ apart. The 2 ma clamped load at pin D cannot be used to bring this input to -3v since it sinks insufficient current.

Direct — Pin P provides a bypass of the diode connected at pin R. This node input can be used with R001 diodes to form a NAnDED input to the W501 as shown in Fig. 1 below. In addition, this input can be used to obtain an integrated input when many contacts or switches are connected as shown in Fig. 2 below. This latter scheme gives an output rise when contacts close.

Integrating — The input to the integrating circuit is a switch or relay contact. To obtain output rise when contacts close connect contacts between pin S and U and connect pins R and T. To obtain output rise when contacts open, connect contacts between pin S and ground, connect pin V to pin S, and connect pin R to pin T.

W501 — \$13.00

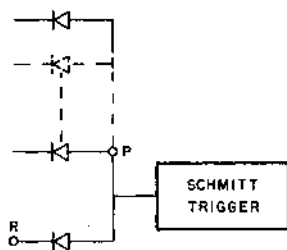


Figure 1. NANDed Input

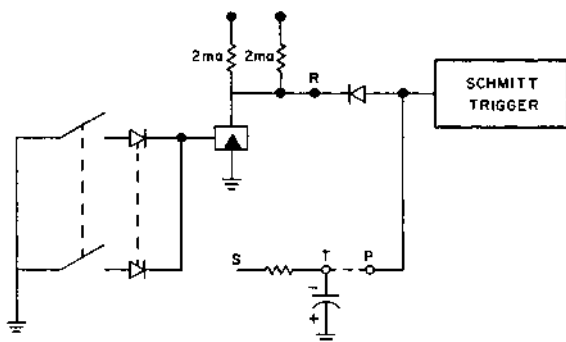


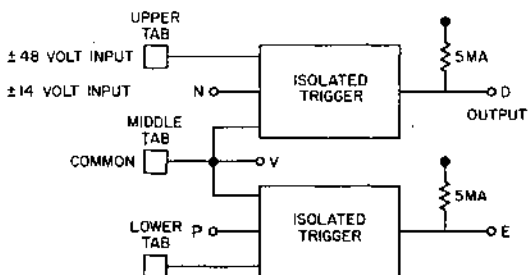
Figure 2. Integrated Input

PHOTON-COUPLED TRIGGER

TYPE W502

W

SERIES



502 PHOTON COUPLED TRIGGER

This special interface module allows process control system 48 volt signals to be transmitted to a digital control over long distances and despite floating supplies and noise. Additional low voltage inputs permit use as a pushbutton input device. Inherent delay in the photon-coupled isolation circuit filters out contact bounce. High voltage connections are at the handle end of the module to optimize isolation.

INPUT: Each input requires 40 ma at nominal input voltage. Input voltage tolerance: $\pm 20\%$. Voltage reversal harmless.

OUTPUT: Each output can drive 15 ma at ground. Output goes to ground when input is energized. Typical switching delay: 20 msec.

WIRING: Three AMP "Faston" tabs replace module handle. Type 914 power jumpers may be used for input connections. Keep input wires separated from logic wiring to avoid interference from transients on 48 volt wires.

POWER: +10v(A)/7 ma; -15v(B)/44 ma.

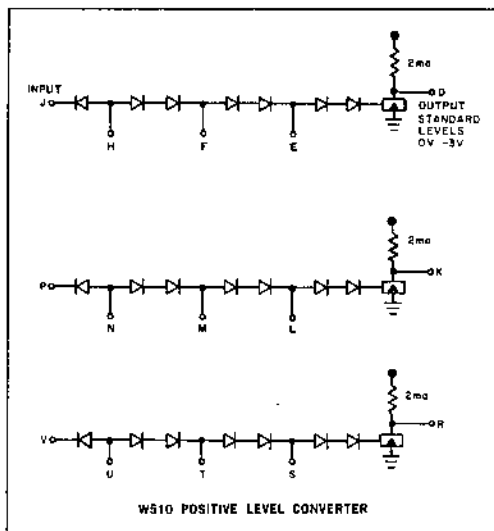
W502 — \$38.00

POSITIVE INPUT CONVERTER

TYPE W510

W

SERIES



The Type W510 Positive Level Converter contains three circuits that convert positive levels to DEC standard levels of ground and $-3v$. Each circuit consists of a grounded-emitter inverter with a diode string between its input and the base of the inverter. By shorting out sections of the diode string, the switching threshold may be varied to either $+2v$,

$+1v$, or $0v$ (see the following table). When the input is more positive than the switching threshold by $1v$, the inverter is cut off and the output is at $-3v$. When the input is more negative than the switching threshold by $1v$, the inverter is saturated and the output is at ground.

| Threshold | Connections | Output = $-3v$ | Output = $0v$ |
|-----------|---------------------|--------------------|--------------------|
| $+2v$ | none | Input $\geq +3.0v$ | Input $\leq +1.0v$ |
| $+1v$ | H & F, N & M, U & T | Input $\geq +2.0v$ | Input $\leq 0.0v$ |
| $0v$ | H & E, N & L, U & S | Input $\geq +1.0v$ | Input $\leq -1.0v$ |

In jumpering pins together to obtain the desired switching point, it is very desirable to use the shortest possible wire. Under no condition may anything else be tied to these pins.

Maximum frequency is 2 mc. Maximum delay for output fall is 100 nsec. Maximum delay for output rise is 60 nsec.

INPUTS: Voltage levels must not exceed $+25v$ or go below $-15v$. For inputs more negative than the

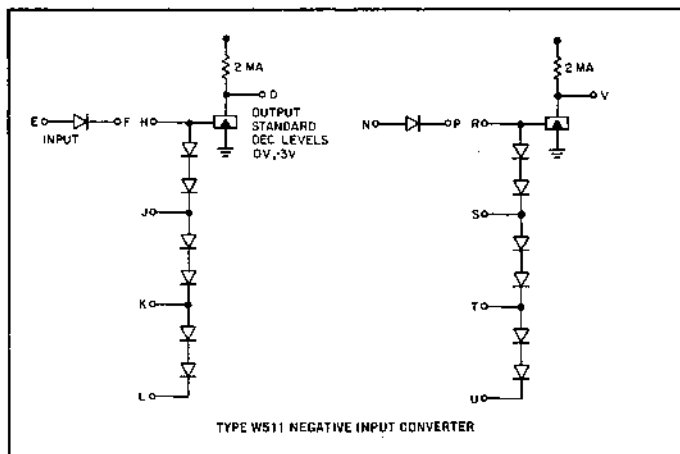
switching threshold by $1v$ or more, the input load is equivalent to 3900 ohms returned to $+10v$. For inputs which are more positive than the switching threshold by $+1.5v$ the input leakage is 100 μa or less.

OUTPUTS: The output is an inverter with a 2-ma clamped load. It can drive 18 ma at ground.

POWER: $+10v(A)/8.0ma$; $-15v(B)/17ma$.

NEGATIVE INPUT CONVERTER TYPE W511

W SERIES



The Type W511 Negative Level Converter contains two circuits that convert negative levels to DEC standard levels of ground and $-3v$. Each circuit consists of a grounded emitter inverter with a string of bias diodes between its base and the input pins. A separate input diode is also provided. By connecting the input diode to various points on the diode

string, the switching threshold can be set at $0v$, $-1v$, $-2v$, or $-3v$ (see the table below). When the input is more positive than the switching threshold by $1v$, the inverter is cut off and the output is at $-3v$. When the input is more negative than the switching threshold by $1v$, the inverter is saturated and the output is at ground.

| Threshold | Connections | Output = $-3v$ | Output = $0v$ |
|-----------|--------------|---------------------|---------------------|
| $0v$ | F & H, P & R | Input $\cong +1.0v$ | Input $\cong -1.0v$ |
| $-1v$ | F & J, P & S | Input $\cong 0.0v$ | Input $\cong -2.0v$ |
| $-2v$ | F & K, P & T | Input $\cong -1.0v$ | Input $\cong -3.0v$ |
| $-3v$ | F & L, P & U | Input $\cong -2.0v$ | Input $\cong -4.0v$ |

In connecting input diodes to the bias string, use short, direct wire. Under no conditions should anything but the input diode be connected to a bias string pin. Inputs must be connected only to pins E and N.

INPUTS: Voltage levels must not exceed $+25v$ or go below $-50v$. Input current required is approximately 1 ma when the input is slightly more positive

than the threshold, rising to a maximum of 4 ma when the input is at $+25v$. Input leakage is $100\text{ }\mu\text{a}$ or less when the input is more negative than the threshold.

OUTPUTS: The output is an inverter with a 2 ma clamped load. It can drive 18 ma at ground.

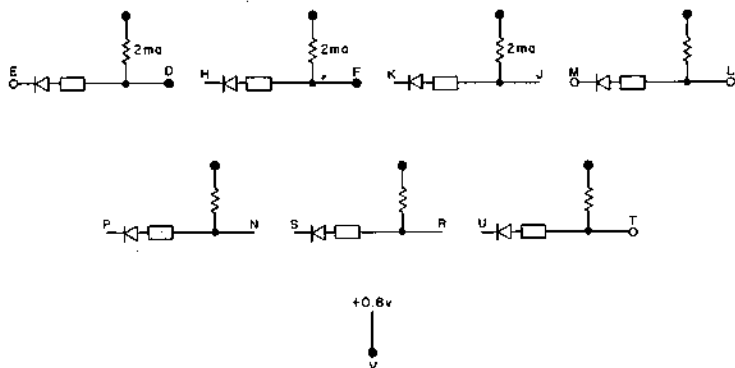
POWER: $+10v(A)/3\text{ ma}$; $-15v(B)/24\text{ ma}$.

POSITIVE LEVEL CONVERTER

TYPE W512

(Single height and width)

W
SERIES



W512 POSITIVE LEVEL CONVERTER

Positive logic systems, such as those using monolithic integrated circuits, can use the W512 to make available standard accessory modules in the W and A series.

Input threshold voltage to each converter is normally 1.6 volts for compatibility with DTL and TTL levels. This threshold can be set at 0.8 volts by grounding pin V for RTL level conversion.

INPUTS: Input current -1 ma or less for input voltages between 0.3 volts and the threshold, 100 ma for

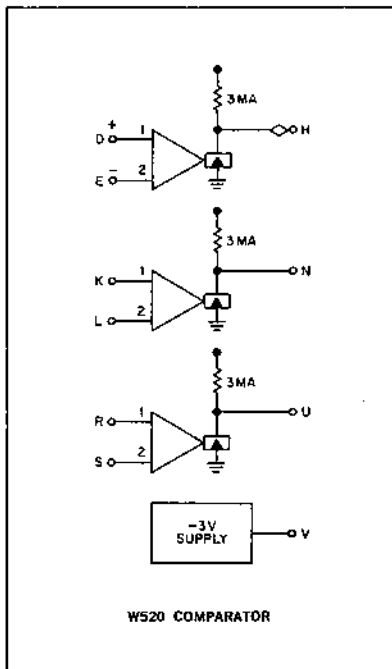
inputs above the threshold. Input voltages must not exceed 6.0 volts with pin V open, or 5.3 volts with pin V grounded. Inputs must exceed nominal thresholds by at least 0.4 volts for full switching with minimum noise rejection.

OUTPUTS: Each output can supply up to 8 ma at ground. Grounded inputs provide grounded outputs and positive inputs provide negative outputs.

POWER: $+10v$ (A)/104 ma; $-15v$ (B)/30 ma.

COMPARATOR TYPE W520

W SERIES



This module is useful as an inexpensive comparator for A/D work, or as a general-purpose input level converter. The W520 contains three four-transistor difference amplifiers which give DEC Standard levels at the output. The state of the output is determined by the relative polarity of the input voltages.

| | |
|-------------------------------|----------------------------------------------------------|
| Max delay for output fall: | } for 200 mv square wave about a fixed reference voltage |
| 75 ns, 50% to 50% | |
| Max delay for output rise: | |
| 150 ns, 50% to 50% | |
| Typical rise time 10% to 90%: | |
| 25 ns | |

The W520 is tested for 100 mv differences minimum. It is not a replacement for the more precise A502.

INPUTS: High impedance inputs to the amplifier are

provided. The more positive input appears as 100 K ohms to $-15v$; the more negative input supplies a maximum of $0.5 \mu a$ from $+10v$ at room temperature. For proper operation of the module, input 2 voltage must remain between $+5v$ and $-10v$, and input 1 between $+10v$ and $-15v$. Input excursions beyond $+10v$ or $-15v$ will cause damage.

OUTPUTS: Standard DEC levels of 0 and $-3v$; capable of driving 17 ma at ground. The internal load is 3 ma. If input 1 is more positive than input 2, the output will be zero. The $-3v$ output should be lightly loaded (less than 1 ma current) by any external path to ground unless an external resistor is added between pin V and -15 volts. Up to 50 ma may be drawn by external path from pin V to $-15v$.

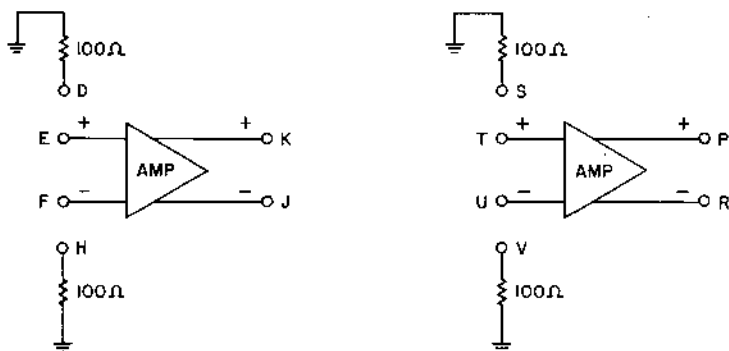
POWER: $+10v(A)/37$ ma; $-15v/32$ ma.

W520 — \$43.00

DUAL AC-COUPLED DIFFERENCE AMPLIFIERS

TYPE W532

W
SERIES



W532 DUAL AMPLIFIERS

The W532 contains two AC-coupled differential amplifiers for use with many magnetic sense systems, including the H201 core memory. These amplifiers provide the high differential gain and common mode noise rejection necessary to amplify information signals in a system using a single sense line per plane for a memory or per channel for a tape system.

INPUTS: Pins E, F, T, U require an input current of 0.15 ma or less and must be terminated to ground through the internal 100Ω resistor or an external resistor or transformer of nominal impedance 1000Ω or less. These terminations bias the inputs at ground. In the absence of common mode signals, the difference signals must not exceed 80 mv for linear amplification. For positive common mode signals the maximum differential input must be reduced by 5mv per half volt of common mode input. Negative common mode voltages allow an increase in maximum differential input by the same ratio. See Table 1 below for additional specifications.

OUTPUTS: The output voltage with no input signal is nominally at -11.5 volts so that a W533 can be used

with a W532 to detect differential signals above a preset threshold. Output impedance is 1000Ω. Due to power supply ripple it is recommended that the output be AC-coupled to other modules. See Table 1 for additional specifications.

TABLE 1. MODULE SPECIFICATIONS

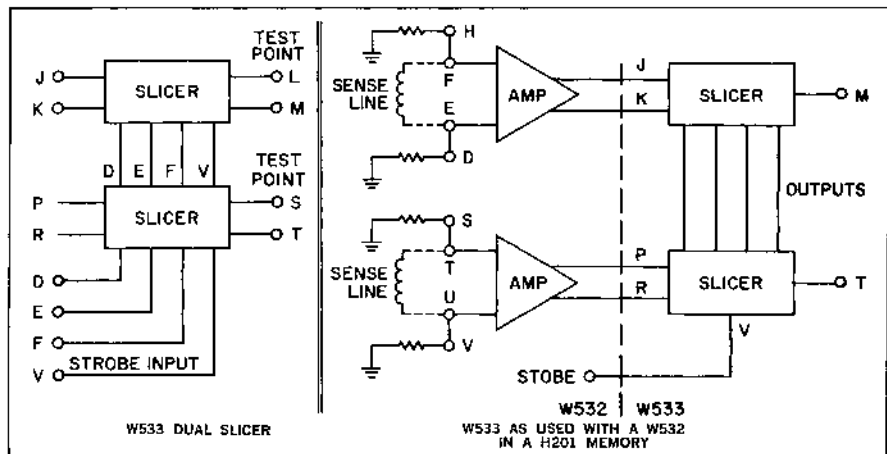
| Specifications | Minimum | Maximum |
|------------------------------------|---------|---------|
| Output Voltage (no signal) | -11.0 | -12.0 |
| Common Mode Input Voltage | -5 | 5 |
| Common Mode Voltage Gain | — | 0.37 |
| Difference Mode Voltage Gain | 88 | 96 |
| Output Rise Time Square Wave Input | — | 250 ns |
| Output Fall Time Square Wave Input | — | 400 ns |
| 3db Bandpass | 1 kHz | 0.8 MHz |

POWER: +10(A)/40 ma, -15(B)/40 ma

W532 — \$30.00

DUAL RECTIFYING SLICER TYPE W533

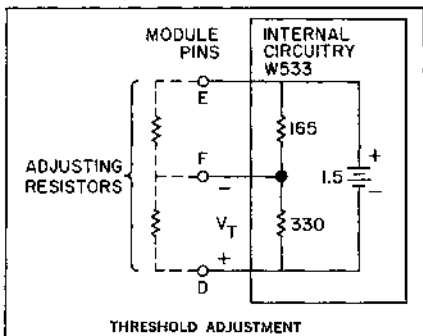
**W
SERIES**



This module is used to detect amplified magnetic system sense signals from a W532 (see above diagram) and convert them to positive DEC pulses. Detection of signals as narrow as 100 nsec is possible over a wide range of detection thresholds. There are two slicer circuits on each W533. Two input terminals per circuit permit rectification so that bipolar difference signals can be sliced and standardized.

INPUTS: AC-coupled inputs J, K, P, and R have an input impedance of $10k\Omega$ and a $1 \mu\text{sec}$ coupling network time constant. When any negative going input exceeds its threshold and a -3 volt to ground strobe pulse is applied at pin V, the output M or T corresponding to the input used will rise to ground. Provided that the strobe pulse is narrower than the time during which the detection threshold is exceeded, the output pulse will be of the same width as the strobe pulse. Input load on pin V is 1 ma to ground. The threshold level is preset at -1 volt, but can be varied by paralleling resistors as shown below. The maximum threshold is -1.5 volts. Pins L and S are test points which will go negative when the

threshold is exceeded. No connections should be made to these points.



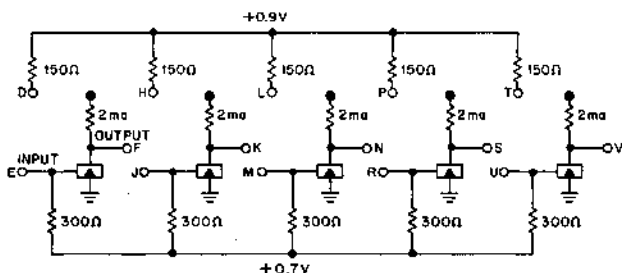
OUTPUTS: Identical to those of a R111 or R123. Drive capability is 20 ma to ground and outputs may be paralleled. Delay from input to output is 50 nsec, from strobe to output 70 nsec.

POWER: $+10(A)/4$ Oms., $-15(B)/28$ ma.

W533 — \$30.00

IBM N LINE TO DEC CONVERTER TYPE W590

**W
SERIES**



W590 IBM N LINE TO DEC CONVERTER

Each of the 5 inverting amplifiers on this module provides input characteristics compatible with three types of IBM N Lines. Input impedance is nominally 300 ohms, with 100 ohm impedance available by connecting 150 ohm shunts provided. Each circuit has a switching threshold near zero volts, with input biasing included to maintain a definite output state when the input is open-circuited.

Unshunted inputs will tolerate input excursions up to +4v and -6v, so these circuits may also be used to convert IBM T, D, or Q lines if the IBM circuits involved can safely drive the W590 input loads.

INPUTS:

| IBM Line | Floating Input | Lower Level | Input Impedance |
|----------------|----------------|---------------------|---------------------------|
| N Transmission | +0.8v | (@ -23 ma) -1.5v | (shunted) 100 Ω |
| C Line | +0.7v | (@ -12 ma) -2.6v | 300 Ω |
| N Logic | +0.7v | (@ -6 ma) -0.8v | 300 Ω |

Maximum input voltages: Unshunted (300 Ω) inputs: +4v, -6v; Shunted (100 Ω) inputs: \pm 4v.

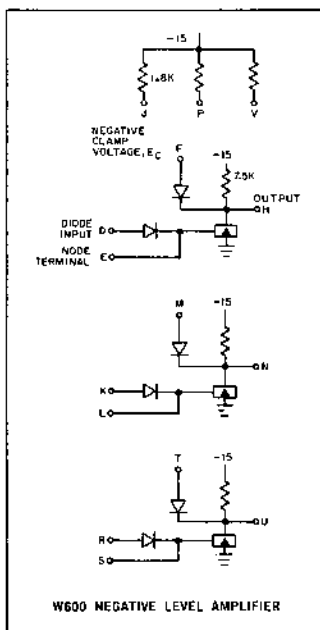
OUTPUTS: 18 ma at ground. 1 ma at -3v.

POWER: +10v(A)/40 ma; -15v(B)/23 ma.

W590 — \$26.00

NEGATIVE OUTPUT CONVERTER TYPE W600

W SERIES



The W600 contains three inverting amplifiers that convert standard levels to outputs of ground and an externally supplied negative voltage. The external clamp voltage is applied to terminal F (M, T) and must be between -1 and -15 v. Additional inputs may be added by tying diode networks, such as those contained on the R001 or R002, to the node terminal. These inputs form a NOR gate for ground levels and a NAND gate for negative levels. That is, if any input diode is at ground, the output is at the external clamp voltage; and if all inputs are at -3 v, the output is at ground.

INPUT: Standard levels. The input load is 1 ma shared by all grounded inputs, including those attached through diode networks to the node terminal.

CLAMP VOLTAGE: The external voltage E_c applied to terminals F, M, and T may be any voltage between -1 and -15 v. The load is 2500 ohms to

-15 v without the extra load resistors or 500 ohms to -15 with the extra loads.

OUTPUT: The output voltage levels are ground and the negative external clamp voltage, V_c . Driving depends on the external clamp voltage and is given in the following table.

| | Maximum Output Current | |
|---------------------------------------------------------------|------------------------|---------------------------|
| | At Ground | At Clamp Voltage |
| Without additional resistor | 18 ma | $\frac{15 + E_c}{7.5}$ ma |
| With additional resistor (H, N, or U connected to J, P, or V) | 10 ma | $\frac{15 + E_c}{1.5}$ ma |

E_c = external clamp voltage, -1 to -15 v. It is therefore a negative number in the above equations.

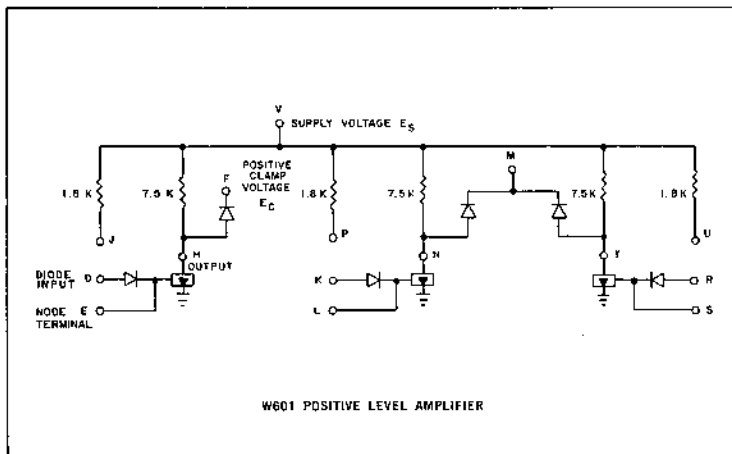
POWER: + 10 v(A)/0.3 ma; -15 v(B)/33 ma.

W600 — \$12.00

POSITIVE OUTPUT CONVERTER

TYPE W601

W
SERIES



The W601 contains three amplifiers for converting DEC standard levels to outputs of ground and an externally supplied clamp voltage level, E_c . This external clamp voltage is applied to terminal F (M) and must be between +1 and +20v. Additional inputs can be added by tying diode networks, such as the R001 or the R002, to the node terminal. These inputs form a NOR gate for ground levels and a NAND gate for negative input levels. That is, if any input diode is at ground, the output will be at ground, and if all inputs are at $-3v$, the output will be at E_c . A positive supply voltage E_s greater than E_c should be tied to terminal V. If E_c is less than +10v, the +10v supply on terminal A may be used at the supply voltage on terminal V.

INPUT: Standard levels. The input load for each amplifier is 2 ma shared by all grounded inputs including those attached through diode networks to the node terminal.

EXTERNAL VOLTAGE: Terminal F (M)—The external clamp voltage E_c applied to terminal F (M) can be between +1 and +20v. The load is 500 ohms to $+E_s$ (if the 1800-ohm resistors are used)

or 2500 ohms to $+E_c$ (if the 1800-ohm resistors are not used). Terminal V—The supply voltage E_s on terminal V should be greater than E_c but not greater than $-120v$. The load is 500 ohms (if the 1800-ohm resistors are used) or 2500 ohms (if the 1800-ohm resistors are not used) to ground.

OUTPUT: Output levels are ground and a positive external clamp voltage, E_c . Output drive depends on the two external voltages. They are given in the table below.

EXTERNAL DRIVING CAPABILITIES OF W601

| | OUTPUT CURRENT | |
|-----------------------------------------------------------------|-----------------------------------|------------------------------------|
| | AT GROUND | AT CLAMP VOLTAGE |
| Without additional resistor | $(20 - \frac{E_c}{7.5})\text{ma}$ | $(\frac{E_c - E_s}{7.5})\text{ma}$ |
| With additional resistor i.e. H (N, T) connected to J, P, or U. | $(20 - \frac{E_c}{1.5})\text{ma}$ | $(\frac{E_c - E_s}{1.5})\text{ma}$ |

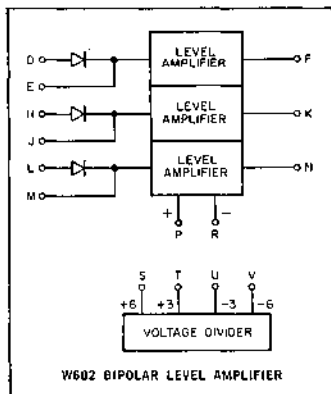
POWER: +10 v(A)/3 ma; -15 v(B)/6 ma.

W601 — \$13.00

BIPOLAR OUTPUT CONVERTER

TYPE W602

W
SERIES



For driving EIA standard communication lines and other applications demanding levels both positive and negative with respect to ground, the W602 provides up to ± 15 ma at up to ± 6 v. There are three inverting amplifiers on the module. To control noise on long transmission lines the output rise and fall times are intentionally slowed to roughly 50 nsec/v, and at low repetition rates capacitance may be connected externally from outputs to ground to further increase rise and fall times. Output upper levels can be set at -6 v, $+3$ v, or 0 v, and lower levels can be set at -6 v, -3 v, or 0 v using clamp voltage supplies provided.

INPUTS: Signals — Diode inputs require 1 ma drive at ground. Input gating can be achieved by connecting R001 or R002 diodes at node inputs. Clamp Voltages — Voltages from 0 v to $+6$ v may be applied to pin P to establish the upper output level for all

three amplifiers. Each circuit whose output is high supplies 4 ma tending to make pin P more positive. Voltages from 0 v to -6 v may be applied to pin R to establish the lower output level for all three amplifiers. Each circuit whose output is low supplies 2 ma tending to make pin R more negative.

OUTPUTS: Signals — Maximum output current from each circuit is ± 15 ma. Outputs are high when inputs are low, and vice versa. Momentary shorts from outputs to ground will not cause damage. If switching speed must be reduced to reduce noise generation, capacitance to ground sufficient to extend transient times to 50% duty factor may be added from outputs to ground. Clamp Voltages — Voltage supplies are adequate for use with the three circuits on the module.

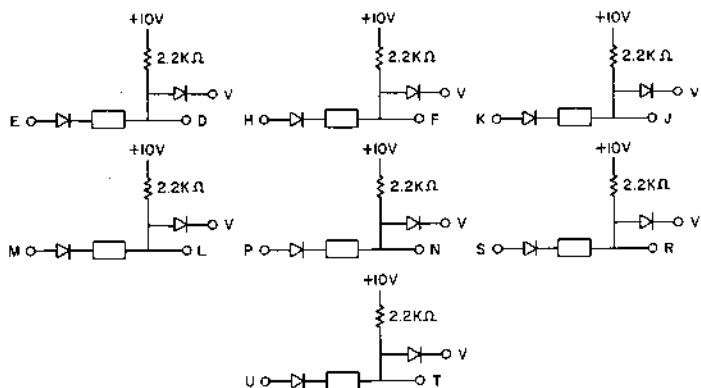
POWER: $+10$ v(A)/32 ma; -15 v/31 ma.

POSITIVE LEVEL AMPLIFIER

TYPE W603

W

SERIES



W603 POSITIVE LEVEL AMPLIFIER

Positive logic systems such as those using RTL, DTL, or TTL monolithic integrated circuits can be driven from FLIP CHIP systems through the W603. Clamped load resistors at the output of each circuit permit output levels to be adjusted to the type of circuit being driven. Normally the clamp voltage at pin V is provided by the logic supply voltage used with the monolithic circuits. This clamp voltage is common to all seven converters on the module.

INPUTS: 1 ma at ground.

OUTPUTS: Each output can supply up to 5 ma at ground. Drive capability at the positive output voltage is provided by internal 2200-ohm resistors returned to +10 volts. The upper positive level will be no more than 0.8 volts above the clamp voltage.

Grounded inputs provide grounded outputs; negative inputs produce positive outputs. Typical rise and fall times are respectively 100 ns and 200 ns.

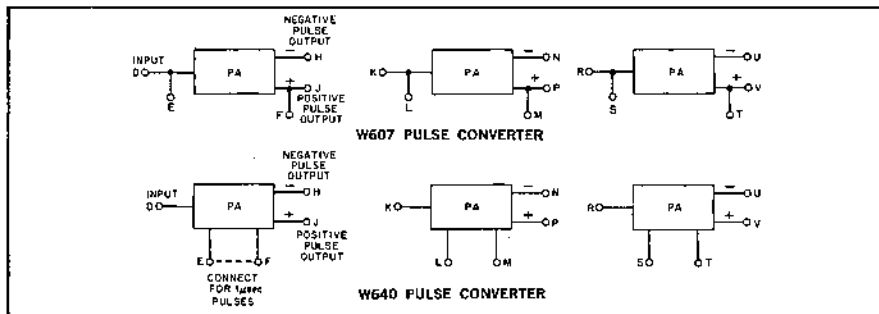
POWER: +10(A)/35 ma, -15(B)/7 ma.

PULSE OUTPUT CONVERTERS

TYPES W607 AND W640

W

SERIES



These pulse converters were designed primarily to facilitate the use of Flip Chip modules in conjunction with Digital Laboratory and System Modules. In addition, the W607 can be useful in setting or clearing B series unbuffered flip-flops via inverters such as B104 or gates such as B113.

Outputs from these pulse converters are taken from floating pulse-transformer windings. In addition to allowing data transmission independent of ground system integrity, this feature permits two or three outputs to be series-connected for larger pulse amplitudes when inputs are driven simultaneously.

For purposes other than driving Digital Laboratory and System Modules, it may be important to consider the effect of pulse transformer backswing at the end of each pulse. When the load is light, this transformer recovery spike approaches the amplitude of the pulse itself.

INPUT: Standard Digital positive pulses or a level change from -3 volts to ground. See table below

for other characteristics. Unless wider than standard output pulses are acceptable, W607 inputs must not be paralleled with clamped loads, such as those internally tied to R107 outputs. W640 output pulse-width is not affected by input loads. No connections should be made to W640 pins E or F (L or M, S or T) other than shorting them together to obtain $1 \mu\text{sec}$ output pulses.

OUTPUT: A standard 2.5v pulse. To obtain a negative output, ground the positive output terminal. To obtain a positive output, ground the negative output terminal. Each output can drive up to 10 ma of load, in addition to a terminating resistor. A terminating resistor must be used. Its value should be about 47Ω for lightest loads, and about 150Ω for heaviest loads. Reactances in loads and leads cause pulses to grow in transmission, and optimum values must be determined empirically. See table for other characteristics.

POWER: W607: $+10\text{v(A)}/0 \text{ ma}$; $-15\text{v(B)}/35 \text{ ma}$.
W640: $+10\text{v(A)}/0 \text{ ma}$; $-15\text{v(B)}/25 \text{ ma}$.

| Module | Input | | | | Output | | | Laboratory Series | System Series |
|----------------------|-------|------------------------|-------------------------|-------------------------|---------|-------------------|------------|-------------------|---------------|
| | Load | Ground | Rise Times | -3 volts | Delay | Width | Max. Freq. | | |
| W607 | 10 ma | $\geq 40 \text{ nsec}$ | $\leq 100 \text{ nsec}$ | $\geq 330 \text{ nsec}$ | 20 nsec | 70 nsec | 2.5 mc | 100 | 1000 |
| W640 | 2 ma | $\geq 70 \text{ nsec}$ | $\leq 250 \text{ nsec}$ | $\geq 1 \mu\text{sec}$ | 40 nsec | 400 nsec | 500 kc | 3000 | 4000 |
| W640 E to F, etc. | 2 ma | $\geq 70 \text{ nsec}$ | $\leq 250 \text{ nsec}$ | $\geq 3 \mu\text{sec}$ | 40 nsec | $1 \mu\text{sec}$ | 200 kc | 3000 | 4000 |

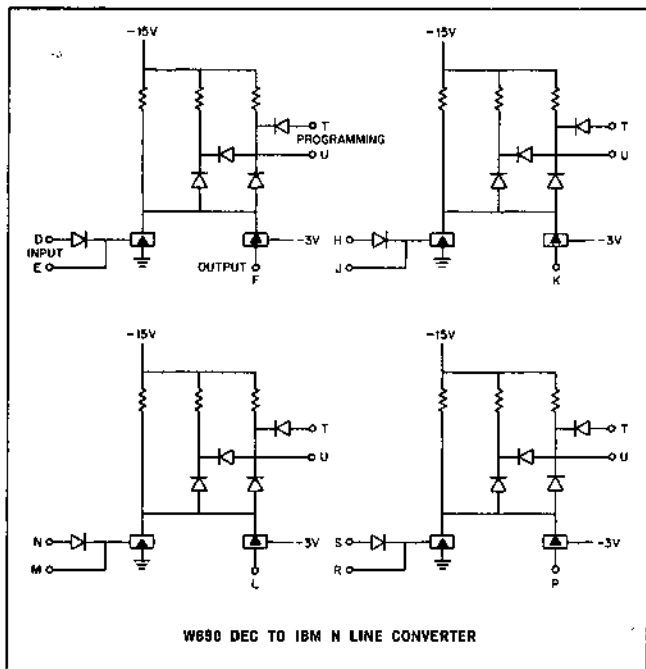
W607 — \$42.00

W640 — \$42.00

DEC TO IBM N LINE CONVERTER

TYPE W690

W
SERIES



Each of the four inverting drivers on this module provides outputs compatible with the three types of IBM N lines, depending upon what output currents are programmed by grounds or open circuits at pins T and U. Node points are provided at each input. Maximum delay: 100 nanoseconds driving N transmission lines.

Outputs will drive loads returned to voltages as high as +12, so this module will also drive T, D, or Q lines with suitable biasing networks added.

INPUTS: 2 ma at ground, 0 ma at -3v in. Node input provided for connection to R001 or R002 diode gate expander cards.

OUTPUTS: Outputs are open for negative inputs. Table below shows nominal output currents for

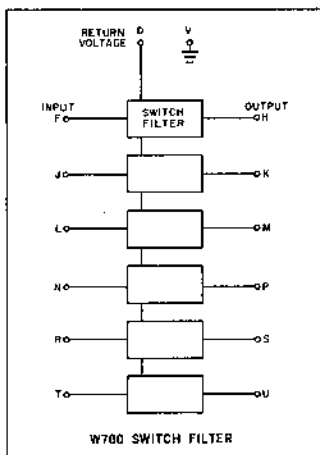
grounded input. Maximum negative output excursions: -3.5v (clamped). Shorting outputs to ground will not cause damage.

POWER: +10v(A)/0 ma; -15v(B)/150 ma.

| IBM LINE | NEGATIVE OUTPUT | OUTPUT PROGRAMMING |
|----------------|-----------------|----------------------|
| N Transmission | 26 ma | T Open U Open |
| ————— | 20 ma | T Ground U Open |
| C Line | 14 ma. | T Open U Ground |
| N Logic | 8 ma | T Ground U Ground |

SWITCH FILTER TYPE W700

W SERIES



The W700 contains six switch filters for reducing contact closures to standard levels. The output drive of the switch filter is determined by the voltage to which the switch contact is returned. For maximum output drive at ground level, terminal D should be connected to -15v and the external contacts should be returned to $+10\text{v}$. In this case, open contacts produce a -3v output, and closed contacts produce a ground output. For maximum output drive at the -3v level, terminal D should be connected to -10v and the external contacts should be returned to -15v . In this configuration, open contacts produce a ground output and closed contacts produce

a -3v output. Typical rise and fall times are given in the table below.

INPUT: When terminal D is connected to -15v , 6 ma flows through a closed contact. When terminal D is connected to $+10\text{v}$, 7 ma flows through a closed contact.

OUTPUT: See table below.

POWER: Terminal D connected to -15v : $+10\text{v(A)}/0\text{ ma}$; $-15\text{v(B)}/31\text{ ma}$. Terminal D connected to $+10\text{v}$: $+10\text{v(A)}/8\text{ ma}$; $-15\text{v(B)}/22\text{ ma}$.

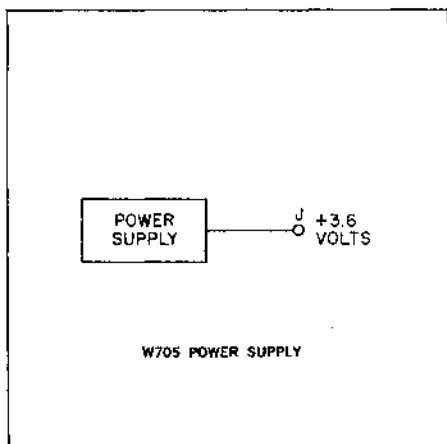
| | Typical Rise Time | Typical Fall Time | Contact Current | Output Drive | |
|-------------------------------------------------------------------------|-----------------------------------|-----------------------------------|-----------------|-------------------------------|-------------------------------|
| | | | | at gnd | at -3v |
| D connected to -15v , switch contact returned to $+10\text{v}$ | 5 msec (switch contacts closing) | 20 msec (switch contacts opening) | 6 ma | 4 ma (switch contacts closed) | 1 ma (switch contacts open) |
| D connected to $+10\text{v}$, switch contact returned to -15v | 25 msec (switch contacts opening) | 3 msec (switch contacts closing) | 7 ma | 1 ma (switch contacts open) | 5 ma (switch contacts closed) |

POWER SUPPLY(+3.6 VOLT)

TYPE W705

(SINGLE HEIGHT, TRIPLE WIDTH)

W
SERIES



This inexpensive power supply is of primary use in conjunction with the W706 and W707 teletype modules. The output can supply up to 1 amp at a nominal voltage of 3.6 volts. Voltage regulation for variable loading is not provided, however, under approximate constant loads the internal filters will minimize supply voltage noise.

It is recommended that this supply be located where air flow is not restricted. Power dissipation is 6-10 watts, depending on load current. This supply should have a minimum output load of 200 ma.

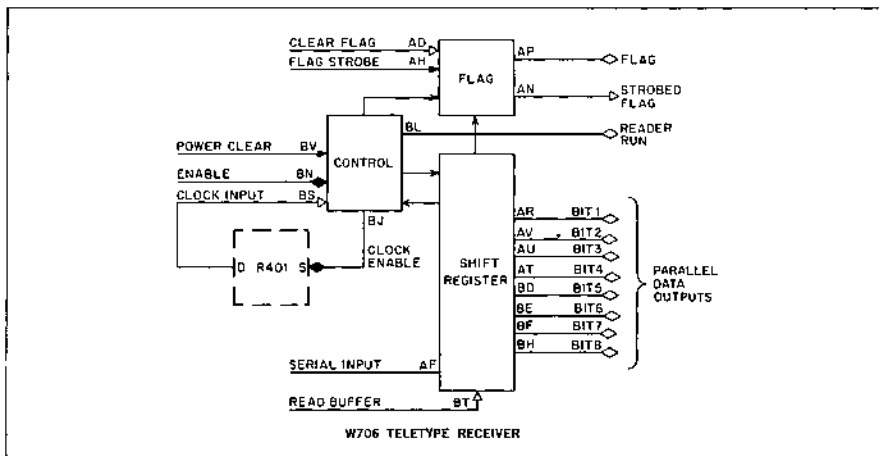
POWER: +10v(A)/1 amp.

TELETYPE RECEIVER

TYPE W706

(DOUBLE HEIGHT)

W
SERIES



The W706 Teletype Receiver is an integrated-circuit, serial-to-parallel Teletype code converter, self contained on a double-height module. This unit includes all of the serial to parallel conversion, buffering, gating, and synchronizing necessary to transfer information between an incoming asynchronous serial teletype line and a parallel binary device. Either a 5-bit serial character consisting of 7.0, 7.5, or 8.0 units or an 8-bit serial character of 10.0, 10.5, or 11.0 units can be assembled into parallel form by the W706 through the use of selective jumpers on the module. The serial input for one character is expected to be in sequence; a one unit -3 volt start signal, the five or eight character bits, a ground level stop signal of 1.0, 1.5, or 2.0 units. When the conversion is complete, the start and stop elements accompanying the serial character are removed. A logical 1 for a character bit is a ground level and a logical 0 is -3 volts. The first bit received on the serial line is Bit 1 at the parallel output.

To perform the serial to parallel conversion, the re-

ceiver continuously examines the serial input line, and when a start element is recognized, the receiver enables the external clock through the Clock Enable Output and synchronizes with the incoming signal.

When the last character bit, either bit 5 or bit 8, is received, the flag is set and a ground level appears at the Flag Output. At this time, the Parallel Data Outputs of the W706 can be examined by a Read Pulse, and if desired, the flag can be cleared by a pulse on the Clear Flag Input. A new serial character must not be put on the Serial Input until the stop time of the previous character is counted out and so indicated by a ground level on the Clock Enable Output. For additional timing information see Figure 1. The W706 may be connected to devices other than a Teletype, providing that their serial output is similar to a Teletype code. Start element noise rejection of the W706 is approximately one volt from ground, requiring a line filter or use of the W708 on noisy teletype lines. To obtain additional Teletype applications data, write for Applications Note AP-W-1.

INPUTS: Standard Digital levels of -3 volts and ground or 400 nsec pulses as generated by module types R602 and W103. Input pins are shown on the diagram above.

CLOCK: 400 nsec positive pulses with a maximum receiver input frequency of 200 kHz. The clock fre-

quency must be twice the required serial input frequency thus defining one unit of character time as two clock periods. Input loading is 2.8 ma at -3 volts. The clock used must be externally gateable and similar to a R401 unless the W706 is used with a W708.

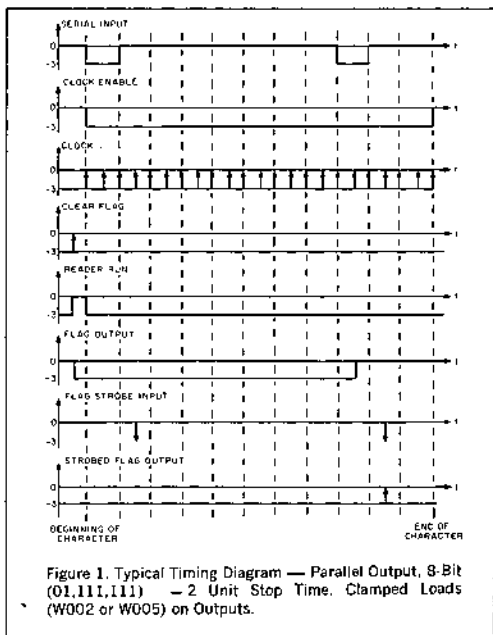


Figure 1. Typical Timing Diagram — Parallel Output, 8-Bit (01,111,111) — 2 Unit Stop Time. Clamped Loads (W002 or W005) on Outputs.

ENABLE: A diode input, which if brought to ground, will disable the clock through clock enable. Disabling (or enabling) the clock during a serial input character can result in incorrect character reception.

CLEAR FLAG: A ground level or Digital standard 400 nsec positive pulse will clear the flag. If a level is used, it must be returned to -3 volts before the flag can be set. Loading is 1.4 ma at -3 volts. Typically the flag is sensed through one of the flag outputs and then cleared.

FLAG STROBE: Digital standard 400 nsec negative pulse or a -3 volt level. Loading is 1.4 ma at -3 volts. This input is Nanded with the flag and provides a ground level Strobed Flag Output signal when the flag is set.

READ BUFFER: A 400 nsec positive pulse provides parallel information from the W706. During this pulse, any bit which is a logical 1 will generate a 400 nsec positive pulse at the corresponding bit output. This input can be held at ground for continuous monitoring of bit outputs. Typically, this pulse is generated after a Flag Output has been sensed so that no incorrect character will be received on the parallel lines. Loading is 2.8 ma at -3 volts.

POWER CLEAR: Same input signals and loading as for Flag Strobe. Initialization of module components by a Power Clear signal is not necessary if the first

character received after power turn-on is insignificant. When not used, Power Clear can be left disconnected.

SERIAL INPUT: Digital standard levels of -3 volts and ground. A ground level during a bit input represents a logical 1. The first character bit to come in on this input appears at Bit 1 output. Loading is 2.8 ma at -3 volts.

OUTPUTS: All outputs are capable of supplying 20 ma at ground. The external load may be connected to any voltage between ground and -20 volts. Clamped loads such as W002 and W005 can also be used.

BITS 1 THRU 8: Buffered outputs generated by Nanding the internal bit and the Read Buffer. A ground level or positive pulse output represents a logical 1 for that bit. Unused outputs can be left open.

FLAG OUTPUT: Ground level output when the flag is set.

STROBED FLAG OUTPUT: Ground level output or pulse output when Flag Strobe is at -3 volts and the flag is set.

CLOCK ENABLE: Used with R401 clock or equivalent to synchronize the clock to incoming serial data. The output is an open circuit whenever a serial input is

present and at ground at all other times. When used with a R401, this output is connected to the enable input of the R401.

READER RUN: Of use in teletypes equipped with relay controlled paper tape readers. The Reader Run Output is enabled (ground level) by a Clear Flag pulse and disabled by the W706 circuitry when a start pulse is received on the serial input. For ad-

ditional information see Figure 1.

JUMPERS: Jumper positions are indicated on the top view physical sketch shown in Figure 2. The W706 is shipped with all jumpers in position.

POWER: -15 (B)/12 ma; +3.6 volts/400 ma. This power is available from a W705 or any commercial supply that has an output regulation of $\pm 5\%$.

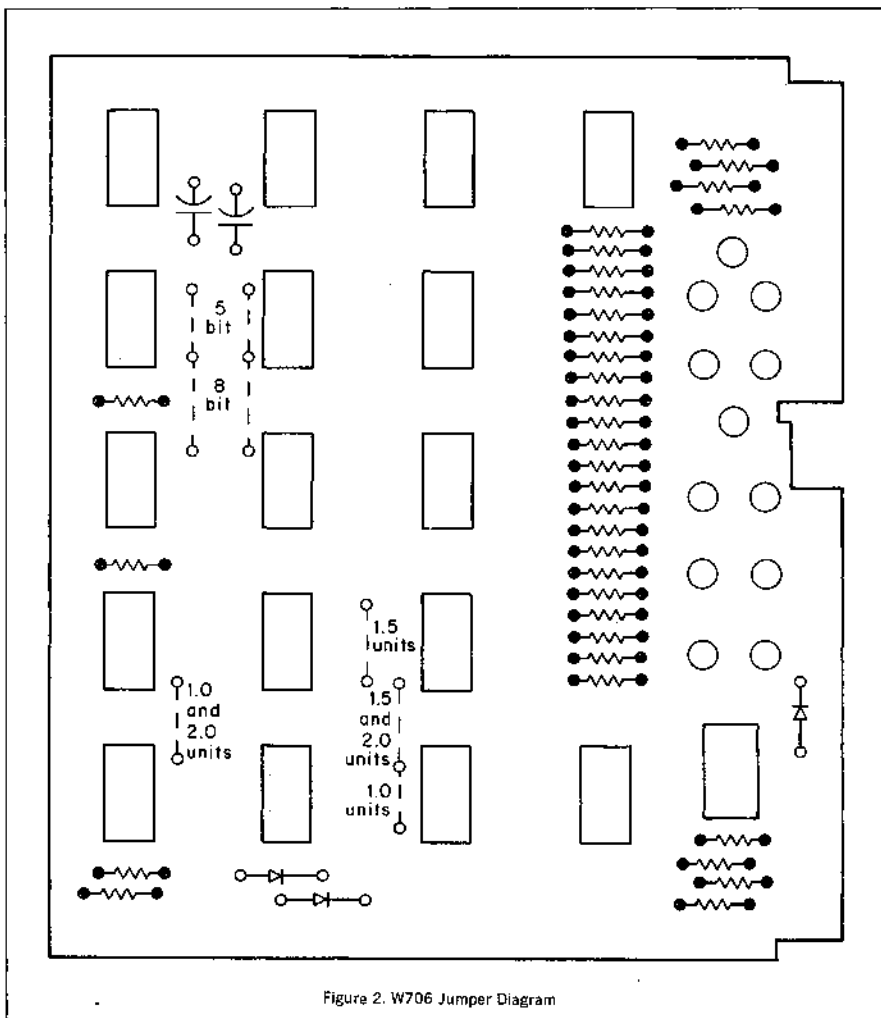


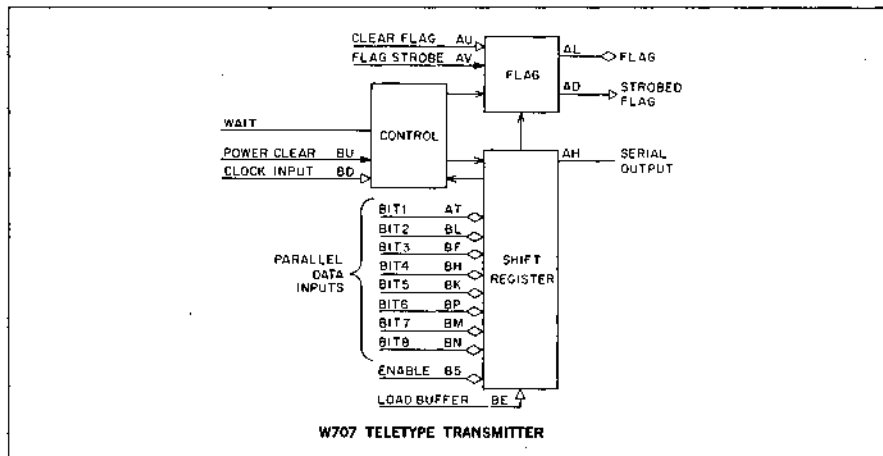
Figure 2. W706 Jumper Diagram

TELETYPE TRANSMITTER

TYPE W707

(DOUBLE HEIGHT)

W
SERIES



The W707 Teletype Transmitter is an integrated-circuit parallel-to-serial teletype code converter, self contained on a double-height module. This unit includes all of the parallel to serial conversion, buffering, gating, and timing necessary to transfer information in an asynchronous manner between a parallel binary device and a serial teletype line. Either a 5-bit or 8-bit parallel character can be assembled into a 7.0, 7.5, or 8.0 unit serial character or a 10.0, 10.5, or 11.0 unit serial character, respectively, by the W707 through the use of selective jumpers on the module. When the conversion is complete, the necessary one unit negative voltage start signal and a ground level stop signal of 1.0, 1.5, or 2.0 units have been added to the original parallel character and transmitted over the serial line. The serial character is transmitted with the start signal first, followed by bits 1 through 8 in that order, and completed by the stop signal. One-half unit after the stop signal is put on the serial line, the flag is set indicating that the previous character has been transmitted and that a new parallel character can now be loaded into the W707. Transmission of this new character will not occur until the stop time from the previous character is completed. See the timing diagram (Figure 1) for additional information.

The W707 may be connected to devices other than a Teletype. For example, two computer systems can be

connected using a serial line as shown in Figure 2. To obtain additional Teletype applications data write for Applications Note AP-W-1.

INPUTS: Standard Digital levels of 3 volts and ground or 400 nsec pulses as generated by modules types R602 or W103. Input pins are shown on the module diagram above.

CLOCK — 400-nsec positive pulses with a maximum transmitter output frequency of 200 kHz. The clock frequency must be twice the required serial output frequency thus defining one unit of character time as two clock periods. Input loading is 2.8 ma at -3 volts.

LOAD BUFFER — A 400-nsec positive pulse which loads the parallel character into the W707. Typically this pulse is generated after a Flag Output has been sensed so that no incorrect characters will be transmitted. Loading is 2.8 ma at -3 volts.

BITS 1 THROUGH 8 AND ENABLE — Digital standard levels or equivalent with input loading 1.4 ma at -3 volts. When an 8-bit character is to be transmitted, all bit inputs are connected to data lines with bit 1 the least significant bit. For 5-bit characters, bits 1 through 5 are connected to data lines with bit 1 the least significant bit. Bit 6 is now used as the

W707 — \$150.00

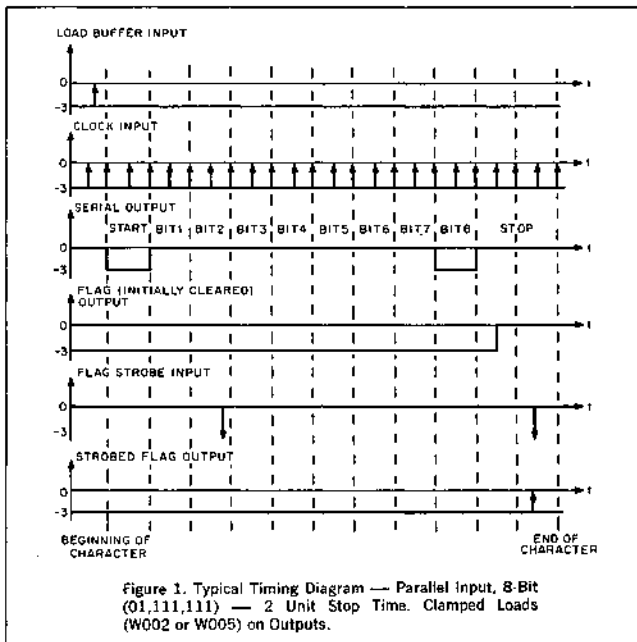


Figure 1. Typical Timing Diagram — Parallel Input, 8-Bit (01,111,111) — 2 Unit Stop Time. Clamped Loads (W002 or W005) on Outputs.

Enable input, and bits 7, 8, and Enable are tied together and either returned to -15 volts through a $2.7K$ resistor or individually connected to W002 clamped loads. If the Enable input (Enable or bit 6 depending on character length) is at -3 volts during a Load Buffer Pulse, the parallel character information is loaded into the W707, but no serial transmission will occur. The Enable input must be at ground during a Load Buffer Pulse for serial information transmission. Ground levels on bit inputs represent a logical 1 or a Teletype "mark," and generate a ground output on the serial line at the corresponding bit times.

CLEAR FLAG: A ground level or DEC standard 400 nsec positive pulse will clear the flag. If a level is used, it must be returned to -3 volts before the flag can be set. Loading is 1.4 ma at -3 volts. Typically the flag is sensed through one of the flag outputs and then cleared.

FLAG STROBE: DEC standard 400 nsec negative pulse or a -3 volt level. Loading is 1.4 ma at -3 volts. This input is NANNDED with the flag and provides a ground level Strobed Flag Output signal when the flag is set.

POWER CLEAR: Same input signals and loading as for Flag Strobe. initialization of module elements by a Power Clear signal is not necessary if the first serial character transmitted after power turn-on need

not be correct. When not used, Power Clear can be left disconnected.

WAIT: This input is available for use with the W708 in half duplex operation. Internal logic levels of $-1.3.6$ and ground appear at this input. It must not be connected to any signal but the WAIT output of the W708. If not used, this input must be left disconnected.

OUTPUTS: All outputs are capable of supplying 20 ma at ground. The external load may be connected to any voltage between ground and -20 volts. Clamped loads such as W002 and W005 can also be used.

SERIAL OUTPUT: Provides the teletype code serial output during character transmission. A logical 1 output is a ground level. If inductive loads are driven by this output, diode protection must be provided by connecting the cathode of a diode to the output and the anode of this diode to the negative supply used at the output.

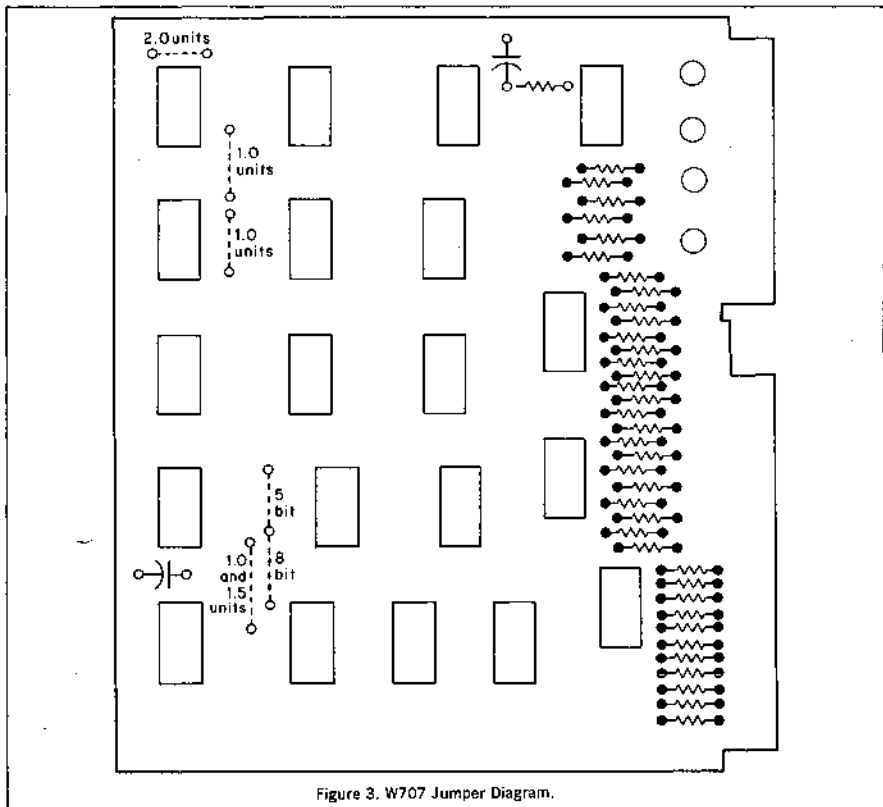
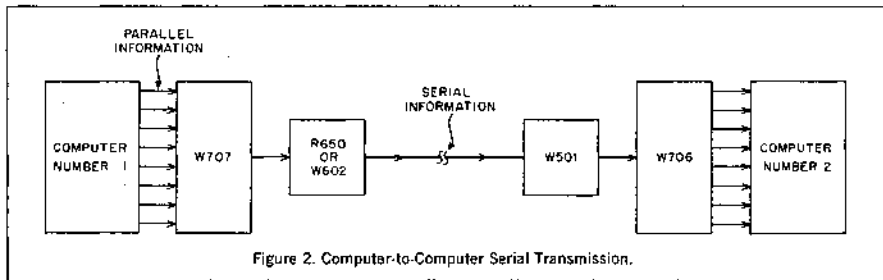
FLAG OUTPUT: Ground level output when the flag is set.

STROBED FLAG OUTPUT: Ground level output when Flag Strobe is at -3 volts and the flag is set.

INVERTER: Pins BJ and AP are the input respectively of an inverter that can be used for any needed buffering. Input load is 1.8 ma at -3 volts.

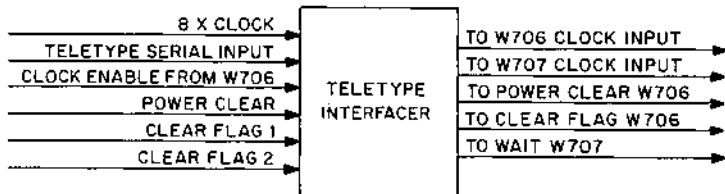
JUMPERS: Jumper positions are indicated on the top view physical sketch shown in Figure 3. The W707 is shipped with all jumpers in position.

POWER: $-15(B)/3$ ma; $+3.6$ volts/400 ma. This power is available from a W705 or any commercial supply that has an output regulation of $\pm 5\%$.



TELETYPE INTERFACER TYPE W708

W
SERIES



W708 TELETYPE INTERFACER

The W708 provides special gating controls and clock synchronization for Teletype and data communications systems, when used with the W706 and W707 Teletype modules. For additional applications data and more complete specifications on the W708, write for Applications Note AP-W-1.

ADDITIONAL FUNCTIONAL CAPABILITY

SPIKE ELIMINATOR: This gating structure provides one-half unit start pulse-noise rejection so that long noisy teletype lines can interface with the W706.

WAIT: Provides the necessary control gating so that the W706 and W707 can be used in half-duplex operation. This control section is used to hold W707 transmission while the W706 is receiving a character.

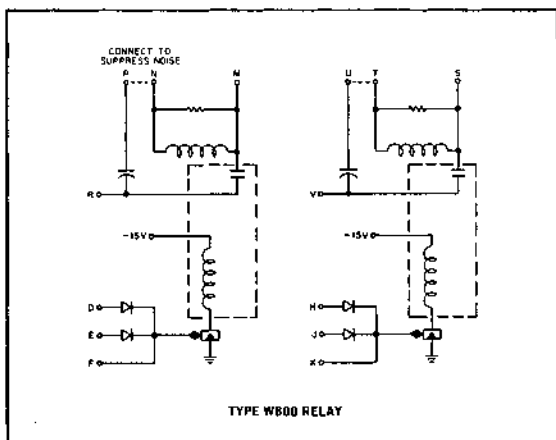
CLEAR FLAG CONVERTER: This control provides additional gating so that the W706 flag can be cleared in either of two modes during half-duplex operation.

SINGLE CLOCK CONVERTER: Reduces the number of clocks needed in a W706 and W707 Teletype system from two to one. This control also allows the use of a non-gateable clock such as the R405 with such a system. The frequency of the required clock is eight times the serial transmission frequency. All start-stop synchronization of the W706 clock input is provided.

POWER: -15(B)/25 ma; +3.6 volts/200 ma. This power is available from a W705 or any commercial supply that has an output regulation of $\pm 5\%$.

RELAY TYPE W800

W SERIES



The Type W800 Relay consists of two separate Form A reed relays, each with an optional protecting circuit. When the protecting circuit feature is desired, N and P (T, U) should be connected together, and the external circuit connected between M and R (S, V). The protecting circuit consists of a capacitor and a parallel combination of an inductor and a resistor. The protection circuit slows down current and voltage rise time at the time of contact closure and voltage rise time at the time of contact closure or opening in order to minimize undesirable effects on sensitive logic in the vicinity of the relay. The

Type W800 is used to drive heavy loads on computer or logic command. The frequency limit is 100 cps. Maximum relay operating time is 2 msec.

INPUT: A Standard Level of $-3v$ operates the relay. Input load is 1 ma at ground, 0 ma at $-3v$, shared by inputs at ground. Pins F and K are for use only with diodes such as R001 and R002. A maximum of 6 in. of wire may be attached to these points.

OUTPUT: The relay contacts close when the input requirements are met. Maximum contact ratings are 250v, 500 ma, 10 watts maximum.

POWER: $-15v/124$ ma; $+10v(A)/0.6$ ma.

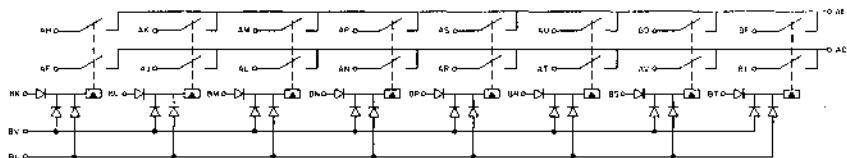
RELAY MULTIPLEXER

TYPE W802

(double height module)

W

SERIES



W802 RELAY MULTIPLEXER

The W802 Relay Multiplexer contains eight double-pole, normally open reed relays. One of its uses is to address memory lines in memory testers. It can also be used as a low-speed multiplex switch where the grounded, low-noise performance of the A111 multiplexer is not required. Maximum closing time: 1.5 msec; typical opening time: 500 μ sec.

INPUTS: Each driver is a 1 ma load shared among

its grounded inputs. Contacts close when inputs are negative.

OUTPUTS: Relay contacts rated at 250v, 500ma, 10 watts maximum. Contact resistance typically 250 milliohms.

POWER: $\pm 10v(A)/2$ ma; $-15v(B)/20$ ma plus 25 ma per energized relay (220 ma max for all relays energized).

BLANK MODULES

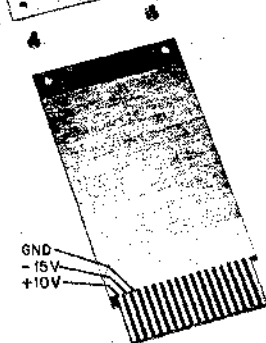
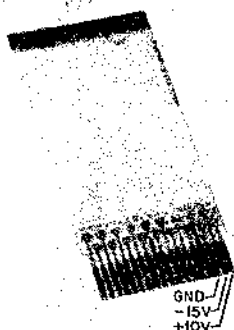
TYPES W970-W973, W990-W995

W SERIES

W970/W990

W972/W992

W994



These 10 blank modules offer convenient means of integrating special circuits and even small mechanical components into a FLIP CHIP system, without loss of modularity. Both single- and double-size boards are supplied with contact area etched and gold plated. The W990 Series modules provide connector pins on only one module side for use with H800 connector blocks. W970 series modules have etched contacts on both sides of the module for use with double density connectors Type H803.

| Type | Pins | Description | Handle | Price |
|------|------|------------------------------------------------------------------------------------------------------------------|----------|--------|
| W990 | 18 | Bare board, split-lug terminals | attached | \$2.50 |
| W991 | 36 | Bare board, split-lug terminals | attached | \$5.00 |
| W992 | 18 | Copper clad, to be etched by user | separate | \$2.00 |
| W993 | 36 | Copper clad, to be etched by user | separate | \$4.00 |
| W994 | 18 | Perforated, 0.067" holes, 18 with etched lands. The holes are on 0.2" centers, both horizontally and vertically. | attached | \$4.40 |
| W995 | 36 | Perforated, 0.067" holes, 36 with etched lands. The holes are on 0.2" centers, both horizontally and vertically. | attached | \$8.80 |
| W970 | 36 | Bare board, no split lugs, similar to W990 | attached | \$4.00 |
| W971 | 72 | Bare board, no split lugs, similar to W991 | attached | \$8.00 |
| W972 | 36 | Copper clad, similar to W992 | separate | \$3.00 |
| W973 | 72 | Copper clad, similar to W993 | separate | \$5.00 |

MODULE EXTENDER TYPE W980

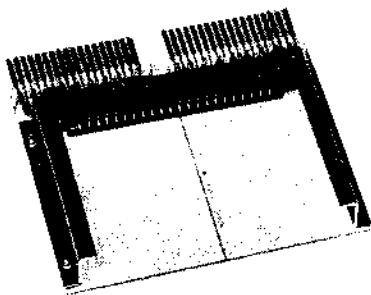
**W
SERIES**



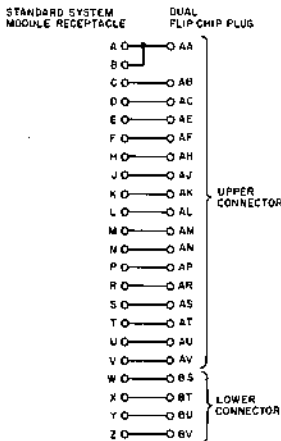
The W980 Module Extender allows access to the module circuits without breaking connections between the module and mounting panel wiring.

**W
SERIES**

SYSTEM MODULE ADAPTER TYPE W985



The W985 is an adapter which permits DEC system modules to be plugged into a FLIP CHIP mounting panel. It requires a block of four (two high and two wide) FLIP CHIP module spaces. The pin connections are made in two vertical slots with all pins being used on the upper connector and only pins S, T, U, and V being used on the lower connector. The two connectors on the component side of the module (to the left as you face the wiring) must be left vacant to accommodate the extra width of the system module. Built on a W991 board.



W980 — \$14.00

W985 — \$34.00



APPLICATION NOTES

ESTIMATING PROPAGATION DELAY

(R107, R111, R113, R121, R123, R151)

**APPLICATION
NOTE**

The chart below shows the effect of logical complexity of R-Series gate delay for output fall. Fall time is often the main source of delay, even though two-thirds of the rise time and only one third of the fall time elapses before the input threshold is reached. This is because the 2 ma load alone must charge wiring and input capacitance during output fall. Ample excess gate output current accelerates rise times, so propagation delay for output rise remains typically 30-40 nsec regardless of fan-out. Gate expansion at node inputs adds 15-30 nsec delay.

If speed is important, excess fanout capability may be traded to obtain it. The dotted line on the chart shows how adding a W005 clamped load affects propagation delay.

There are many factors that influence propagation delay: wiring capacitance, node expansion, enabling of connected gates, even ambient temperature. Since all of these factors together can account for substantial variations, the chart is a guide only.

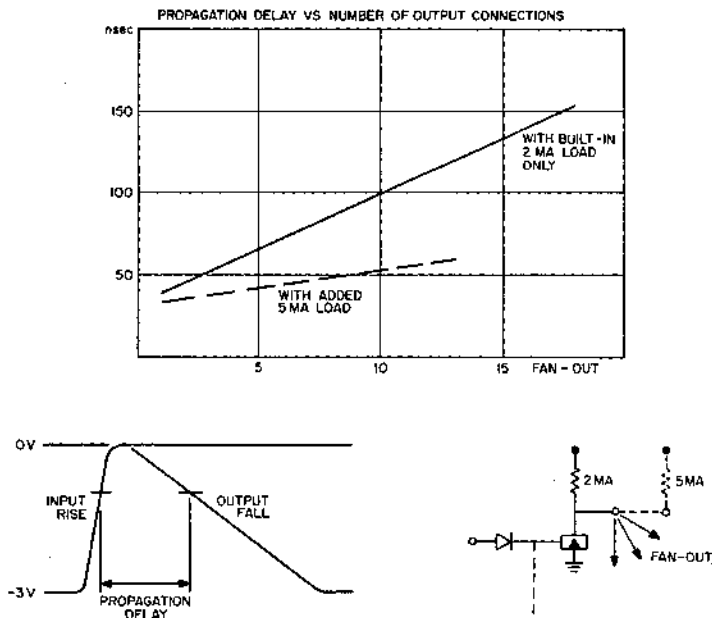


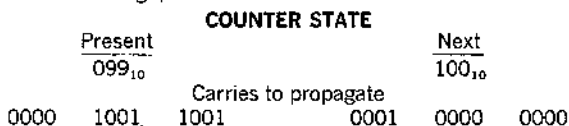
Figure 1 Propagation Delay

BCD COUNTING

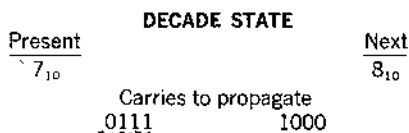
APPLICATION NOTE

It is sometimes preferable to represent binary numbers as decimal, especially when ease or speed of recognition by an operator is an important consideration. Familiar examples are elapsed time measurements, event recording, digital volt meters, and digital servo systems. The Application Note, General Purpose Digital Clock, describes one specific use of BCD counting.

The Application Note on Binary Coded Decimal Codes lists various popular codes in use today. Four of the most commonly used codes are implemented in this application note as single digit (decade) elements. These elements can be cascaded to provide long counting chains by simply connecting the proper carry out of the most significant bit in the decade to the proper carry input of the least significant bit of the next decade. In using the decades as elements in a system, it must be remembered that the longest carry propagation time may not be the time for propagating carries between successive digits (decades) in the counter. In a three digit, 8421 up counter, there are only two such carries between digits and one carry within each digit, as shown.



When one decade is changing from a decimal 7 to a decimal 8 there are three carries which must propagate within the decade itself.



One of the most common BCD codes is 8421 code. Figure 1 is an up counter for this code. The inhibit decade input may be used to turn a counter off from a control level rather than shutting off the pulse train. Note that the level should change at least 400 nsec prior to the next pulse occurring at the pulse input in order for that pulse to be excluded from being counted. Figure 2 is an 8421 down decade. It is more expensive than an up counter because it requires a pair of gates in addition to the DCD gates on the R202's.

Figure 3 is a bi-directional 8421 counter decade that requires level control of the direction of count. The least significant decade of such a counter requires only a single pulse source, so on this digit the up and down pulse inputs may be tied together. It is important that direction levels do not conflict with one another. A ground level enables the direction, so the opposite direction must be at a $-3v$ level. Changes in the direction level should occur at least 400 nsec prior to the next pulse. A single flip-flop may be used to furnish the direction levels in order to prevent conflicts from occurring.

Figure 4 is an 8421 up down counter with pulse control of direction. Here, two separate pulses must be furnished to the least significant digit. Changes in direction should occur no closer than 500 nsec.

Another popular decimal code is 2421. Figure 5 is a 2421 up decade. Figures 6 and 7 are up decade counters for the 5421 and XS3 (excess 3) decimal codes.

When interconnecting decades in a counter configuration it is the positive going edge of a pulse or level that causes the decade to increment or decrement. Figure 8 shows block diagram interconnections for up, down, and up/down decades.

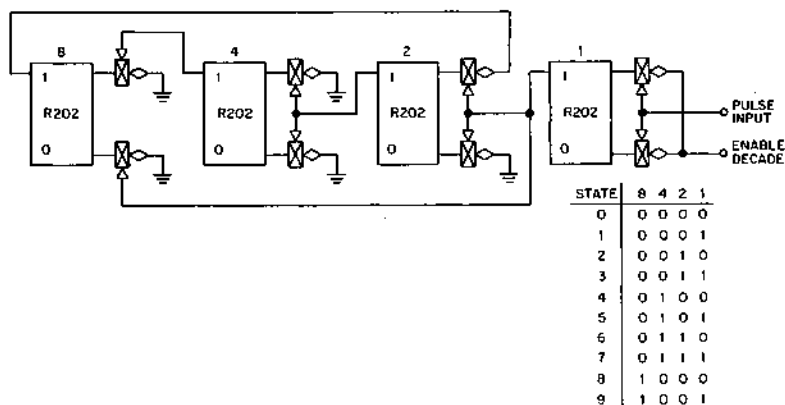


Figure 1 8421 Up Decade

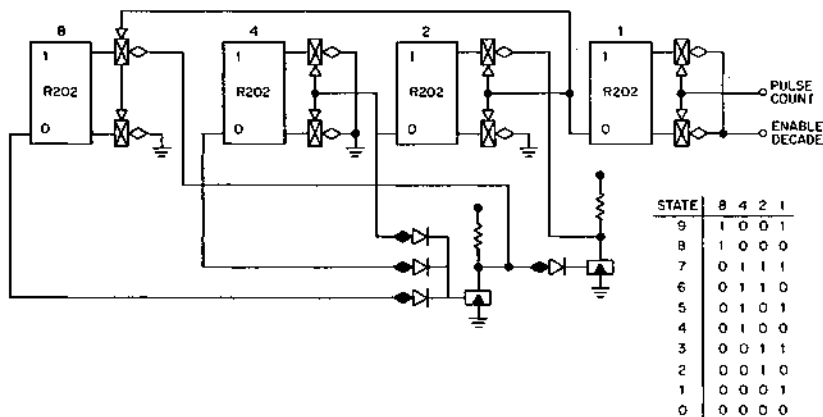


Figure 2 8421 Down Decade

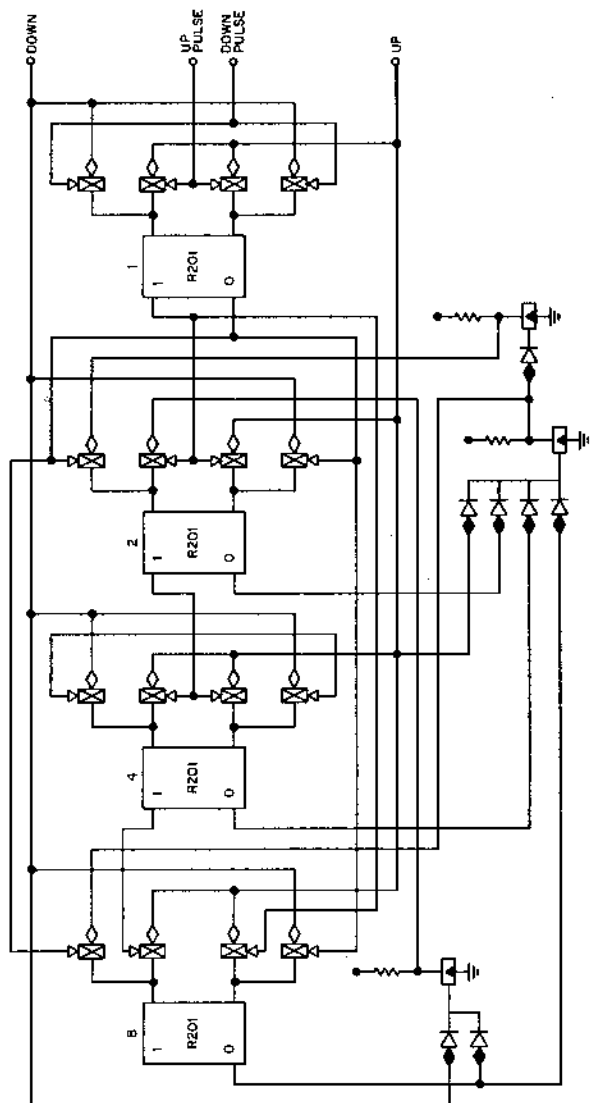


Figure 3 8421 Up/Down Decade, Level Control

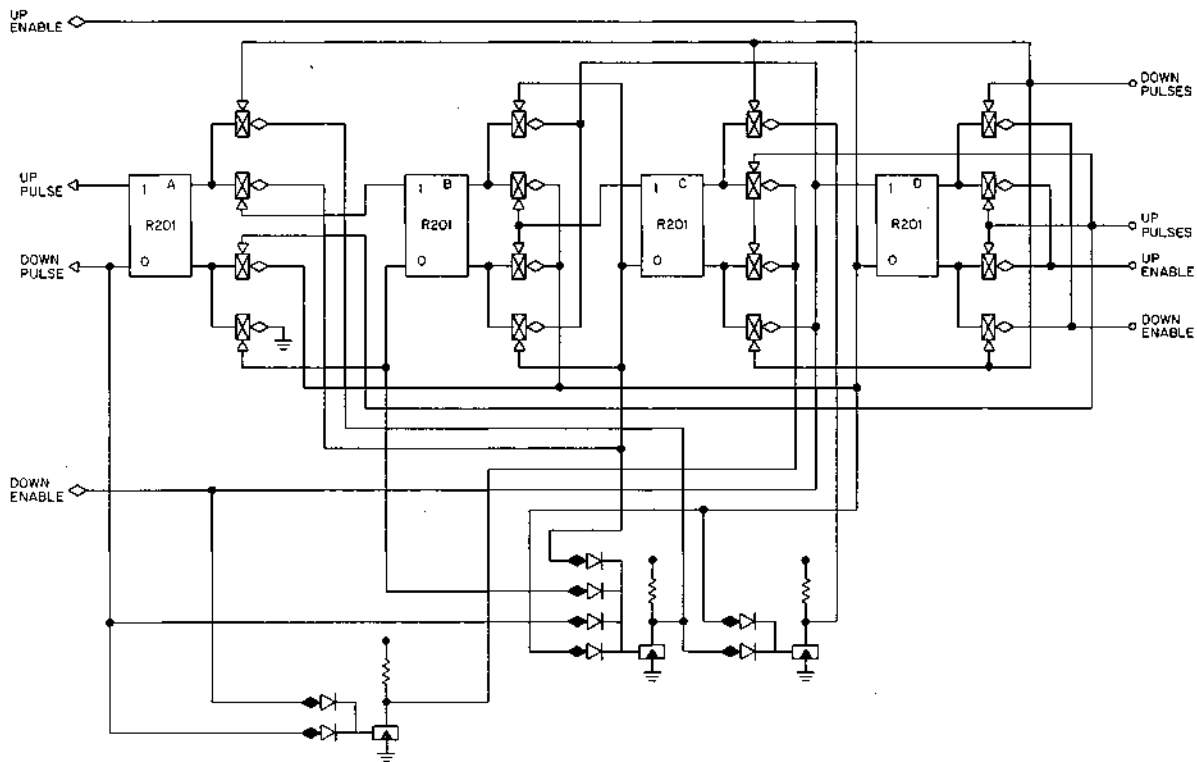


Figure 4 8421 Up/Down Decade, Pulse Control

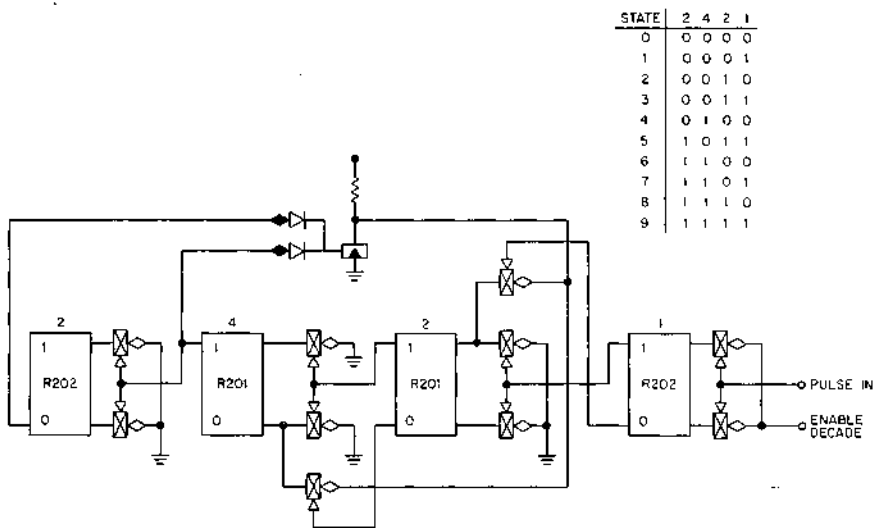


Figure 5 2421 Up Decade

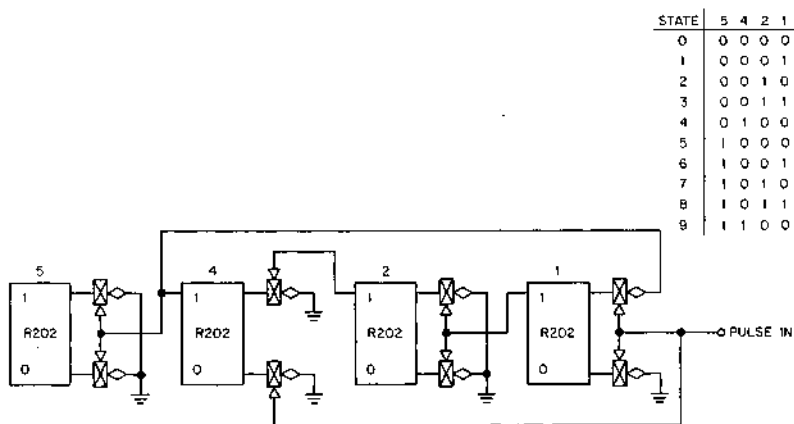


Figure 6 5421 Up Decade

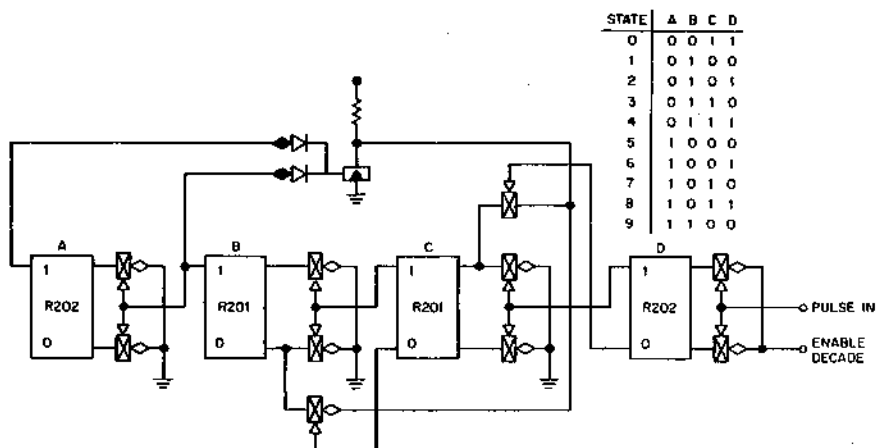


Figure 7 XS3 (Excess 3) Up Decade

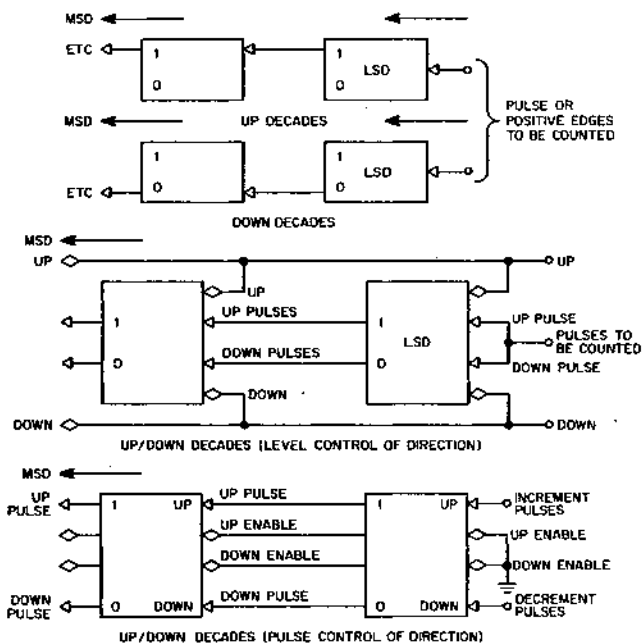


Figure 8 Interconnecting Decades

PARTS LIST

| | Type | Quantity | Description |
|--------------------------------------------------|------|----------|---------------|
| 8421 Up Decade (Figure 1) | R202 | 2 | 2 Flip-Flops |
| 8421 Down Decade (Figure 2) | R202 | 2 | 2 Flip-Flops |
| | R111 | 1 | 3 Diode Gates |
| | R001 | 1 | Diode Network |
| 8421 Up/Down Decade, Level Control (Figure 3) | R201 | 4 | Flip-Flop |
| | R111 | 1 | 3 Diode Gates |
| | R002 | 1 | Diode Network |
| 8421 Up/Down Decade, Pulse Control (Figure 4) | R201 | 4 | Flip-Flop |
| | R111 | 1 | 3 Diode Gates |
| | R002 | 1 | Diode Network |
| 2421 Up Decade (Figure 5) | R202 | 1 | 2 Flip-Flops |
| | R201 | 2 | Flip-Flop |
| | R111 | 1 | 3 Diode Gates |
| 5421 Up Decade (Figure 6) | R202 | 2 | 2 Flip-Flops |
| XS-3 Up Decade (Figure 7) | R202 | 1 | 2 Flip-Flops |
| | R201 | 2 | Flip-Flop |
| | R111 | 1 | 3 Diode Gates |

GENERAL PURPOSE DIGITAL CLOCKS

APPLICATION NOTE

In most digital systems which collect data or record events, it is often desirable to have a general purpose digital clock from which real time of day may be read for recording along with measurements. The clock is also useful for generating periodic time signals which may be used to interrupt a computer when performing periodic scans of inputs, etc.

Such clocks most often derive their base frequency from the line frequency. The rest of the clock is usually a decimal divider chain which keeps track of the hours, minutes, seconds, and any smaller desired increments. The block diagram of the clock is shown in Figure 1.

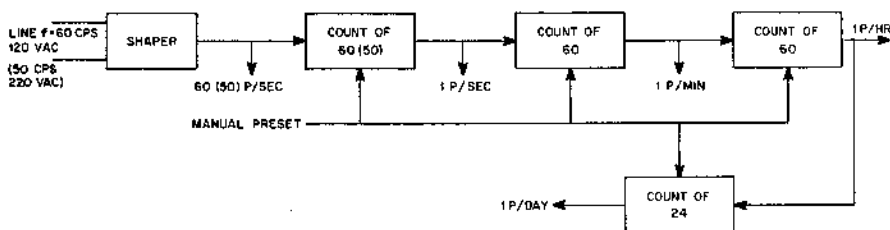


Figure 1 Block Diagram of Clock

Desirable features of such a clock are that it provide 24 hour time, may be preset to any time, may be read as a binary or BCD word, and that single pulses may be derived at periodic intervals for use as an auxiliary signal.

Two designs are offered here are:

- 120v, 60 cps line, BCD clock, and
- 220v, 50 cps line, BCD clock.

The only differences between the clocks are whether or not the first stage is a count of 60 or a count of 50. The count of 60 produces output changes at a 1 pps rate from a 60 cps source, while the count of 50 derives a 1 pps rate from a 50 cps source.

The input network consists simply of a 6.3v rms filament transformer, a small integrator to minimize high frequency noise, and a Schmitt Trigger (W501) to shape the negative portion of the cycle between $-0.75v$ and $-2.25v$ into a pulse which drives between $-3v$ and ground. The positive edge of the output pulse occurs when the input reaches $-2.25v$. Figure 2 shows the shaper.

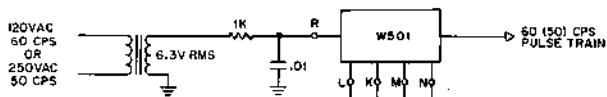


Figure 2 Line Frequency Shaper

The first counter is either for a 60 cps source (Figure 3), or a 50 cps source (Figure 4). The output of this chain is 1 pulse per second. Following this are two counts of 60 providing minute and hourly pulses, and finally, a count of 24 providing daily pulses. (Figure 5).

The preset logic is the same for each counter unit. Figure 6 shows typical preset logic for two digits. Only the bits required for the counter unit are implemented. A block diagram showing the pulse logic for presetting the clock is shown in Figure 7. The one shot (R302) provides a delay between clearing and presetting the bits of the clock, which should be ones. The PA's must generate 400-nsec pulses to insure proper clock clearing.

PARTS LIST

| Type | Quantity | Description |
|------|----------|-----------------------|
| R202 | 14 | Counter |
| W002 | 1 | Preset Logic |
| R111 | 5 | Diode Gate |
| R601 | 1 | Pulse Amplifier |
| R302 | 1 | Delay (One Shot) |
| W501 | 1 | Schmitt Trigger |
| W501 | 1 | Line Frequency Shaper |

Additional Hardware

| | |
|---|------------------|
| 1 | 6.3v fil XFMR |
| 1 | 1K -1/4 watt res |
| 1 | .01 μ f cap |
| 4 | decade switches |

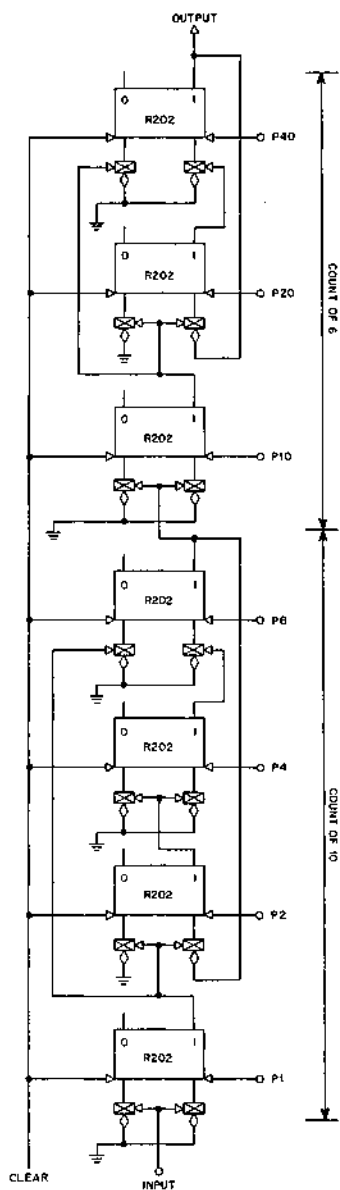


Figure 3 BCD Count of 60 Logic Counts 0 through 59

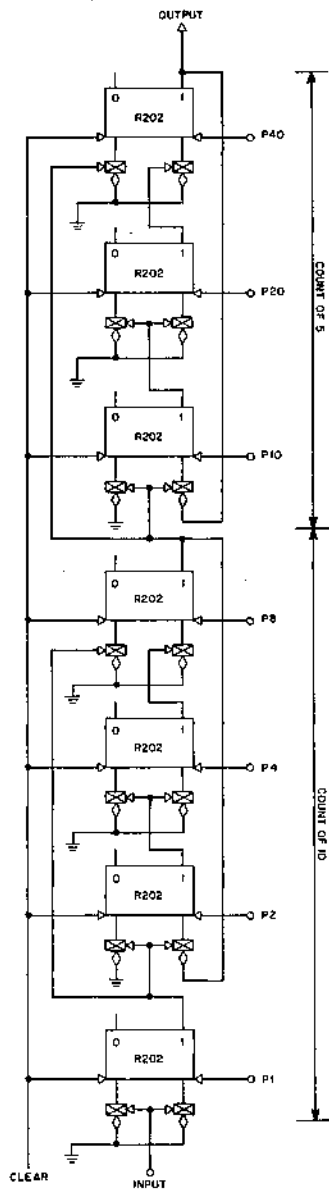


Figure 4 BCD Count of 50 Logic Counts 0 through 49

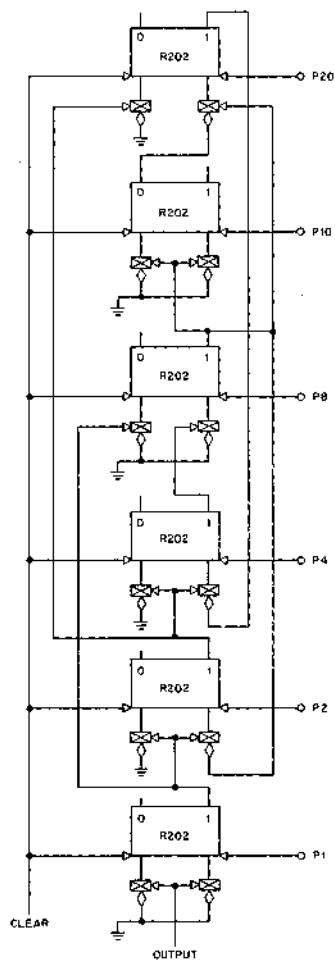


Figure 5 BCD Count of 24 Logic Counts 0 through 23

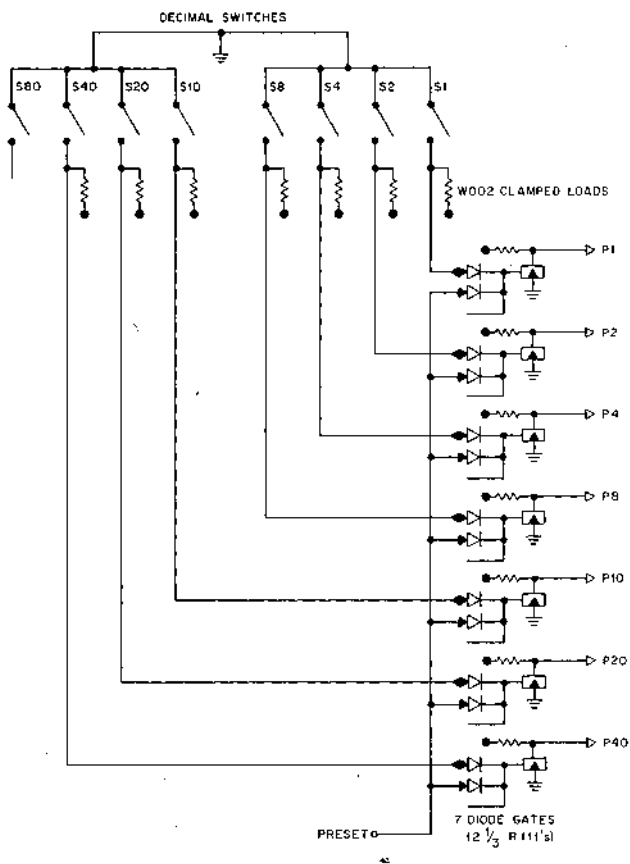


Figure 6 Preset Switch Logic (Hours or Minutes)

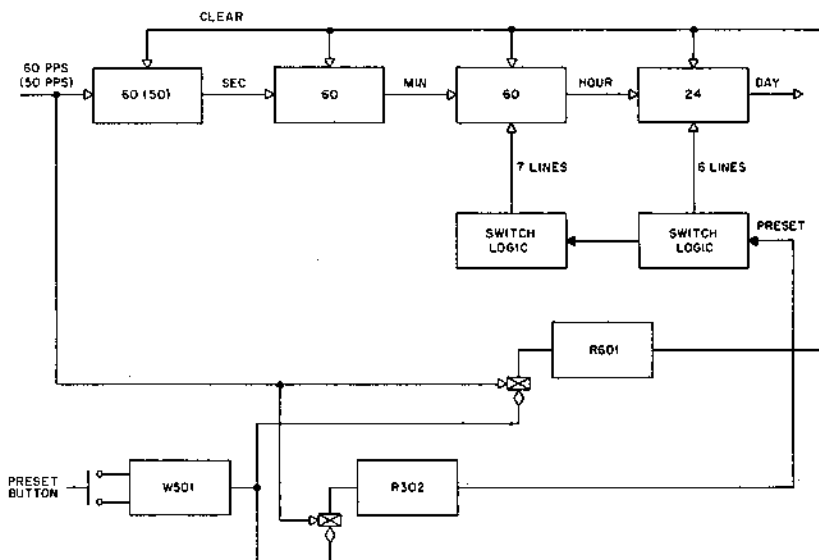


Figure 7 Clock Preset Logic

HIGH-SPEED PARALLEL ADDERS

APPLICATION
NOTE

Parallel adders can be used to add two binary numbers. The augend is called the resident number and is stored in the accumulator register (AC_{0-7}). The addend, or incident number, is stored in the incident register (I_{0-7}). The sum appears in the accumulator. R series Type R201 Flip-flops can be used as shown in the logic diagram, Figure 1. Addition is performed in two steps. The first step is a half-add. Each digit of the accumulator is complemented (made negative) if the corresponding digit of the incident number is 1 (inner pair of DCD gates on AC_{0-7}). The second step is a carry. A carry is generated if a digit in the accumulator is 0 and the corresponding incident number is 1 (R111 gates). A carry is also propagated if an accumulator digit is 1 and it receives a carry pulse from the next less significant accumulator digit (upper DCD gate on each pulse amplifier). Each stage will propagate one carry at most. After all carries have been propagated, addition is complete and the accumulator contains the sum of the incident and the resident numbers.

When the most significant bit is used as a sign bit, a carry pulse amplifier is provided on the input to AC_7 (least significant bit) to provide for End Around Carry (EAC). EAC only occurs when dealing with negative numbers (AC_0 and I_0 are considered the sign bits). If the full 8 bits of the AC are to be used as a positive accumulator, the EAC pulse amplifier must be disabled so that end carries will not affect bit AC_7 .

Overflow can occur only in adding two positive numbers or two negative numbers together (in the latter case it sometimes is referred to as underflow). Overflow is characterized as a carry out of the most significant bit when adding two positive numbers, or a lack of a carry out of the most significant bit when adding two negative numbers. In the case of the unsigned adder (where AC_0 is the most significant bit) the overflow is the EAC pulse. In this case the output of the unused EAC pulse amplifier may be used to set an overflow flip-flop.

Subtraction

An adder may also be used for subtraction. To subtract a number from the accumulator, the AC is complemented and added to the incident number. The result is then recomplemented as the final step.

The steps involved in performing a subtraction depend on whether the 1's complement or the 2's complement number system is used to represent a negative number. Since the 1's complement number system is easiest to implement, it is the one described here. To subtract a number from the accumulator, the steps are (1) complement the AC by means of the complement pulse input, (2) half-add, (3) carry, and (4) recomplement the AC. With this number system, it is necessary to use the end around carry into AC_7 as shown in Figure 1. One's complement subtraction may also be performed by (1) complementing the incident number, (2) half-add, and (3) carry. Note that in 1's complement arithmetic, there are two possible zeros. This is because the 1's complement of $+0$ is -0 (11111111).

When subtraction is included in the arithmetic capability of the unit, the AC and incident numbers must be considered as signed numbers (bits AC_0 and I_0 being the sign bits). Overflow and underflow detection is quite important here, for one of the properties of 1's

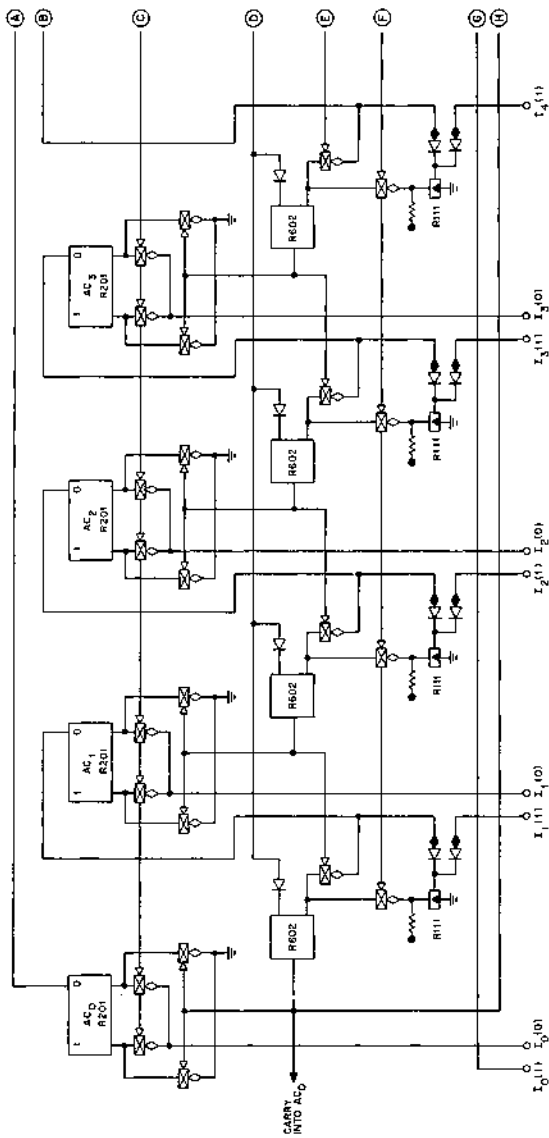


Figure 1a 8-Bit Parallel Adder (4 Most Significant Bits)

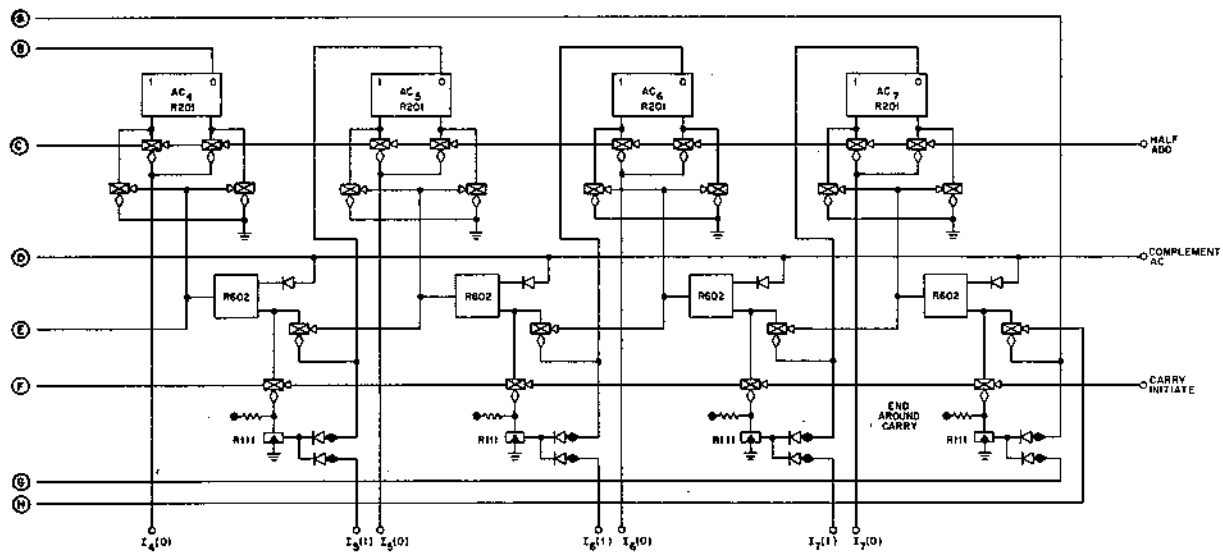


Figure 1b 8-Bit Parallel Adder (4 Least Significant Bits)

complement arithmetic is that the sign of the result is incorrect if overflow or underflow has occurred. Detection of overflow is simply derived from the previous definition of 1's complement overflow. If the result of the sign bit after the half-add is a 0, then the carry into bit AC_n is allowed to set the overflow flip-flop (see Figure 2). Precautions must be taken to prevent this carry from setting overflow when performing a complement of the AC. This may be done by gating AC_n with a status level to indicate that an addition is being performed.

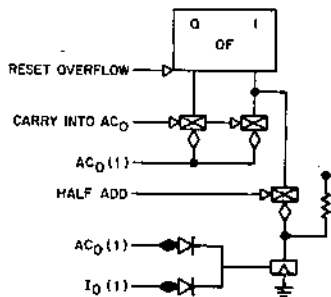


Figure 2 Overflow Logic

Underflow is detected by implementing the rule that no carry into the sign bit occurs. We allow the overflow to set on the half-add step if I_0 and AC_n are both ones. When the carry into AC_n occurs if AC_n is a 0 (after half-add), the overflow flip-flop will reset. If there is no carry into AC_n , the overflow flip-flop remains set indicating an underflow. The overflow flip-flop must not be looked at until after the addition is completed (after carries have rippled). The overflow bit must be reset before the next addition.

The timing for the adder is as follows:

1. Time between half-add pulse and carry initiate: ≥ 500 nsec
2. Time for settling after carry initiate: 560 nsec maximum (EAC initiating a ripple down the length of the counter)

PARTS LIST

| Adder and Control System | | | Overflow Detection | | |
|----------------------------------------------------|----------|--------------------|--------------------|----------|------------------------------------|
| Type | Quantity | Description | Type | Quantity | Description |
| R201 | 8 | Flip Flop | R201 | 1 | Flip Flop |
| R602 | 4 | 2 Pulse Amplifiers | R111 | 1 | 3 Diode Gates (use spare in adder) |
| R111 | 3 | 3 Diode Gates | | | |
| Buffer Register for Incident Number where required | | | | | |
| Type | Quantity | Description | | | |
| R203 | 3 | 3 Flip Flops | | | |

32-POSITION DECODING

APPLICATION
NOTE

A five-bit binary number can be decoded into its 32 permutations by using 32 five-input NAND gates made from: eleven R111, five R001, and six R002, a total of 22 modules. Various classical techniques of decoding can be used to achieve different degrees of simplicity and/or economy. In applying these techniques to the decoding problem the degree of simplicity and/or economy that may be attained is a function of the module configurations available, such as packing density, optimum number of inputs per gate, special matrix configurations of gates, etc.

One of the classical techniques employs a matrix. This method may be used to minimize the number of inputs per gate, but at the expense of increasing the number of gates. In logic configurations which are input limited, this technique may be the only economical solution to the problem. In pure diode logic systems (true AND functions) the technique actually produces more economical results.

In the DEC FLIP CHIP line, the R151 module performs a binary to octal conversion. That is, given both sides of three flip-flops, the module produces eight mutually exclusive outputs which represent the eight permutations of the three flip-flops. Figure 1 shows the truth table for the R151 Binary to Octal decoder.

Truth Table for R151 Binary to Octal Decoder (1 = -3v; 0 = 0v)

| Inputs | | | | | | Outputs | | | | | | | |
|----------------|---|----------------|---|----------------|---|---------|---|---|---|---|---|---|---|
| H | J | F | E | L | K | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2 ² | | 2 ¹ | | 2 ⁰ | | | | | | | | | |
| 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |

In addition to the six input lines for the complementary outputs of three flip-flops, there is one additional input which is a control line. When the control line is at 0 (0 volts), the decoder is enabled and functions according to the truth table. When at 1 (-3 volts), the decoder is disabled and all output lines produce a 1 regardless of input. Note that input pairs (HJ, FE, and LK) represent the 1 and 0 sides of a flip-flop respectively and that the zeros of the truth table on the output lines may be used for the assertion of each of the eight states of the three flip-flops.

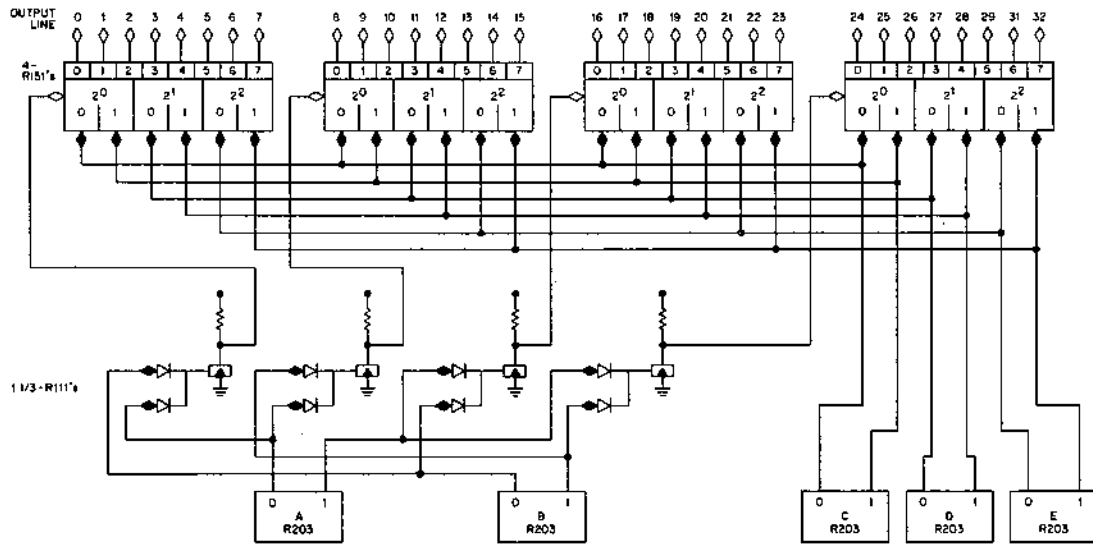


Figure 1 32-Position Decoder

The minimization technique applied in this case to make optimum use of the R151 module involves breaking the five bit binary number into two groups of three bits and two bits each. The least significant three bits may be considered one octal digit. If we now consider the two most significant bits we find that there are only four permutations of these bits. For each of these permutations, the least significant three bits may assume eight unique states for a total of 32 permutations which, of course, is the correct number of combinations of five bits.

To implement this technique, we use four R151's which all have parallel inputs from the least significant three bits. Thus, there will be four out of the 32 lines at ground for each of the eight combinations of the least significant three bits. All that remains now is to turn off three of the four active lines as a function of the most significant two bits. A two bit decoder made from four two-input gates ($1\frac{1}{2}$ R111) will cause one out of its four output lines to be at ground for each of the four permutations of the two input bits. Remembering that the R151 inhibit inputs are enabled by a ground signal, the four unique ground outputs of the two bit decoder furnish the necessary four disabling signals for the four R151's.

PARTS LIST

| | Type | Quantity | Description |
|--------------|------|----------|-------------------------|
| Decoder | R151 | 4 | Binary to Octal decoder |
| | R111 | 2 | 3 two-input gates |
| 5-Bit Buffer | R203 | 2 | 3 Flip Flops |

The W042 driver card was designed to handle a variety of high power driving applications, including stepping motors. Stepping motors come in a variety of types, but the two we will deal with here are the Superior Electric Slo-Syn (model SS50-1001) and the United Shoe Machinery Responsyn (model HDUM-16-100-161). The phasing of the pulses that drive the steppers is varied. Three different phasing requirements and simple methods for deriving them are described in this application note.

Most stepping motors have four leads plus a common lead. To make the motors step, a sequence of pulses on the four leads is required. Three of the desired pulse timings are shown in Figure 1. To reverse the direction of either motor, simply reverse the sequence of pulses.

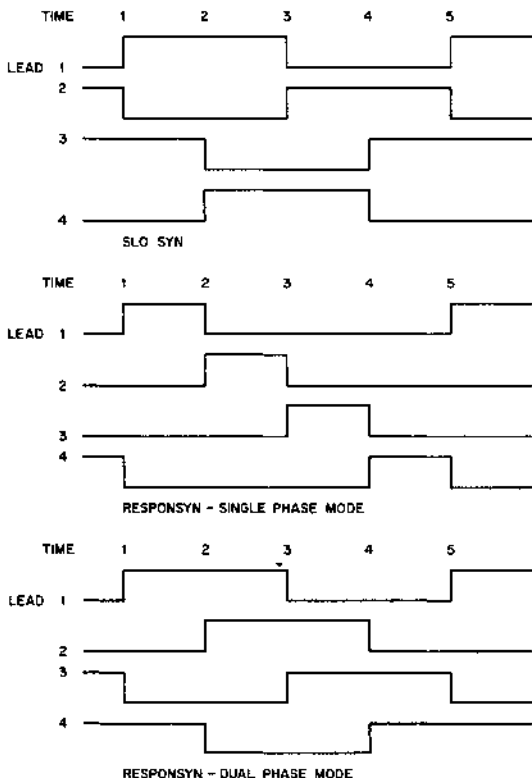


Figure 1 Pulse Timing for Stepping Motors (Positive Level means on)

All of these timing sequences can be generated with two R201's in a switch tail ring counter configuration and the diode gate on the WO42 driver card (two diodes per driver). The basic counter is shown in Figure 2.

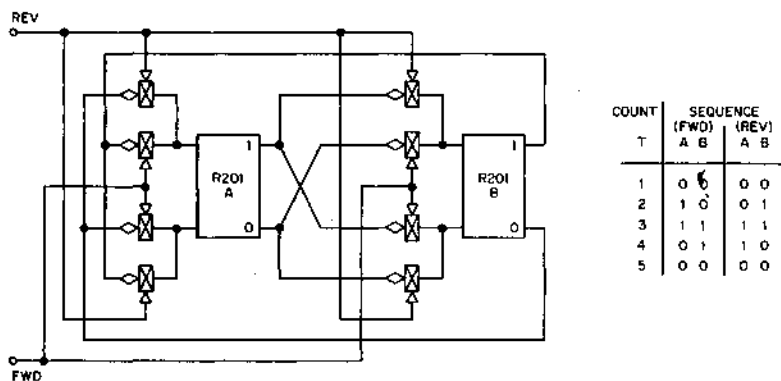


Figure 2 Basic Counter

By using the diode gating, the three different sequences shown in Figure 1 can be decoded from the one counter. Figures 3, 4, and 5 show the pulse sequences and logic diagram for each configuration. The decoding requirements have been simplified to one input per driver in the Slo-Syn and Responsyn single phase mode configurations.

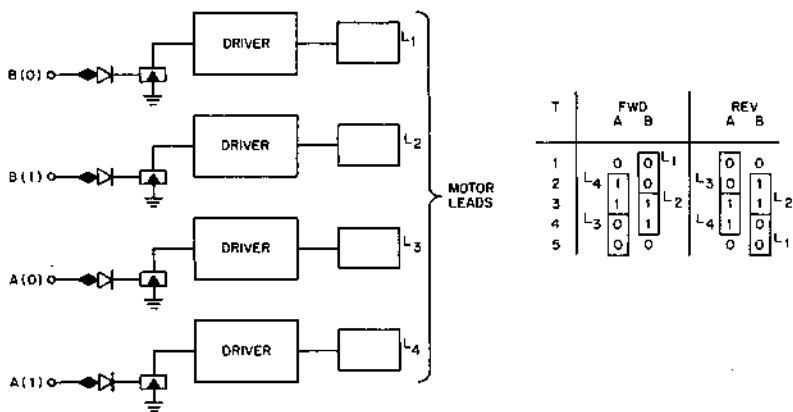


Figure 3 Slo-Syn Configuration

| T | FWD | | | REV | | |
|---|-----|---|----------------|-----|---|----------------|
| | A | B | | A | B | |
| 1 | 0 | 0 | L ₁ | 0 | 0 | L ₁ |
| 2 | 1 | 0 | L ₂ | 0 | 1 | L ₄ |
| 3 | 1 | 1 | L ₃ | 1 | 1 | L ₃ |
| 4 | 0 | 1 | L ₄ | 1 | 0 | L ₂ |
| 5 | 0 | 0 | L ₁ | 0 | 0 | L ₁ |

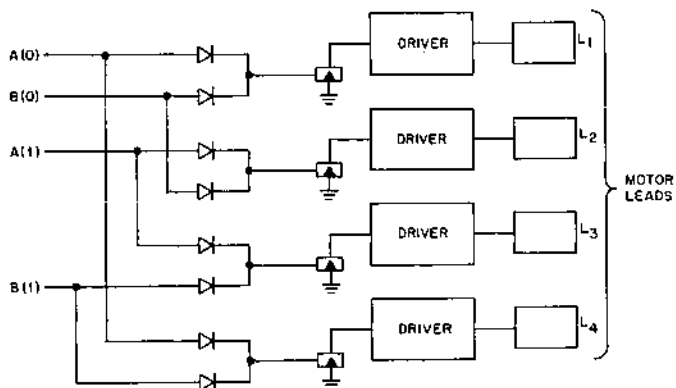
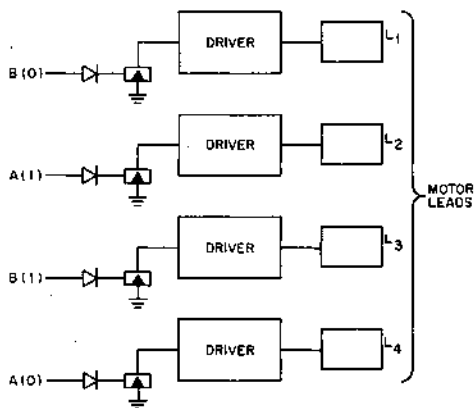


Figure 4 Responsyn Single Phase Mode Configuration



| T | FWD | | | REV | | |
|---|-----|---|----------------|-----|---|----------------|
| | A | B | | A | B | |
| 1 | 0 | 0 | L ₁ | 0 | 0 | L ₄ |
| 2 | 1 | 0 | L ₂ | 0 | 1 | L ₃ |
| 3 | 1 | 1 | L ₃ | 1 | 1 | L ₂ |
| 4 | 0 | 1 | L ₄ | 1 | 0 | L ₁ |
| 5 | 0 | 0 | | 0 | 0 | |

Figure 5 Responsyn Dual Phase Mode Configuration

The W042 driver board supplies current from -15v to the motor leads. Generally, some external resistance will be required. The Slo-Syn motor SS50-1001 is rated at 14 v and requires little to no external resistance. The time constant of the motor coils is smaller than its minimum pulse period and does not require external resistance to decrease it (only to insure proper motor dissipation).

The Responsyn HDUM-16-100-161, however, is a 4 v motor and has a time constant which is larger than the minimum pulse period. It requires the external resistance and higher supply voltage to insure maximum running rate. The values of external resistance depend upon the motor parameter and coil configuration. Two such configurations are shown in Figures 6 and 7. Also, the dissipation requirements of the W042 driver must be obeyed. See the W042 data sheet for use restrictions.

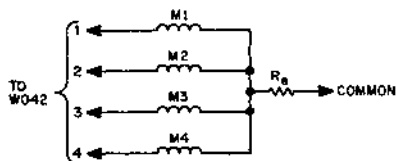


Figure 6 External Resistance for Slo-Syn and Responsyn (dual phase mode only)

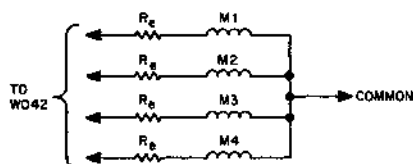


Figure 7 External Resistance for Responsyn (single phase or dual phase modes)

Stepping Motor Characteristics

| Motor | DC Volts | Amps/Winding |
|----------------|----------|--------------|
| Slo-Syn Motors | | |
| SS50 -1010 | 2.0 | 3.3 |
| SS50 -1009 | 5.5 | 1.3 |
| SS50 -1008 | 8.0 | 0.85 |
| SS50 -1001 | 14.0 | 0.53 |
| SS150-1023 | 1.4 | 8.5 |
| SS150-1009 | 2.5 | 4.0 |
| SS150-1010 | 10.0 | 1.25 |
| SS250-1006 | 2.5 | 5.0 |
| SS250-1002 | 9.0 | 1.55 |

Responsyn Motor

HDUM-16-100-161 4 7.3

Slo-Syn SS150 series:

| | | | | |
|-----------------------|----------------------|-------------|-------------|------------|
| Static Holding Torque | 310 oz.-in. | | | |
| Resolution | 1 part in 200 (1.8°) | | | |
| Speed | 50 s/sec | 100 s/sec | 150 s/sec | 200 s/sec |
| Torque | 156 oz. in. | 125 oz. in. | 100 oz. in. | 62 oz. in. |

Responsyn HDUM-16-100-161

| | | | |
|-----------------------|----------------------|-------------|------------|
| Static Holding Torque | 375 oz. in. | | |
| Resolution | 1 part in 800 (0.4°) | | |
| Speed | 200 s/sec | 400 s/sec | 800 s/sec |
| Torque | 100 oz. in. | 100 oz. in. | 75 oz. in. |

The Slo-Syn motor has a solid, conventional motor rotor, and hence a high inertia.

The Responsyn motor has a thin wall cup rotor with essentially negligible inertia.

PARTS LIST

| Type | Quantity | Description |
|------|----------|--------------------------------|
| R201 | 2 | Flip Flop (Translator) |
| W042 | 1 | 10-amp Driver (Driver/decoder) |

GENERATION OF PSEUDO-RANDOM SEQUENCES

APPLICATION
NOTE

In transmitting information digitally, it is often desirable to code it in such a way that a single bit of data is represented by a burst of pulses. Such techniques are useful in combatting noise and interference of the type encountered in sonar, radar, and high-frequency communications. Codes having special autocorrelation properties are widely used for this purpose. Receiving systems can be constructed which will produce an analog output whose shape is similar to the autocorrelation function of the coded signal. This analog output signal is developed as the code train passes through a filter which is "matched" to the coded sequence. The signal out of such a filter is usually a narrow pulse similar in shape to the single bit of information which was encoded originally.

BARKER CODE

One of the earliest codes used for this purpose was the Barker code, which was seven bits long. It is a bipolar signal as follows:

$$+1, +1, +1, -1, -1, +1, -1$$

A digital matched filter for receiving such a code could be implemented as shown in Figure 1. It will be observed that a signal coded in this fashion and having a peak amplitude of E will be compressed into a single spike having a peak amplitude of $7E$.

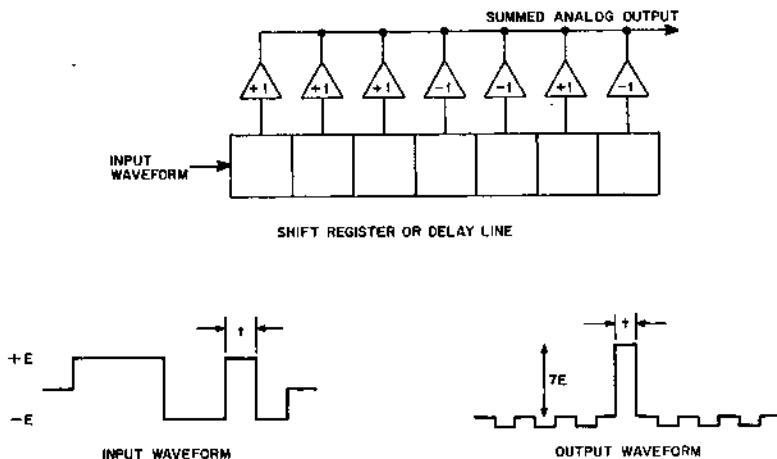


Figure 1 Barker Sequence

In addition, various sidelobe signals having an amplitude of $-E$ will be present. The width of both the main lobe and the side lobes is equal to t , the sub-interval used in the pulse sequence. In order to identify the position of the received bit of information in time, it is necessary to detect it at a threshold above the sidelobe level. The peak-to-sidelobe ratio is therefore a characteristic of some importance in the choice of a sequence for pulse compression. The Barker Code is one of a family of sequences having such properties. They are commonly referred to as maximal-length, or merely M-sequences. This reference is to the fact that a code of length $2^n - 1$ can be generated by using a shift register only n bits long. Because of the ease with which these codes can be generated and detected, they are becoming widely used in communications and control systems.

31-BIT SEQUENCE GENERATOR

Figure 2 shows a five-bit shift register and the necessary control electronics to generate a sequence which is 31 bits long. It is a slight modification of a ring counter in that it uses an exclusive OR condition of the state of the third and the fifth flip-flops to determine whether a 1 or a 0 is to be set into the first flip-flop on each shift operation. The state of the fifth flip-flop may be used to generate the code shown.

A filter matched to this sequence could be constructed either from a linear tapped delay line or its digital equivalent, a shift register. In either case, a resistive summing network could be used to produce an analog output which should be similar in shape to the auto-correlation function of the sequence. The following module list includes the modules necessary to construct an N-sequence generator and also a 31-bit shift register to receive it. The control electronics will include a clock which will sample the incoming waveform at a rate at least twice the bit rate used in sending the compressed signal.

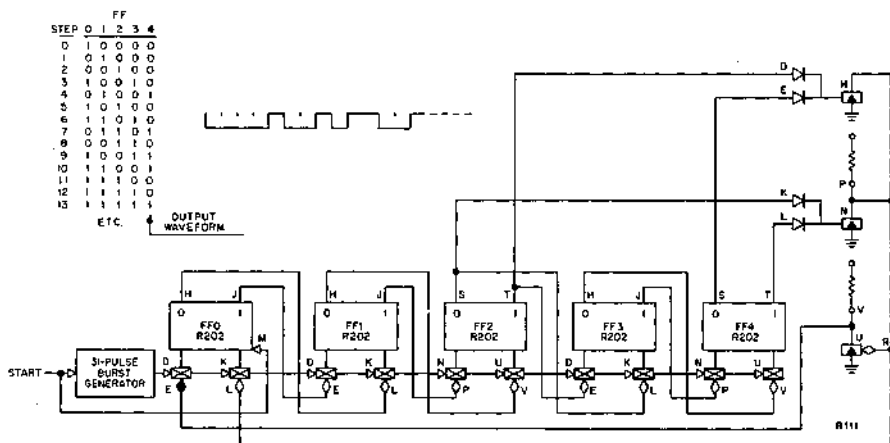


Figure 2 M-Sequence Generator

PARTS LIST

| | Type | Quantity | Description |
|------------------------|------|----------|--------------------|
| Shift Register | R202 | 3 | 2 Flip-Flops |
| | R111 | 1 | 3 Diode Gates |
| Burst-of-31 | R202 | 3 | 2 Flip-Flops |
| | R302 | 1 | 2 Delays (oneshot) |
| | R602 | 1 | 2 Pulse Amplifiers |
| Matched Digital Filter | R202 | 17 | 2 Flip-Flops |
| | R401 | 1 | Variable Clock |

PART III: LOGIC LABORATORY



INTRODUCTION

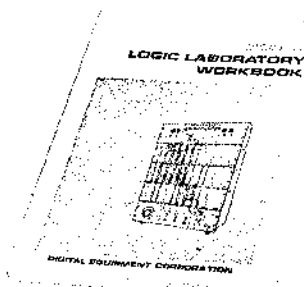
The DEC Logic Laboratory is a low cost device for use in laboratory training, function breadboarding, and testing. When used in conjunction with the Logic Laboratory Workbook, a student who is not completely familiar with digital logic can quickly learn to construct operating logical networks and understand their function. In addition to the training function, the Logic Laboratory can be used to breadboard complex algorithms in order to verify the logic design prior to its inclusion in a system.

The Laboratory is also a very effective tool for testing individual logic modules as is evidenced by the fact that each DEC field service office uses a Logic Laboratory for computer module testing and maintenance.

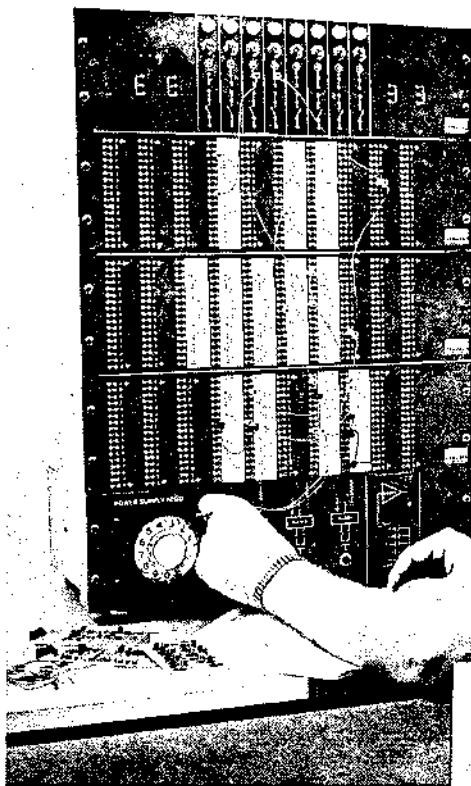
The Logic Laboratory is a completely self-contained system consisting of a power supply, pulse generator, controls, indicators, mounting hardware, and a basic complement of logic modules necessary to construct a working system.

Education And Training

Flexibility is the key to the excellence of the Logic Laboratory as a training device. Far from a complicated do-it-yourself kit, the Laboratory is a well-conceived and implemented teaching aid. The Workbook provides a step-by-step approach to building an understanding of various digital logic functions. With only three module types, the student is taught to use the operations of NAND and NOR to perform the basic AND, OR, NOT, and EXCLUSIVE OR (Half add) functions. In the process of constructing these, the student learns by doing, as opposed to learning by rote.



Experiments contained in the Workbook are designed so that experiments can be short and simple, or extended by the numerous possibilities suggested by additional problems contained in the Workbook. The Logic Laboratory is designed to teach universal logic principles rather than a narrow system, rigidly tied to a company's product line. The logic symbology used in the Workbook closely resembles the generally accepted standard. These symbols have been field-tested by leading training directors and found to be easily understood.



The Workbook was prepared specifically for use with the Logic Laboratory. It contains 15 graded experiments, or laboratory sessions, each of over three hours duration. No prior knowledge of electronics or digital logic is required, although the experiments should be performed in conjunction with a course in logic design or textbook study (a number of texts are recommended). All basic logic elements and techniques are covered, and all can be carried out with the basic Laboratory. Each chapter or laboratory session of the Workbook contains tutorial text and projects to be performed. A considerable amount of latitude is allowed in the assignment of projects, so that a given chapter can stimulate well over three hours of experimentation. The Workbook is also arranged so that various material may be omitted by the instructor, should he desire a less thorough coverage.

One of the most valuable features of the Logic Laboratory is its Analog-Digital Converter section. Two chapters are allocated to the techniques of analog to digital (ADC) and digital to analog (DAC) conversion. Since most of the measuring devices which exist today are analog in form, an understanding of the techniques and operation of A/D conversion equipment is absolutely necessary. In addition to the data acquisition problem, an understanding of the conversion of digital values to analog outputs for control and display (strip charts, meters, etc.) is essential for an overall understanding of data processing.

The following list of chapter titles indicate the scope of the material covered.

- | | |
|----------------------------------------------|---------------------------------------------------|
| 1. Binary Numbers | 9. Binary Coded Decimal Arithmetic |
| 2. Binary Coded Decimal | 10. Code Conversion |
| 3. Basic Digital Circuits — Gates | 11. Control |
| 4. Flip-Flops and DCD Gates | 12. Timing |
| 5. From Boolean Equations to Gating Networks | 13. Introduction to Analog-Digital Conversion |
| 6. Boolean Equations and Flip-Flops | 14. Advanced Studies in Analog-Digital Conversion |
| 7. Addition | 15. Computer Design |
| 8. Parallel Addition and Subtraction | |

The Standard Logic Laboratory contains the necessary equipment to perform experiments 1 through 10. The Advanced Logic Laboratory, when added to the Standard, contains the necessary equipment to perform experiments 11, 12, and 15. The Advanced Logic Laboratory with Analog-Digital Conversion provides the equipment for experiments 13 and 14.

Breadboarding And Testing

The Logic Laboratory is much more than a training device when used by a competent logic designer or technician. It is designed and manufactured to the same high quality as DEC modules and computers as well as being electrically and physically compatible with all Flip Chip modules. The Logic Laboratory power supply is capable of supplying drive to about 100 modules. There is no restriction on the size of the system which can be implemented since additional equipment can be ordered and Logic Laboratories interconnected directly. Many logic problems are complex enough to require assurance beyond the level of the Boolean equation before the final implementation. There is no substitute for actually building the system and verifying the logic using the Laboratory. The inherent flexibility and ease of interconnection modification results in a checkout time which is faster than building a complete prototype. The Laboratory is also very useful in building

Excerpt from Experiment 1 of the Logic Laboratory Workbook

A digital computer is an assemblage of extremely simple circuits. Consider the familiar elements in the logic laboratory — the toggle switches and push buttons. Examine these elements in detail. Compare them.

Each has only two states. The switch may be up or down. The button may be depressed or released. Digital circuits also have two states, a negative voltage level and a positive level. In the logic laboratory the negative level is -3 volts; the more positive level is ground.

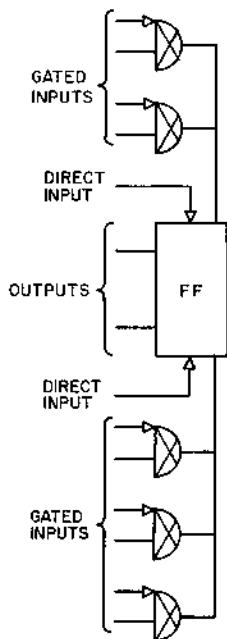
Note the differences. The button makes contact only when depressed. When released, it always returns to its original position. The switch, by contrast, always remains where last positioned. It remembers. In this same sense, digital circuits are divided into two classes, those which remember and those which follow.

A BINARY COUNTER

In this experiment, you will study the binary number system by constructing a counter, using the Flip-Flop Type R201. The flip-flop is the circuit equivalent of the toggle switch. It remembers.

The flip-flop circuit is shown symbolically in Figure 1. The two outputs are always in opposite states. That is, if one output is at -3 volts, the other is at ground and vice versa. To see this, connect the two flip-flop outputs to indicator lights. One will be on while the other is off.

To change the state of the flip-flop, connect a push-button pulser to each of the direct inputs. Notice that the flip-flop always remembers which button was depressed last.



"one of a kind" systems for experimentation when the system is used for a single pass operation.

Some common uses of the Logic Laboratory are listed below. Many of these are described in detail near the back of this catalog under the heading Application Notes. The uses to which the Laboratory can be put are without limit. Digital's highly trained field engineers are always available to assist customers with logic design problems.

| | |
|-----------------------------------------------|--------------------------------|
| Peak Amplitude and Zero Crossing Measurements | General Purpose Digital Clocks |
| Computer Controlled Communications Systems | Analog Signal Multiplexing |
| Generation of Pseudo-Random Sequences | Decoding |
| Digital Filtering of Analog Signals | Sequence Control |
| Highly Accurate Timing Systems | Data Acquisition |
| Stepping Motor Drives (Translators) | Hybrid Computation |
| Teletype Send-Receive Logic | Pulse Train Techniques |
| Real-Time Computer Interfaces | Typewriter Drive Logic |
| | Voltage-Time Conversion |
| | Digital Spectrum Analyzers |
| | Elapsed Time Measurements |

Basic Equipment Lists

STANDARD LOGIC LABORATORY

The following equipment is sufficient to study the basic principles of digital logic, as set forth in Experiments 1 through 10 in the Logic Laboratory Workbook. Total price is \$886.20

| | | |
|---|---------|--------------------------------------------------------|
| 1 | H901 | Module Mounting Panel |
| 1 | H902 | Indicator-Switch Panel (complete with W052 module) |
| 6 | R201 | Flip-Flops |
| 3 | R121 | Four NOR Gates |
| 1 | R122 | Four NAND Gates |
| 4 | 911-2" | Box of 2" Patch Cords |
| 5 | 911-4" | Box of 4" Patch Cords |
| 2 | 911-8" | Box of 8" Patch Cords |
| 1 | 911-16" | Box of 16" Patch Cords |
| 1 | 700D | Power Supply and Signal Generator Panel (with modules) |
| 1 | 4913 | Mounting Rack |

ADVANCED LOGIC LABORATORY

Added to the standard equipment above, the following items permit the study of control, timing, and computer design, as covered in Experiments 11, 12, and 15 of the Workbook. Total price of added equipment is \$321.50

| | | |
|---|---------|------------------------|
| 1 | H901 | Module Mounting Panel |
| 3 | R201 | Flip-Flops |
| 1 | R121 | Four NOR Gates |
| 2 | R302 | Two Delay One-Shots |
| 1 | R602 | Two Pulse Amplifiers |
| 1 | 911-4" | Box of 4" Patch Cords |
| 1 | 911-8" | Box of 8" Patch Cords |
| 1 | 911-16" | Box of 16" Patch Cords |
| 1 | 911-32" | Box of 32" Patch Cords |

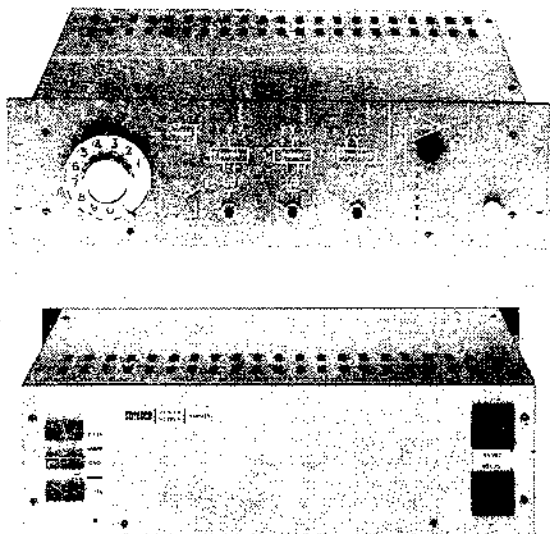
ADVANCED LOGIC LABORATORY WITH ANALOG-DIGITAL CONVERSION

The converter listed below opens up the large and varied field of interfacing digital logic with external analog equipment. As described in Experiments 13 and 14 of the Workbook, analog-to-digital converters can convert analog outputs from thermometers, pressure gauges, flowmeters, etc. into digital values for processing, and digital-to-analog converters can convert the resulting digital numbers into analog signals to control devices such as motors, oscilloscopes, and valve actuators. Converter price \$143.00

| | | |
|---|------|------------------------------------------------------------------------------------------------|
| 1 | H903 | Analog-Digital Conversion Panel (Provides D to A and A to D Conversion. Complete with modules) |
|---|------|------------------------------------------------------------------------------------------------|

POWER SUPPLIES AND INPUT PANEL TYPES 700D, 700DA

LOGIC
LABORATORY
COMPONENTS



The 700D is a combination power supply and input panel. The input devices include a dial, three push buttons and pulsers, and a clock. The power supply can drive approximately ten Type H901 Panels of R-series FLIP CHIP logic, or up to 10 basic Logic Laboratories. Details on the pulser circuits are given in the module description of the Type W501. Details on the clock are given on the module description of the Type R401. The 700D is a combination of the 900 Control Panel plus an H701 Power Supply.

ELECTRICAL CHARACTERISTICS

INPUT VOLTAGE: Power Supply — 700D: 115v, 60 cps, 700DA: 112.5, 123.5, 195, 220, 235v, 50 cps. See "50 cps power."

OUTPUT VOLTAGE: $\pm 10v$, -15 vdc, floating
OUTPUT CURRENT: $+10v$: 0 to 0.4 amp; $-15v$: 0.5 amp to 3 amp.

LINE AND LOAD REGULATION: The output voltage remains between -15.5 and $-16.5v$ for the $-15v$

output and within $+9.2$ and $+11.5v$ for the $+10v$ output, when load varies from minimum to maximum and line voltage varies from 105 to 125 vdc.

P-P RIPPLE: Less than 0.6v. for $+10v$ output; less than 0.6v for $-15v$ output (20% more ripple on the 50-cps type).

LINE FREQUENCY TOLERANCE: $\pm 2\%$ of line frequency

MECHANICAL CHARACTERISTICS

PANEL WIDTH: 19 in.

PANEL HEIGHT: 5-3/16 in.

DEPTH: 12 in.

FINISH: Chassis: Chromicoat; Panel: DEC Blue

POWER UNIT CONNECTION: Amphenol 160-5

Socket

POWER OUTPUT CONNECTION: Hayman Tab Terminals which fit AMP "Faston" receptacle series 250, part 41774 or Type 914 Power Jumpers.

700D — \$323.00
700DA — \$343.00

CONTROL PANEL TYPE 900

LOGIC
LABORATORY
COMPONENTS



The Type 900 Control Panel uses the same chassis and input controls as the 700D but does not contain a power supply. It is designed for multi-student installations of DEC Logic Laboratory units powered by a single 700D Power Supply. Connections are available on the rear of the 900 to accept power from the master 700D Power Supply.

The input devices include a dial, three pulsers with pushbuttons, and a variable clock. Details of the Type W501 Pulser Circuits and the Type R401 Clock can be found in the module description section of the catalog.

MECHANICAL CHARACTERISTICS

PANEL WIDTH: 19 in.
PANEL HEIGHT: 5-3/16 in.
DEPTH: 12 in.

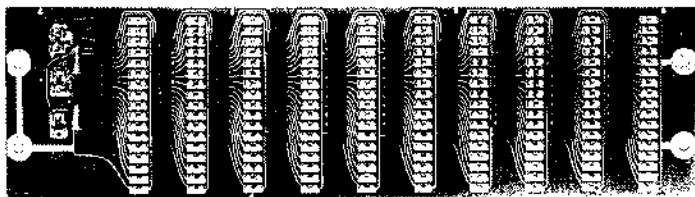
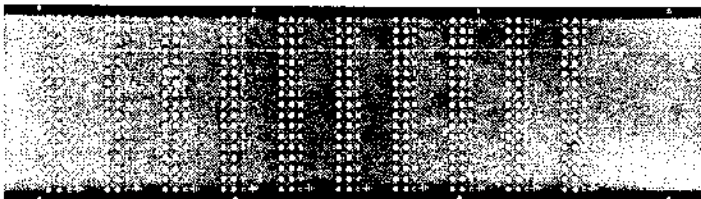
FINISH: Chassis: Chromicoat; Panel: DEC Blue
AC POWER CONNECTION: Amphenol 160-5 Socket

is provided, but not wired
DC POWER INPUT CONNECTION: Hayman Tab Terminals which fit AMP "Faston" receptacle series 250, part 41774 or Type 914 Power Jumpers.

MISCELLANEOUS ACCESSORIES

TYPES H901, 911

LOGIC
LABORATORY
COMPONENTS



H901 PATCHCORD MOUNTING PANEL

This panel provides up to ten FLIP CHIP modules with power and patch connections. Space between patching sockets allows insertion of logic diagrams. Logic diagrams are printed on all FLIP CHIP module data sheets. More permanent plastic diagrams are available for those modules required to complete the logic laboratory workbook experiments.

PANEL WIDTH: 19 in.

PANEL HEIGHT: 5-3/16 in.

DEPTH: 6½ in. with FLIP CHIP modules inserted

FINISH: DEC Blue

POWER INPUT CONNECTIONS: Tabs which fit AMP "Faston" receptacle series 250, part 41774.

911 PATCHCORDS

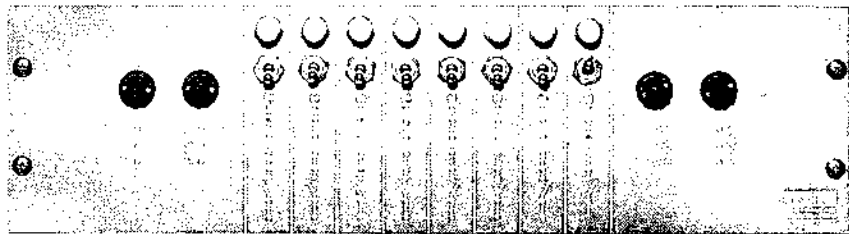
DEC Type 911 Banana-Jack Patchcords are supplied in color-coded lengths of 2 in. (brown), 4 in. (red), 8 in. (orange), 16 in. (yellow), 32 in. (green), and 64 in. (blue). Patchcords may be stacked to permit multiple connections at any circuit point on the graphic panels of the DEC H901 Mounting Panel. The cords are supplied in snap-lid plastic boxes of ten for handy storage.



H901 — \$82.50
911 — \$9.00/pkg. of 10

INDICATOR SWITCH PANEL TYPE H902

LOGIC
LABORATORY
COMPONENTS



The H902 Panel provides facilities for control and observation of the Logic Laboratory. It contains eight indicator lights and a lamp driver module, eight toggle switches and four potentiometers. Connections to these devices are made with Type 911 Stacking Banana-Jack Patchcords.

INDICATORS: Indicators inputs accepts signals of $-3v$ and ground. A ground input lights the indicator. If the input is returned to $-3v$ or open circuited, the indicator will not light. The load is 1 ma.

TOGGLE SWITCHES: The toggle switches are single pole, single throw with a logic diagram to show the open and closed positions.

POTENTIOMETERS: The potentiometers are 20,000 ohms. They may be used to control the frequency of delay one-shots or clock circuits in the H901 Mounting Panel.

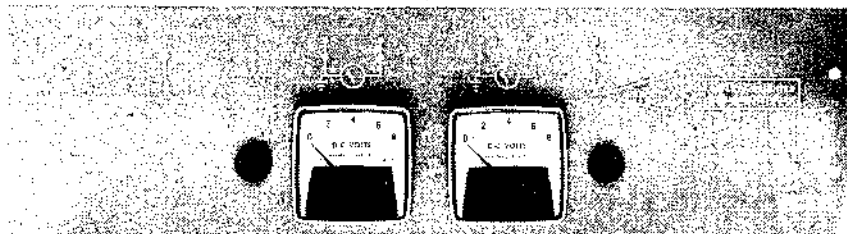
MECHANICAL CHARACTERISTICS

PANEL WIDTH: 19 in.
PANEL HEIGHT: 5-3/16 in.
DEPTH: 6½ in.

FINISH: DEC Blue
POWER INPUT CONNECTIONS: Tabs which fit AMP
"Faston" receptacle series 250, part 41774.

ANALOG-DIGITAL PANEL TYPE H903

LOGIC
LABORATORY
COMPONENTS



This panel provides facilities for experimenting with analog-digital techniques. It contains a 4 bit variable output D-A converter and a comparator circuit. Also includes two 8 volt panel meters and a potentiometer for producing 0 to -8v test signal. Connections to these devices are made with Type 911 Stacking Banana-Jack Patchcords.

ELECTRICAL CHARACTERISTICS

D-A CONVERTER ZERO OFFSET: $\pm 0.4\text{v}$ or less
LINEARITY: $\pm 3\%$ of full scale
ALL ONES OUTPUT (FULL SCALE): adjustable from -7v to -8v driving 3000 ohm load
D-A CONVERTER OUTPUT IMPEDANCE: typically less than 100Ω
COMPARATOR OFFSET: $\pm 0.2\text{v}$ or less
COMPARATOR INPUT CURRENT: typically less than $100\ \mu\text{a}$.
INPUT VOLTAGE OPERATING RANGE: 0 to -10v

INPUT: D-A converter inputs each require 1 ma at ground. No load at -3v .

OUTPUT: D-A converter output may be shorted to ground accidentally without harm. Comparator output supplies up to 8 ma at ground; 1 ma at -3v . Because the inputs may pass through the switching region slowly or hesitantly in most A-D converter applications, the comparator output transition is not suitable for driving DCD gate pulse inputs.

POWER: $+10\text{ v(A)}/8\text{ ma}$; $-15\text{ v}/30\text{ ma}$.

MECHANICAL CHARACTERISTICS

PANEL WIDTH: 19 in.
PANEL HEIGHT: 5-3/16 in.
DEPTH: 6½ in. with FLIP CHIP modules inserted

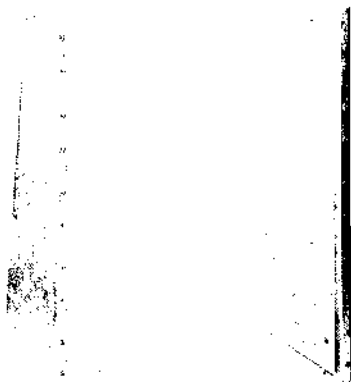
FINISH: DEC Blue
POWER INPUT CONNECTIONS: Tabs which fit AMP "Faston" receptacle series 250, part 41774.

H903 — \$143.00

MISCELLANEOUS ACCESSORIES

TYPES 4913, 914

LOGIC
LABORATORY
COMPONENTS



4913 MOUNTING RACK

The 4913 Mounting Rack provides support for a 700D Power Supply and up to four H901 Patchcord Mounting Panels, for a total of up to 40 FLIP CHIP modules ready to be patched together for experiments. It may also be used to mount general purpose mounting panels such as the 1943 for use with the H700 Power Supply. The power supply must be mounted at the bottom for stability.

Height: 26 $\frac{1}{4}$ in.

Threads for mounting panels: 10-32

914 POWER JUMPERS

For interconnections between power supplies, mounting panels, and logic lab. Panels these jumpers use AMP "Faston" receptacles series 250. Specify 914-7 for interconnecting adjacent mounting panels, or 914-19 for other runs of up to 19 inches. 914-7 contains 10 jumpers; 914-19 contains 5.

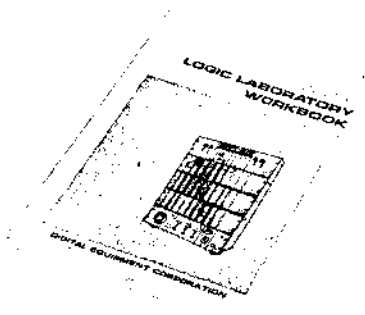
4913 — \$47.00

914-7 — \$4.00

914-19 — \$4.00

ORDER FORM

DIGITAL LOGIC LABORATORY WORKBOOK



SEE PAGE 182 FOR
DETAILED DESCRIPTION

FOLD HERE

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PART IV: HARDWARE, OCTAIDS AND PANELAIDS

INTRODUCTION

Digital manufactures a complete line of hardware accessories in support of its module series. Module connectors are available for as few as one module and as many as 64. A complete line of cabinets is available to house the modules and their connector blocks, as well as providing a convenient means for system expansion. Power supplies for both large and small systems as well as marginal check and reference supplies are also available.

A major new addition to the hardware line is the H201 Core Memory. The H201 gives the logic designer the capability of designing a complete random access storage system for off-line storage, programming automatic equipment, or controlling of a general-purpose computer.

Coupled with the recent additions to the hardware line, Digital has made every effort to maintain or improve the high standards of reliability and performance of its present line. Through the availability of a wide range of basic accessories, DEC feels that it is offering the logic designer the necessary building blocks which he requires for complete system design.

MARGINAL CHECKING

The use of variable output power supply Type 786 and marginal check switches on the mounting panels allow preventive maintenance routines to be established on systems that must not become inoperative without warning, even after years of use. Varying the power supply voltages is an excellent way to determine the safety margins and can also help in pinpointing a logic design or wiring mistake that causes baffling sporadic errors with normal voltage applied. All systems built by Digital are tested under conditions of varying +10 and -15 supply voltages before shipment, and standard practice on large computers is to make margin checks at regular intervals, to detect any deteriorating components before they threaten an unscheduled shutdown.

50-CYCLE POWER

Because of the demand for Digital's products in areas where 115-v, 60-cps power is not available, each of the power supplies with a frequency-sensitive regulating transformer is also available in a multi-voltage 50-cps version. All 50-cps supplies have the same input connections. The line input is on pins 3 and 4. Jumpers should be connected depending on the input voltage. These connections are shown below along with a schematic.

WIRING HINTS

These suggestions may help reduce mounting panel wiring time. They are not intended to replace any special wiring instructions given on individual module data sheets or in application notes. For fastest and neatest wiring, the following order is recommended.

- (1) All power wiring (pins A, B, and C) and any horizontally bussed signal wiring. Use Horizontal Bussing Strips Type 932.
- (2) Vertical grounding wires interconnecting each chassis ground with pin C grounds. Start these wires at the uppermost mounting panel and continue to the bottom panel. Space the wires 2 inches apart, so each of the chassis-ground pins is in line with one of them. Each vertical wire makes three connections at each mounting panel.
- (3) All other ground wires. Always use the nearest pin C above the pin to be grounded, unless a special grounding pin has been provided in the module.
- (4) All signal wires in any convenient order. Point-to-point wiring produces the shortest wire lengths, goes in the fastest, is easiest to trace and change, and generally results in better appearance and performance than cabled wiring. Point-to-point wiring is strongly urged.

The recommended wire size for use with the H800 Mounting Clocks and 1943 mounting panel is 24 for wire wrap, and 22 for soldering. The recommended size for use with H803 block is #30 wire. Larger or smaller wire may be used depending on the number of connections to be made to each lug. Solid wire and a heat resistant spaghetti (Teflon) are easiest to use when soldering.

Adequate grounding is essential. In addition to the connections between mounting panels mentioned above, there must be continuity of grounds between cabinets and between the logic assembly and any equipment with which the logic communicates.

When soldering is done on a mounting panel containing modules, a 6-v (transformer) soldering iron should be used. A 110-v soldering iron may damage the modules.

When wire wrapping is done on a mounting panel containing modules, steps must be taken to avoid voltage transients that can burn out transistors. A battery- or air-operated tool is preferred, but the filter built into some line-operated tools affords some protection.

Even with completely isolated tools, such as those operated by batteries or compressed air, a static charge can often build up and burn out semiconductors. In order to prevent damage, the wire wrap tool should be grounded except when all modules are removed from the mounting panel during wire wrapping.

AUTOMATIC WIRING

Significant cost savings can be realized in quantity production if the newest automatic wiring techniques are utilized. Every user of FLIP CHIP modules benefits from the extensive investment in high-production machinery at Digital, but some can go a step further by taking advantage of programmed wiring for their FLIP CHIP digital systems.

While the break-even point for hand wiring versus programmed wiring depends upon many factors that are difficult to predict precisely, there are a few indications:

1. One-of-a-kind systems will probably not be economical with automatic wiring, even when the size is fairly large; programming and administrative costs are likely to outweigh savings due to lower costs in the wiring itself.

2. At the other end of the spectrum, production of 50 or 100 identical systems of almost any size would be worth automating, not only to lower the cost of the wiring itself but also to reduce human error. At this level of volume, machine-wired costs can be expected to be less than the cost of hand wiring.
3. For two to five systems of several thousand wires each, a decision on the basis of secondary factors will probably be necessary: ease of making changes, wiring lead time, reliability predictions, and availability of relevant skills are factors to consider.

The Gardner-Denver Corporation, and Digital can supply further information to those interested in programmed wiring techniques. At Digital, contact the Module Sales Manager, Sales Department.

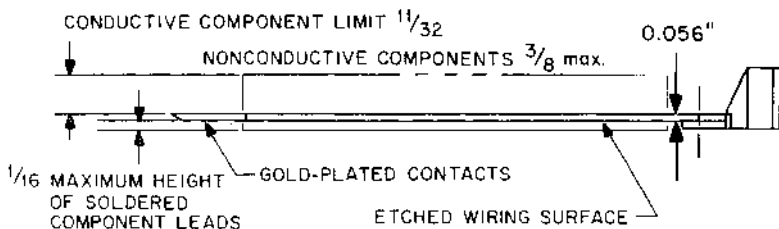
COOLING OF FLIP CHIP MODULES

The low power consumption of R-series modules results in a total of only about 25 watts dissipation in a typical 1943 Mounting Panel with 64 modules. This allows up to six panels of R-series modules to be mounted together and cooled by convection alone, if air is allowed to circulate freely. In higher-dissipation systems using modules in significant quantities from the W, B, and A series, the number of mounting panels stacked together must be reduced. For example, no more than three panels of B-series modules may be mounted together without forced-air cooling. In general, total dissipation from all modules in a convection-cooled system should be 150 watts or less (about 9-amp total current at -15v).

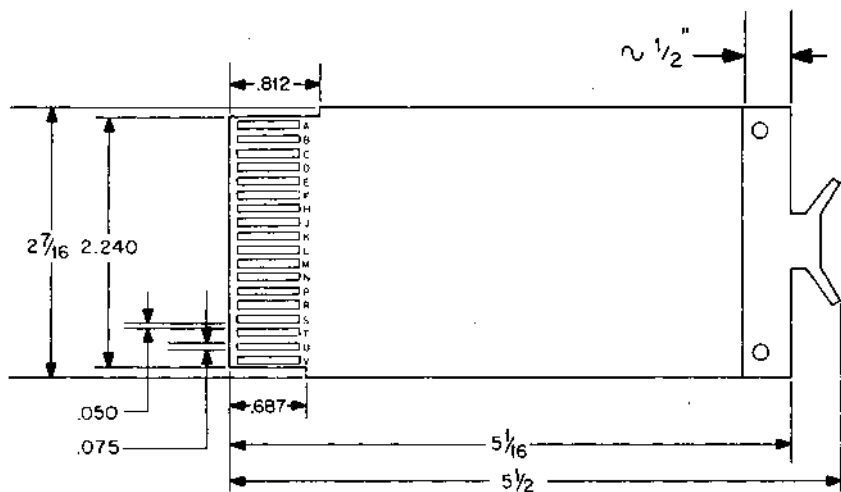
The regulating transformers used in most DEC power supplies have nearly constant heat dissipation for any loading within the ratings of the supply. Power dissipated within each supply will be roughly equal to half its maximum rated output power. If power supplies are mounted below any of the modules in a convection-cooled system, this dissipation must be included when checking against the 150 watt limit.

STANDARD MODULE SIZES

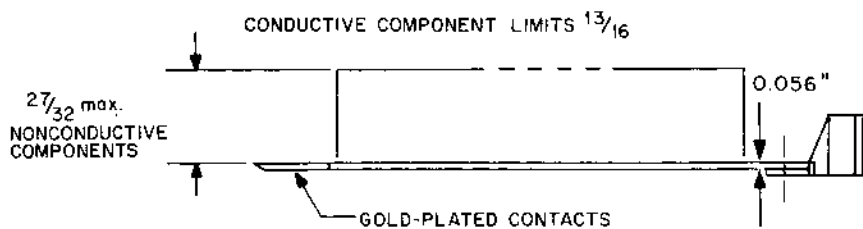
SINGLE-WIDTH FLIP CHIP MODULE



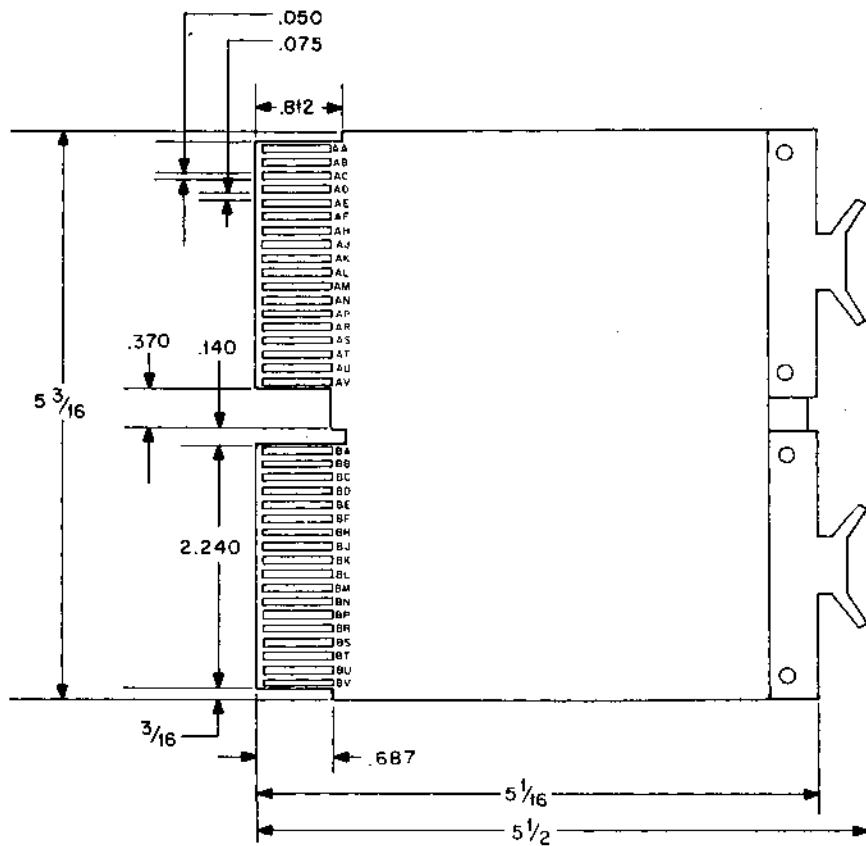
SINGLE-HEIGHT FLIP CHIP MODULE



DOUBLE-WIDTH FLIP CHIP MODULE



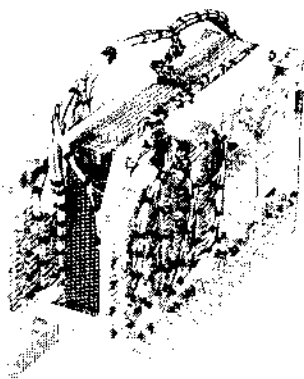
DOUBLE-HEIGHT FLIP CHIP MODULE



CORE MEMORY

TYPE H201

HARDWARE
ACCESSORIES



The H201 Core Memory can store 4096, 13-bit words. By combining with other modules, a complete random access memory storage system with a cycle time of $8 \mu\text{s}$ can be built. This system may be used to provide off-line data storage, program automatic equipment, or control a general-purpose computer.

SPECIFICATIONS

| | | | |
|------------------------|---------------------------------------------------------|----------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| ADDRESS: | 4096 | RISE TIME: | $0.5 \mu\text{s}$ nominal |
| BITS: | 13 | u^V_1 (UNDISTURBED "1"): | 50 mv typical |
| ORGANIZATION: | 4 wire, 3D | d^V_z (DISTURBED "0"): | 8 mv typical |
| SELECTION: | 2 diodes per line, 8x8 "X" matrix, 8x8 "Y" matrix | PEAKING TIME: | 0.7 us typical |
| 1/2 SELECT CURRENT: | 200 ma nominal | PHYSICALLY: | Occupies 24 module locations, 4 vertically by 6 horizontally. Note mounting panels must be aligned to permit core to plug in. |
| SELECTION PULSE WIDTH: | $2 \mu\text{s}$ nominal | | |

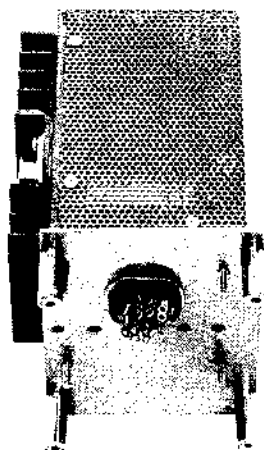
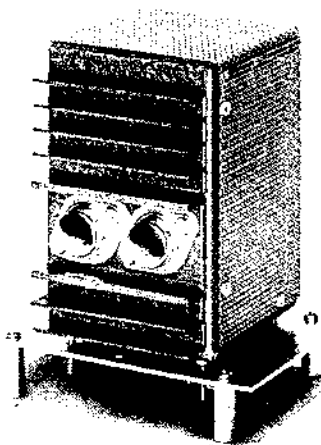
H201 — \$2,000.00

POWER SUPPLY

TYPE H704

± 15 VOLTS

HARDWARE
ACCESSORIES



The Type H704 Power Supply (± 15 v) is a precision unit designed to supply the voltage requirements for up to six operational amplifier modules. It is an all silicon modular supply capable of delivering 400 ma on both outputs. Remote sensing terminals are provided.

The H704 is supplied with all the hardware required for computer cabinet, 1943, or H900 mounting. When the H704 is installed in a 1943 or H900 Mounting Panel, it takes the place of two module connector blocks.

MECHANICAL CHARACTERISTICS

DIMENSIONS: $3\frac{1}{4} \times 3\frac{3}{8} \times 5$ in. height

CONNECTIONS: All input-output wires must be soldered to octal socket at the base of the power

supply.

OPERATING TEMPERATURE: -20 to $+71^{\circ}\text{C}$ ambient

ELECTRICAL CHARACTERISTICS

INPUT VOLTAGE: 105 to 125 vac; 47-420 cps.

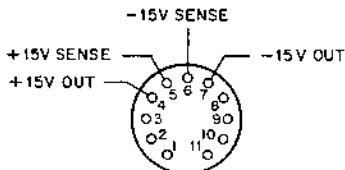
OUTPUT VOLTAGE: floating ± 15 v at 400 ma

OUTPUT VOLTAGE ADJUSTMENT: ± 1 v each output

REGULATION: 0.05% line, 0.1% load for both voltages

RIPPLE: 1 mv rms max for both outputs

OVERLOAD PROTECTION: The power supply is capable of withstanding output short circuits indefinitely without being damaged.



IF REMOTE SENSING IS NOT USED, CONNECT: 5 TO 4
6 TO 7

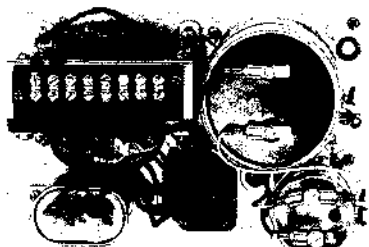
H704 — \$200.00

POWER SUPPLIES

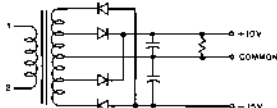
TYPES H701, H701A, 782, 782A

+10, -15 VOLTS

**HARDWARE
ACCESSORIES**



**TYPE H701 DESIGNED FOR PLENUM
OR COMPUTER CABINET MOUNTING**



TYPE 782 DESIGNED FOR 19 INCH RACK MOUNTING

The 782 and 782A power supplies are ruggedly built, low cost units that fit into a standard 19-inch rack. The H701 and H701A are identical to these units, except they can be mounted on a chassis or panel in applications where space is added to an existing device. The basic supply can be mounted in various configurations and is identical to the power supplies used in models 700D and H900. The Types 782A and H701A are Power Supplies with 50 Hertz transformers.

ELECTRICAL CHARACTERISTICS

INPUT VOLTAGE: H701: 115 v 60 cps. H701A: 112.5, 123.5, 195, 220, 235 v, 50 cps. See "50 cps power"

OUTPUT VOLTAGE: +10 v, -15 vdc, floating

OUTPUT CURRENT: -15 v: 1/2 to 3 amp; +10 v: 0 to 0.4 amp.

LINE AND LOAD REGULATION: The output voltage remains between -14.5 and -16.5 v for the -15

output, and within +9.2 and +11.5 v for the +10 output, when load varies from minimum to maximum and line voltage varies $\pm 10\%$.

P-P RIPPLE: Less than 0.6 v for +10 output. Less than 0.5 v for -15 output; 20% more ripple on the 50-cps type.

LINE FREQUENCY TOLERANCE: $\pm 2\%$ of line frequency.

MECHANICAL CHARACTERISTICS

LENGTH: 8"

WIDTH: 4-15/16"

HEIGHT: 5 3/4"

FINISH: Chromicoat

POWER CONNECTIONS: Screw terminals are provided on transformer for input power connections. Output power connections are made via tab terminals which fit the AMP "Faston" receptacle series 250, part #41774 or Type 914 power jumpers. All required mounting hardware is supplied with this unit.

| | |
|-------|------------|
| H701 | — \$116.00 |
| H701A | — \$136.00 |
| 782 | — \$128.00 |
| 782A | — \$148.00 |

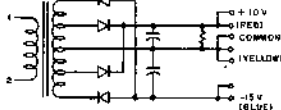
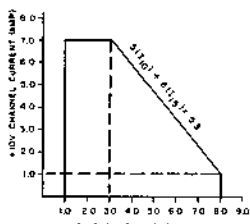
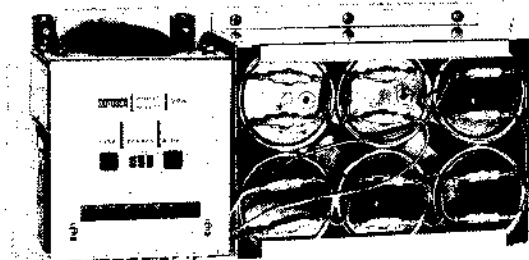
POWER SUPPLIES

TYPES 728, 728A

+10, -15 VOLTS

**HARDWARE
ACCESSORIES**

DESIGNED FOR COMPUTER CABINET MOUNTING



The Types 728 and 728A (+10, -15 v) Power Supplies are capable of withstanding wide line and load variations for general system use. When used singly, the 10-v channel can supply 0 to 7.5 amp, or the 15-v channel can supply 1.0 to 8.5 amp. The 728 Power Supply is electrically identical to the 783 but is made on a shorter chassis specifically designed for mounting on the plenum door of a DEC computer cabinet.

ELECTRICAL CHARACTERISTICS

INPUT VOLTAGE: 728: 115 v, 60 cps, 728A: 112.5, 123.5, 195, 220, 225 v, 50 cps. See "50 cps power"

OUTPUT VOLTAGE: +10 v, -15 vdc, floating.

OUTPUT CURRENT: 1) When only one output is loaded: +10 v: 0 to 7.5 amp -15 v: 1.0 to 8.5 amp. 2) When both outputs are loaded: +10 v: 0 to 7 amp* -15 v: 1.0 to 8.0 amp.* At least 1.0 amp must be drawn from the -15 v channel to assure proper load regulation.

LINE AND LOAD REGULATION: The output voltage remains between -14.5 to -16.5 v for the -15 v

channel and within +9.5 to +11.5 v for the +10 v channel, when load varies from minimum to maximum and line voltage varies from 105 to 125 vac.

P-P RIPPLE: Less than 0.7 v for +10 v output; less than 0.7 v for -15 v output (20% more ripple on the 50 cps type).

LINE FREQUENCY TOLERANCE: ±2% of line frequency.

*The sum of the output currents is limited by the following equation: $5(I_{10}) + 6(I_{15}) = 53$ (see Figure).

MECHANICAL CHARACTERISTICS

PANEL WIDTH: 16½ in.

PANEL HEIGHT: 8¾ in.

DEPTH: 5¾ in.

FINISH: Chromicoat.

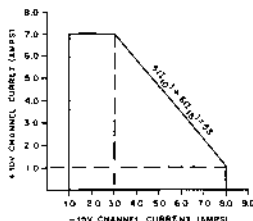
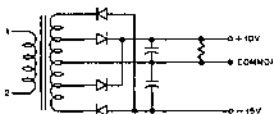
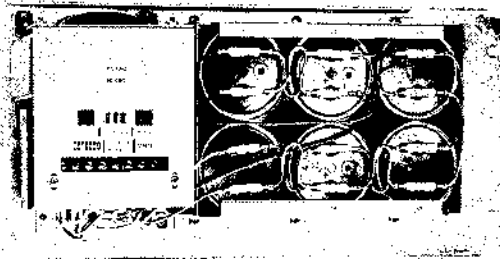
POWER INPUT CONNECTION: Screw terminals on transformer.

POWER OUTPUT CONNECTION: Heyman tab terminals to fit with AMP "Faston" receptacles series 250, part 41774 or Type 914 power jumpers.

| | | |
|------|---|----------|
| 728 | — | \$240.00 |
| 728A | — | \$260.00 |

**POWER SUPPLIES
TYPES 783, 783A
+10, -15 VOLTS**

DESIGNED FOR 19 INCH RACK MOUNTING



The Type 783 Power Supply (+10, -15 v) is a simple, rugged supply capable of withstanding wide line and load variation for general system use. The graph above shows the permissible region of operation when both outputs are used. When used singly, the 10-v output can supply 0 to 7.5 amp, or the 15-v output can supply 1.0 to 8.5 amp. It is designed for mounting in a standard 19-in. rack. The Type 783A is a 783 Power Supply with a 50-cps transformer.

ELECTRICAL CHARACTERISTICS

INPUT VOLTAGE: 783: 115 v, 60 cps. 783A: 112.5, 123.5, 195, 220, or 235 v, 50 cps. See "50 cps power"

OUTPUT VOLTAGE: +10 v, -15 vdc, floating.

OUTPUT CURRENT: 1) When only one output is loaded: +10 v: 0 to 7.5 amp, -15 v: 1.0 to 8.5 amp; 2) When both outputs are loaded: +10 v: 0 to 7.0 amp*, -15 v: 1.0 to 8.0 amp*. At least 1.0 amp must be drawn from the -15 v channel to assure proper load regulation.

LINE AND LOAD REGULATION: The output voltage remains between -14.5 and -16.5 v for the -15 v

output and within +9.5 and +11.5 v for the +10 v output, when load varies from minimum to maximum and line voltage varies from 105 to 125 vac.

P-P RIPPLE: Less than 0.7 v for +10 v output. Less than 0.5 v for -15 v output. (20% more ripple on the 50-cps type.)

LINE FREQUENCY TOLERANCE: ±2% of line frequency.

*The sum of the output currents is limited by the following equation: $5(I_{10}) + 6(I_{15}) = 53$

MECHANICAL CHARACTERISTICS

PANEL WIDTH: 19 in.

PANEL HEIGHT: 8¾ in.

DEPTH: 5¾ in.

FINISH: Chromicoat

POWER INPUT CONNECTION: Screw terminals on transformer.

OUTPUT POWER CONNECTION: Heyman tab terminals designed to mate with AMP "Faston" receptacles series 250, part #41774 or Type 9144 power jumpers.

783 — \$240.00
783A — \$260.00

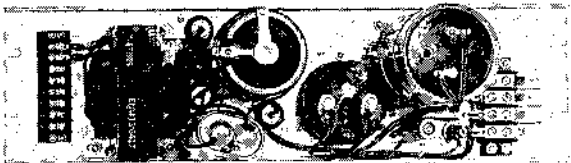
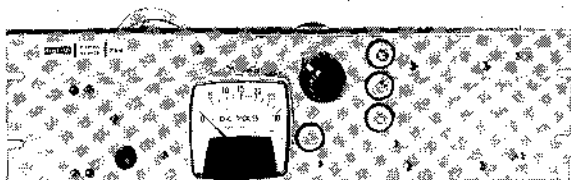
POWER SUPPLIES

TYPES 786, 786A

VARIABLE 0 TO 24 VOLTS

HARDWARE
ACCESSORIES

DESIGNED FOR MARGINAL CHECK APPLICATIONS



The 786 is a floating variable-power supply for mounting on a standard 19 in. rack. A resonant input transformer isolates the output from line voltage variations, while the variable transformer and 0 to 30 v meter allow precise control of output voltage. Although designed for marginal checking of digital systems, this rugged supply will fill many other laboratory needs.

ELECTRICAL CHARACTERISTICS

INPUT VOLTAGE: 786: 115 v, 60 cps; 786A: 112.5, 123.5, 195, 220, or 235 v, 50 cps. See "50 cps power."

OUTPUT VOLTAGES: 0 to 24 vdc continuously variable.

MAX. OUTPUT CURRENT: 2.5 amp.

LINE REGULATION: 2% for input variation $\pm 10\%$.

LOAD REGULATION: Maximum 3.0 v drop at 20 v going from no load to full load.

RIPPLE: ≤ 1.0 v, p-p at 20 v and 2.5 amp (20% more on 50-cps model).

LINE FREQUENCY TOLERANCE: $\pm 2\%$ of line frequency.

OVERLOAD PROTECTION: 4-amp fuse accessible from front panel.

MECHANICAL CHARACTERISTICS

PANEL WIDTH: 19 in.

PANEL HEIGHT: 5-3/16 in.

DEPTH BEHIND PANEL: 5 in.

FINISH: Chromicoat

POWER INPUT CONNECTION: Screw terminal strip provided on panel.

POWER OUTPUT CONNECTION: Barrier strip with screw terminals and tabs which fit AMP "Faston" receptacle series 250, part 41774 or Type 914 power jumpers.

786 — \$215.00
786A — \$235.00

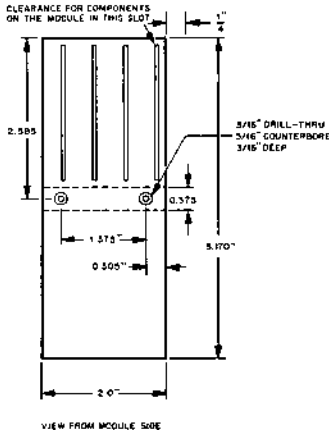
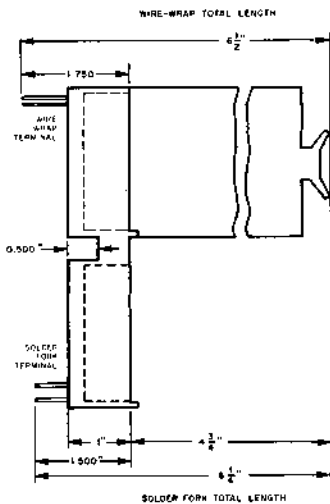
CONNECTOR BLOCKS

TYPES H800-W, H800-F

**HARDWARE
ACCESSORIES**

This is the 8-module molded socket assembly used in FLIP CHIP mounting panels. Aside from its function as a replacement part, there may be times when a special mounting fixture with one or more

H800 blocks must be made by a manufacturer who wishes to fit a few modules into a confined or irregular space. The drawings below show the pertinent dimensions.



REPLACEMENT CONTACTS TYPES H801-W, H801-F

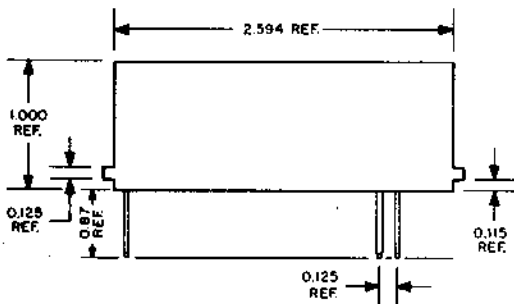
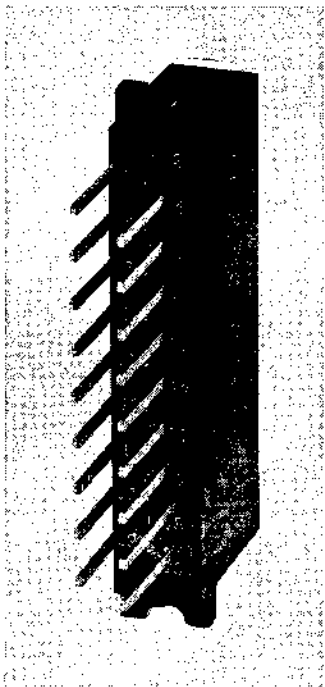
These contacts are offered in packages of 18 for replacement purposes. In each package, nine straight and nine offset contacts are included, enough to replace all contacts in one socket.

H801-W is for wire-wrap connectors; H801-F is for solder-fork connectors.

| | |
|-------|----------|
| H800F | — \$8.00 |
| H800W | — \$8.00 |
| H801F | — \$4.00 |
| H801W | — \$4.00 |

CONNECTOR BLOCK TYPE H 802

HARDWARE
ACCESSORIES

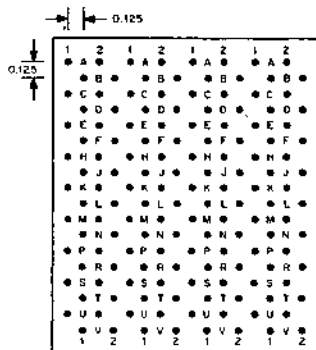


This is a connector block for a single flip-chip module like the H800, the H802 can be used to fit a single module in a confined or irregular space. Often the H802 is used as a connector for a cable at some remote location. The H802 is only available with wire wrap pins.

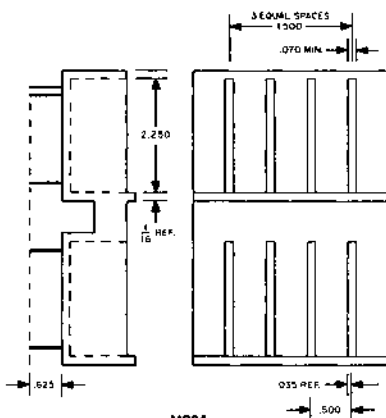
MODULE SOCKETS

TYPES H803, H804, AND H805

HARDWARE
ACCESSORIES



H804 PIN LAYOUT



H804

The H803 and H804 are 8 module sockets used in the H910 and H911 mounting panels. They can also be used separately to provide convenient sockets for up to eight modules. The H803 is a 36-pin connector with the pins forming a 0.125-inch staggered grid. The H804 is the same connector with only half the pins present (pins A2, B2, etc.) so that it mates with the standard Flip-Chip modules. A standard module will also plug into an H803, with 18 pins contacting the circuit on the normal side and the additional 18

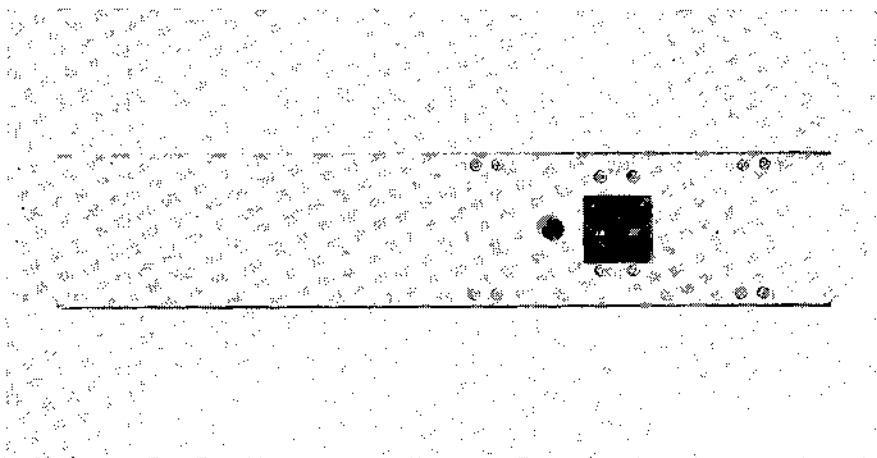
pins on the back side (A1, B1, etc.) making no contact. The blocks have the same physical dimensions as the H800 with the exception of pin length. These blocks are only available with wire wrap pins which are designed to be wrapped with number 30 wire. Pin dimensions are 0.025 inches square.

The H805 Package of 18 pins for use as spares and replacements for those used in H803 and H804. The package contains nine each straight and off-set pins.

H803 — \$13.00
H804 — \$ 9.00
H805 — \$ 4.00

**POWER CONTROL
TYPE 831**

**HARDWARE
ACCESSORIES**



The Type 831 Power Control Panel features a 2-pole circuit breaker which provides convenient 1-step control and protection for entire systems, including auxiliary equipment. The panel fits standard 19-in. racks and is finished with a protective aluminum coating. Available in 4-, 10-, 20-, or 30-amp. capacity.

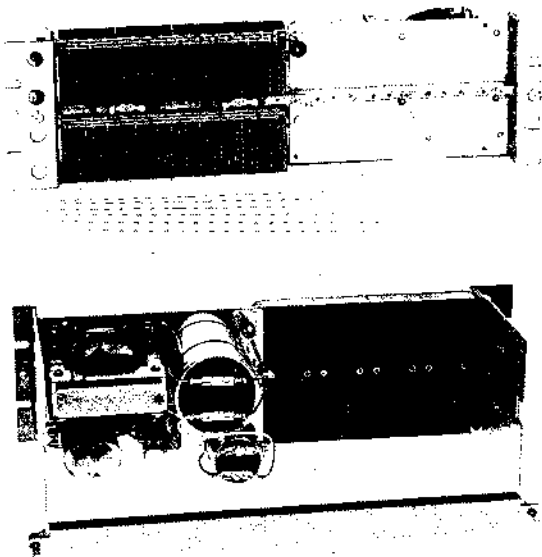
PANEL HEIGHT: 3-7/16 in.

Space available for mounting other controls and indicators: 3 in. by 8 in.

PANEL WIDTH: 19 in.

MOUNTING PANELS WITH POWER TYPES H900, H900A , H910, H910A

HARDWARE
ACCESSORIES



TYPES H900 AND H900A

This dual function mounting panel offers a way to build complete digital systems of up to 32 FLIP CHIP modules into only 5¼ in. of rack space. More power is available than is ever likely to be consumed in a 32 module system; a typical mix of as many as 96 R and W series modules (one H900 and one 1943) can be adequately supplied. Power in excess of that required for 32 modules can be obtained at the terminal block, which is convenient to the input terminal block on any adjacent 1943 Mounting Panel.

ELECTRICAL CHARACTERISTICS

INPUT VOLTAGE: H900: 115 v, 60 cps. H900A: 112.5, 123.5, 195, 220, 235 v, 50 cps. See "50 cps power".

OUTPUT VOLTAGE: +10 v, -15 vdc.

OUTPUT CURRENT: -15 v: ½ to 3 amp; +10 v: 0 to 0.4 amp.

LINE AND LOAD REGULATION: The output voltage remains between -14.5 and -16.5 v for the -15v

output and within +9.2 and +11.5 v for the +10 v output, when load varies from minimum to maximum and line voltage varies ±10%.

P-P RIPPLE: Less than 0.6 v for +10 v output; less than 0.6 v for -15 v output (20% more ripple on the 50-cps. type).

LINE FREQUENCY TOLERANCE: ±2% of line frequency.

MECHANICAL CHARACTERISTICS

PANEL WIDTH: 19 in.

PANEL HEIGHT: 5-3/16 in.

DEPTH: 6-3/4 in.

FINISH: Chromicoat

POWER INPUT CONNECTIONS: Screw terminals pro-

vided on transformer.

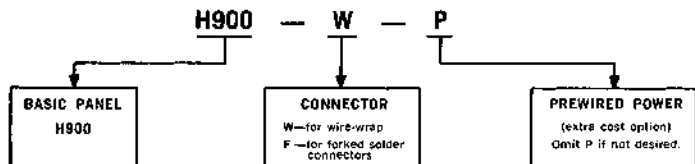
MODULES ACCOMMODATED: 32

POWER OUTPUT CONNECTIONS: Barrier strip with screw terminals and tabs which fit AMP "Faston" receptacle series 250, part no. 41774 or Type 914 power jumpers.

H900, H900A OPTIONS AND ORDERING

There are two kinds of sockets available for FLIP CHIP modules: wire-wrap and solder fork. Rewiring of pins A, B, and C for +10 v, -15 v, and ground

is also optional. The example below shows how to specify wire-wrap connectors and prewired power:



1945-19 HOLD DOWN BAR: Secures modules for shipping, or other vibrational environments.

932 BUS STRIP: Simplifies wiring of register pulse busses, power, and grounds.

TYPES H910 AND H910A

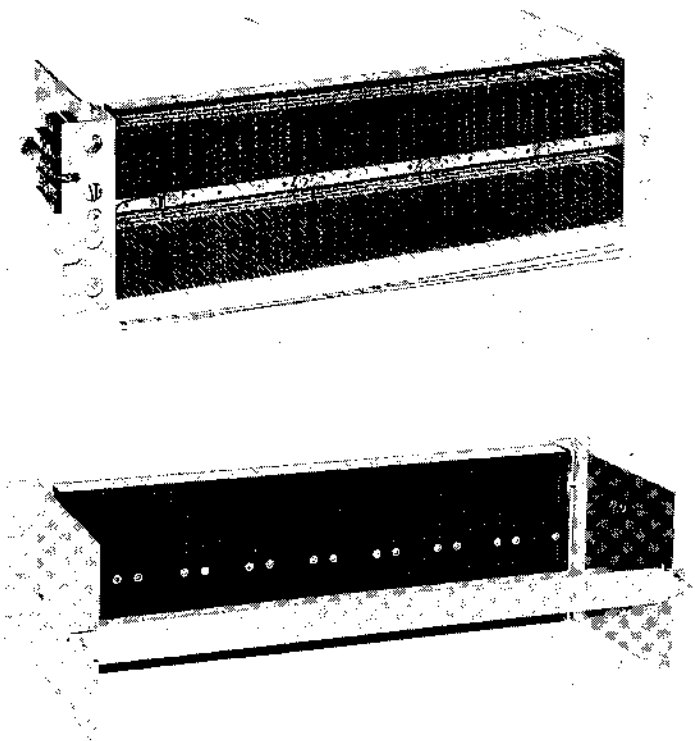
The H910 and H910A are similar to the H900 and H900A mounting panels. The only difference being that the H910 panels are built from four H803 connector blocks. The panels are then capable of housing 32, 36 pin modules with sufficient room available for an H701 power supply. The H910 is not available with the solder connectors. However, the prewired power option is available at a small additional charge. Wire wrapping of the pins should be accomplished with #30 wire.

Electrical and mechanical specifications are identical to those for the H900 and H900A with the exception of pin length. Pin length is 0.625" for the H910 and 0.75" for the H900.

| | | |
|----------|---|----------|
| H900 | — | \$180.00 |
| H900A | — | \$200.00 |
| Option P | — | \$5.00 |
| H910 | — | \$200.00 |
| H910A | — | \$220.00 |

**MOUNTING PANEL
TYPE 1943 , H911**

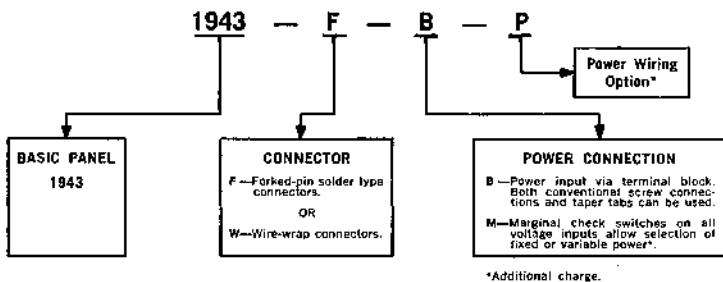
**HARDWARE
ACCESSORIES**



TYPE 1943 MOUNTING PANEL

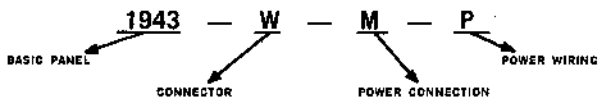
The 1943 Mounting Panel houses 64 modules. It is designed for mounting in a standard 19-in. rack. The mounting panel is finished with an aluminum conversion coating (Chromicoat). Filter capacitors are included on all power supply lines.

Available options are solder or wire-wrap connectors, power input via terminal strip or marginal check switches, and power wiring. The chart below shows how the options are indicated when ordering.



EXAMPLE: If you require a Type 1943 Mounting Panel with wire-wrap connectors, marginal check

switches on the power connection, and prewired power, you would order:



MECHANICAL DIMENSIONS: 19 in. wide; 5-3/16 in. high; 6-3/4 in. deep. Tabs for power connections fit AMP "Faston" receptacles, series 250, part 41774 or Type 914 power jumpers.

keeps modules securely mounted when panel or system is moved. Adds 1/2 in. to depth of mounting panel.

1945-19 HOLD DOWN BAR: Reduces vibration and

932 BUS STRIP: Makes wiring power and register pulse busses easy.

H911 MOUNTING PANEL

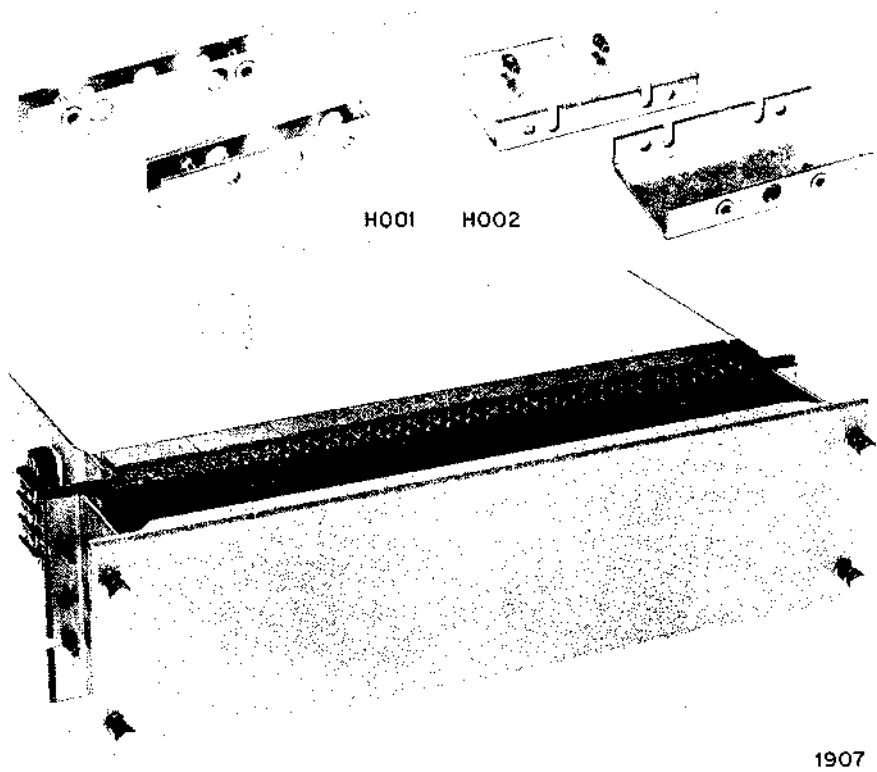
The H911 mounting panel is similar to the 1943. It houses 64, 36 pin connectors. Mechanical dimensions are identical to those of the 1943 with the exception of the pin length. Pins on the H803 blocks are 0.626" long while those on the H800 are 0.75 inches long. The H911 is available with wire wrap pins only. Marginal check and power wiring options are available on the H911.

| | |
|------------|------------|
| H911B | — \$151.00 |
| H911BP | — \$161.00 |
| H911-M | — \$172.00 |
| H911-MP | — \$182.00 |
| 932 | — \$.60 |
| 1943-F-B | — \$111.00 |
| 1943-W-B | — \$111.00 |
| 1943-F-B-P | — \$121.00 |
| 1943-W-B-P | — \$121.00 |
| 1943-F-M | — \$132.00 |
| 1943-W-M | — \$132.00 |
| 1943-F-M-P | — \$142.00 |
| 1943-W-M-P | — \$142.00 |
| 1945-19 | — \$15.00 |

MOUNTING PANEL ACCESSORIES

TYPES H001, H002, 1907

HARDWARE
ACCESSORIES



H001

H002

1907

H001 PANEL COVER BRACKET

The H001 consists of a pair of U-brackets that fit under the mounting screws of a 1943, H900, H910, or H911 FLIP CHIP mounting panel, providing a way to mount 1907 cover panels. The $\frac{3}{4}$ " standoff obtained makes these cover plates approximately flush with DEC cabinet edges.

H002 PANEL SETBACK BRACKET

The H002 consists of a pair of U-brackets which are used to setback a power supply or mounting panel from a 1907 panel cover. The H002 permits the use

of controls on the 1907 cover plate with protrusions, up to 2".

DEPTH: 3 in. (bridges DEC cabinet mounting rails)

1907 MOUNTING PANEL COVER

The Type 1907 Mounting Panel Cover is designed to cover the logic and power wiring for the 1943, H900, H910, or H911 Mounting Panels. The 1907 should be used with the H001 or H002 Panel set back brackets and is finished in brown "tweed" or blue. Dimensions are $5\frac{1}{4}$ by 19 in. Specify color when ordering.

| | |
|------|----------|
| H001 | — \$8.00 |
| H002 | — \$8.00 |
| 1907 | — \$9.00 |

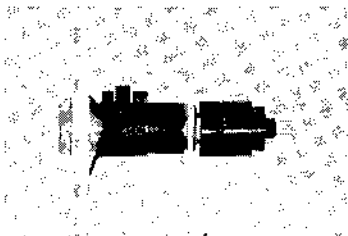
INDICATORS

TYPES 4908, 4906, 4917, 4918

HARDWARE
ACCESSORIES

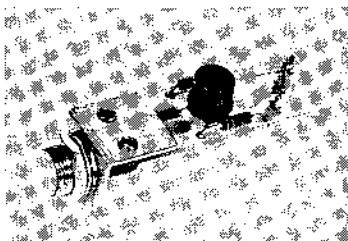
4908 PANEL INDICATOR ASSEMBLY

Consists of lamp, spring clip, and terminal. Facilitates panel mounting of individual indicator lamps. Power required is -15 v at 30 ma. Requires a $5/16$ in. hole for mounting. Wires can be any length, since their capacitance is isolated from the logic by a driver such as W050.



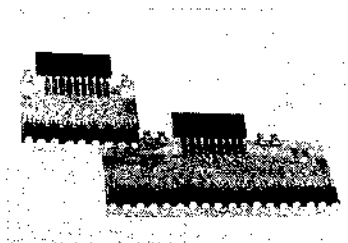
4906 INDICATOR WITH AMPLIFIER

Single indicator lamp with transistor driver. May be panel mounted in $3/8$ in. hole; bulb is replaceable from the front. Power required is -15 v at 30 ma. Overall dimensions are $2\frac{1}{2}$ in. x $5/8$ in. x $7/8$ in. The input to the transistor driver requires DEC standard levels or equivalent. The input load is 1 ma at -3 v. Minus 3 v lights the lamp; 0 v turns it off.



4917, 4918 Indicators with Amplifiers

The 4917 is a 9-bit indicator and the 4918 is an 18-bit indicator from R series logic without the requirement of additional buffering or clamped loads. The indicators must be used in conjunction with a W018 connector. All 18 pins of the cable connector are used for signal leads. Ground and -15 v are brought to the module through quick disconnect jumpers. Plugging the W018 into a connector slot with $+10$ v and -15 v on pins A and B will not damage the indicators. A -3 v or open circuit turns the indicator on. A ground input turns the indicator off. Load at ground is 1ma. The W018 should be plugged into the logic mounting and panel and a W023 should be used on the end of the cable that connects to the 4917 or 4918.



Power required is 540 ma at -15 v (4918). Overall dimensions are $9\frac{1}{2}$ in. x $15/16$ in. Bulbs are on $7/16$ centers and each requires a $5/16$ in. hole.

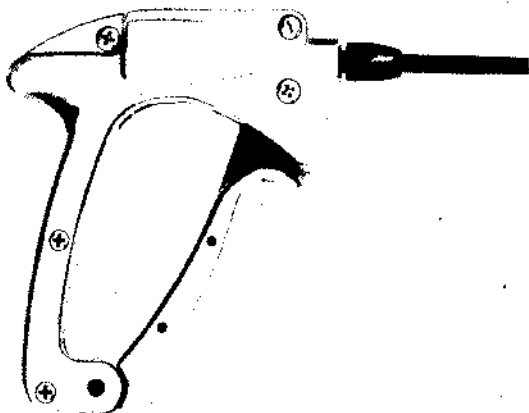
All indicators utilize 28-v bulbs which are operated at 15 v. This provides more than adequate illumination and greatly extends the life of the bulbs. When driving type 4906 from R-series flip-flops, one or more W002 or W005 clamped loads must be added to supply the current at -3 v demanded by these circuits.

| | |
|------|-----------|
| 4908 | — \$ 3.00 |
| 4906 | — \$ 9.50 |
| 4917 | — \$73.00 |
| 4918 | — \$96.00 |

WIRING ACCESSORIES

H810, H811, H812

HARDWARE
ACCESSORIES



H810 PISTOL GRIP HAND WIRE WRAPPING TOOL

The type H810 Wire Wrapping Tool is designed for wrapping #24 or #30 solid wire on Digital-type connector pins. The H810 Kit includes the proper sleeves and bits. It is recommended that five turns of bare wire be wrapped on these pins. This tool may also be purchased from Gardner-Denver Co. (Gardner-Denver part No. 14H-1C) with No. 26263 bit and No. 18840 sleeve for wrapping #24 wire. Specify bit #504221 and sleeve #500350 for wrapping #30 wire. When ordering from Digital specify the sleeve and bit size desired for #24 and #30 wire.



H811 WRAPPING AND TYPE H812 UNWRAPPING TOOLS

The Type H811 Hand Wrapping tool is useful for service or repair applications. It is designed for wrapping #24 solid wire on DEC Type H800-W connector pins. This tool may also be purchased from Gardner-Denver Co. as Gardner-Denver Part #A20557-12.

Wire wrapped connections may be removed with the Type H812 Hand Unwrapping tool. This tool may also be purchased from Gardner-Denver Co. as Gardner-Denver Part #500130.

The H811A and H812A are equivalent to the H811 and the H812 except that the A versions are designed for #30 wire. Both tools may be purchased from Gardner-Denver directly under the following part numbers: H811A A-20557-29; H812A 50 5084 — (LH).

| | |
|-------------|----------|
| H810(24) | \$99.00 |
| H810(30) | \$99.00 |
| H810(24&30) | \$150.00 |
| H811(24) | \$21.50 |
| H811A(30) | \$43.00 |
| H812(24) | \$10.50 |
| H812A(30) | \$10.50 |

WIRING ACCESSORIES

TYPES 913, 932, H820, H825

HARDWARE
ACCESSORIES



913 PATCHCORDS

Slip-on patchcords for wire-wrap FLIP CHIP mounting panels. Type 913 Grip Clip Patchcords are available in color-coded standard lengths of 2, 3, 4, 6, 8, 12, 16, 24, 32, 48, and 64 in. All cords are shipped in quantities of 100 in handy polystyrene window-type, snap-lid boxes. These patchcords use AMP Terminal Type 60530-1.

932 SOLID BUS STRIP

The 932 Bus Strip is designed for use with 1943 and H900 Mounting Panels. The bus strip fits either wire-wrap or solder-fork pins and simplifies wiring of register pulse busses, power and grounds. Length: 16 inches

H820 GRIP CLIPS FOR SLIP-ON PATCH CORDS

The Type H820 GRIP CLIP is identical to slip-on connectors used in the Type 913 Patchcords. These connectors are shipped in packages of 1000 and permit fabrication of patchcords to any desired length. Up to three GRIP CLIPS may be stocked on any H800-W connector pin. The GRIP CLIPS will take size 24-20 awg wire and may also be purchased from Amp, Inc. as Amp part #60477-2. H820 — \$47.80/1000.

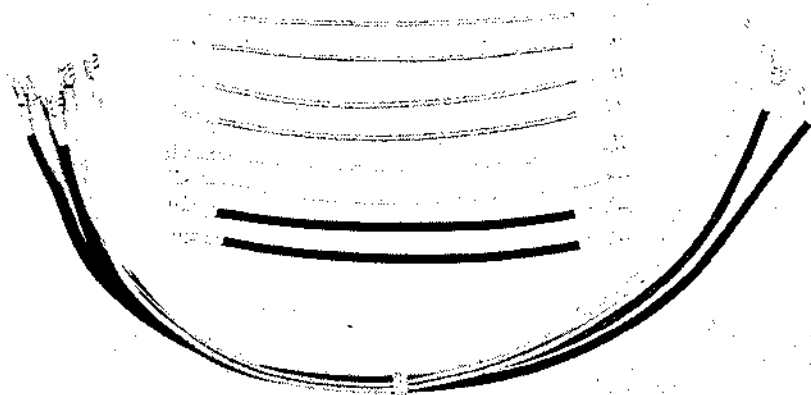
H825 HAND CRIMPING TOOL

The Type H825 Hand Crimping Tool may be used to crimp the Type H820 GRIP CLIP connectors. Use of this tool insures a good electrical connection. This tool may also be obtained from Amp, Inc. as Amp part #90084. H825 — \$146.70.

| | |
|--------|----------------------|
| 913 — | \$18.00 /pkg. of 100 |
| 932 — | \$.60 |
| H820 — | \$47.80 |
| H825 — | \$146.70 |

WIRING ACCESSORIES
POWER JUMPERS
TYPE 914

**HARDWARE
ACCESSORIES**



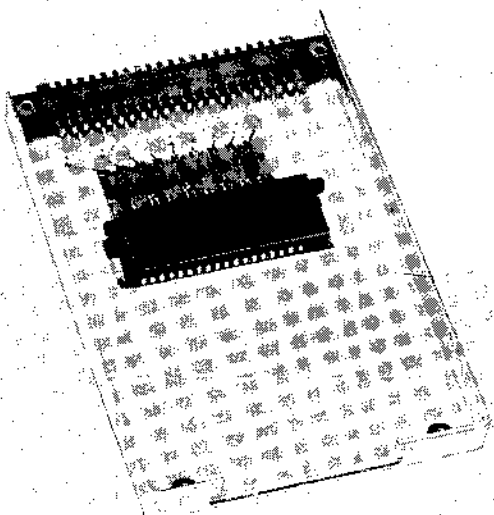
For interconnections between power supplies, mounting panels, and logic lab. panels these jumpers use AMP "Faston" receptacles series 250. Specify 914-7 for interconnecting adjacent mounting panels, or 914-19 for other runs of up to 19 inches. 914-7 contains 10 jumpers per package; 914-19 contains 10 jumpers per package.

914-7 — \$4.00/pkg.
914-19 — \$4.00/pkg.

SOCKET ADAPTER TYPE 4912

HARDWARE
ACCESSORIES

| FLIP CHIP | SYSTEM MODULE |
|--------------|------------------|
| A | A |
| B | B |
| C | C |
| D | D |
| E | E |
| F | F |
| G | G |
| H | H |
| I | I |
| J | J |
| K | K |
| L | L |
| M | M |
| N | N |
| O | O |
| P | P |
| Q | Q |
| R | R |
| S | S |
| T | T |
| U | U |
| V | V |
| | W |
| | X |
| | Y |
| | Z |

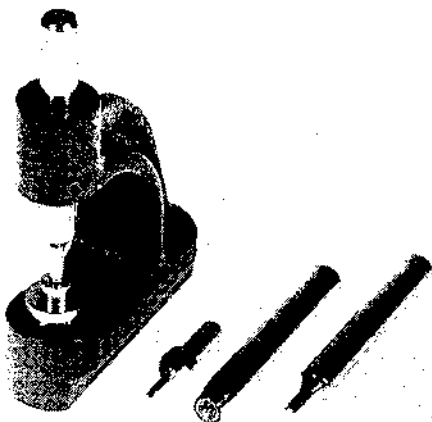


This accessory occupies one slot of a system module mounting panel, allowing a FLIP CHIP module to be plugged in. The +10 v for the FLIP CHIP module is taken from pin A of the system module connector. The handle of a FLIP CHIP module plugged into the adapter projects 1½ in. beyond a standard System Module handle. Because components on the FLIP CHIP module project above the normal limit of components on system modules, some care should be taken to see that these components do not contact adjacent printed boards while power is applied.

Stack-On Riveting Tool

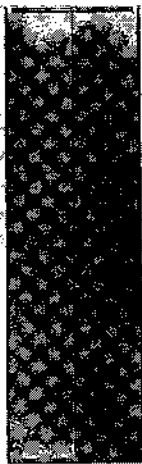
Type H830

HARDWARE
ACCESSORIES

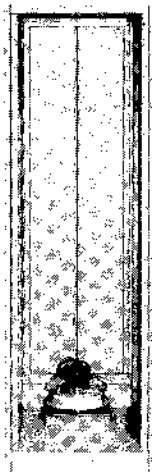


The H830 is designed for clinching on rivets on the 1951, W992, and W993 blank modules. Fits into any vise and once the module and eyelet are positioned, a slight tap of the hammer will clinch the eyelet.

The unit has a $3\frac{1}{2}$ " height and weighs 1 lb.



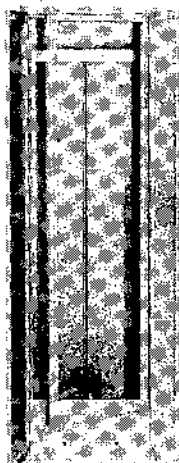
CAB-1



CAB-2

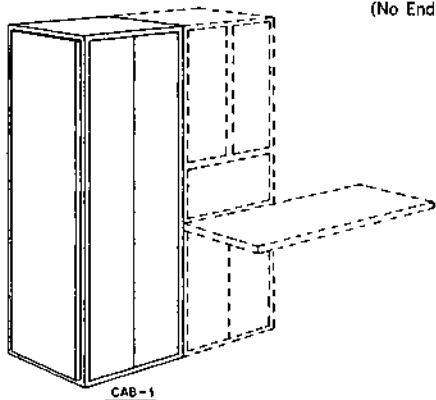


CAB-3

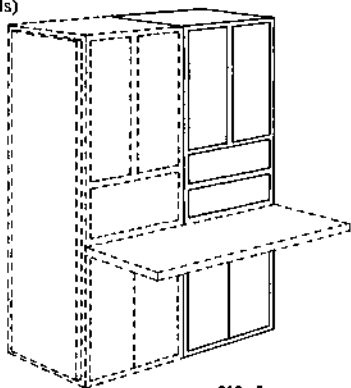


CAB-6 (Inside view)

EXPANDER CABINETS
(No End Panels)

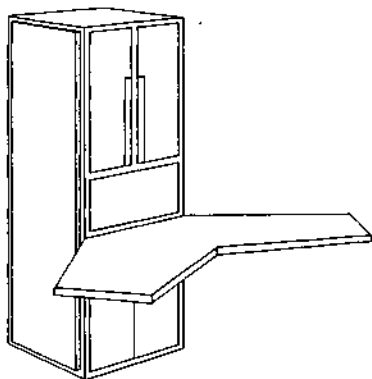


CAB-1

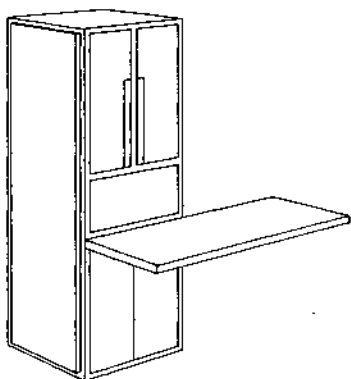


CAB-3

FREE-STANDING
CABINETS



CAB-8A



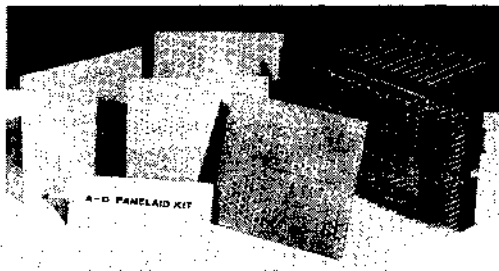
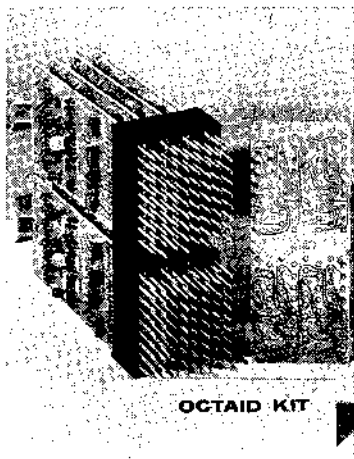
CAB-8B

OCTAIDS™ AND PANELAIDS™

Digital's new OCTAID and PANELAID kits are designed to provide the logic user with an easy-to-assemble, time-saving group of components to achieve common logic functions, such as up-down counting, decoding digital-to-analog and analog-to-digital conversion, and computer interfaces. Standard FLIP-CHIP modules and connectors are used in conjunction with special purpose printed circuit interconnectors.

The OCTAID series has up to eight standard FLIP-CHIP modules, and the PANELAID series has up to 64 modules. Each kit includes the necessary modules, connectors, and specially designed printed-circuit, back-panel wiring eliminating the necessity for hand-wiring. Since hand-wiring and trouble shooting are eliminated, a significant reduction in the amount of manufacturing time can be achieved.

Input/Output Buffer kits are designed to interface between Digital's PDP-8 or PDP-8/S computers and other OCTAID kits or specially designed systems. PANELAID kits, in general, can be interfaced directly to the PDP-8 or PDP-8/S.



DIGITAL-ANALOG CONVERTER KITS

KITS D001A-F

**OCTAID
SERIES**

Each converter can have from 8 to 13 bits depending upon the module and input pin combination. Each D001 kit includes two printed-circuit boards (F728 and F843) that are used for all digital-analog converter common connections, one H800W connector block, one A704 reference supply, and the necessary converter modules.

MODULE LOCATION AND TYPES VERSUS BITS (KIT)*

| BITS (KIT) | 8(A) | 9(B) | 10(C) | 11(D) | 12(E) | 13(F) |
|------------|------|------|-------|-------|-------|-------|
| A02 | A601 | A601 | A601 | A601 | A601 | A601 |
| A03 | A601 | A601 | A601 | A601 | A601 | A601 |
| A04 | A601 | A601 | A601 | A601 | A604 | A604 |
| B02 | — | A604 | A604 | A604 | A604 | A604 |
| B03 | — | — | — | A604 | A605 | A605 |
| B04 | — | — | — | — | — | A605 |

*The double height A704 fills locations A01 and B01 for all converters.



MODULE LOCATION DIAGRAM (WIRING SIDE)

The following table illustrates the digital input pins and analog output pin as specified for each size of converter. Bit 0 is designated the most significant bit.

INPUT/OUTPUT PINS FOR CONVERTERS

| SIGNAL | 8(A) | 9(B) | 10(C) | 11(D) | 12(E) | 13(F) |
|---------------|------|------|-------|-------|-------|-------|
| Analog Output | A04K | B02K | B02K | B03K | B03K | B04K |
| Bit 0 in | A04U | B02U | B03U | B03U | B03U | B04U |
| Bit 1 in | A04T | B02T | B02T | B03T | B03T | B04T |
| Bit 2 in | A04V | A04U | A04U | B02U | B02U | B03U |
| Bit 3 in | A03U | A04T | A04T | B02T | B02T | B03T |
| Bit 4 in | A03T | A04V | A04U | A04U | A04U | B02U |
| Bit 5 in | A03V | A03U | A03U | A04T | A04T | B02T |
| Bit 6 in | A02U | A03T | A03T | A04V | A03U | A04U |
| Bit 7 in | A02T | A03V | A03V | A03U | A03T | A04T |
| Bit 8 in | — | A02U | A02U | A03T | A03V | A03U |
| Bit 9 in | — | — | A02T | A03V | A02U | A03T |
| Bit 10 in | — | — | — | A02U | A02T | A03V |
| Bit 11 in | — | — | — | — | A02V | A02U |
| Bit 12 in | — | — | — | — | — | A02T |

INPUT: Standard Digital levels of —3 volts or ground are required. Loading for all digital inputs is 1 ma each at ground. If all inputs on a module are not required, the most significant inputs should be used and the least significant ones should be left open-circuited.

OUTPUT: The analog output is the equivalent of the digital input. The most negative output is - 10 volts, less the value of the least significant bit. The most positive output is ground. The offset of the least significant bit may be overcome by adjusting the —10 volt reference to —10 volts plus the value of the LSB to obtain a full scale value. Output impedance is 1000 ohms.

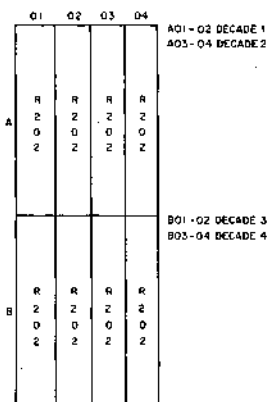
| | |
|-----------------|----------|
| D001A (8 bits) | \$377.25 |
| D001B (9 bits) | \$439.25 |
| D001C (10 bits) | \$439.25 |
| D001D (11 bits) | \$501.25 |
| D001E (12 bits) | \$519.25 |
| D001F (13 bits) | \$597.25 |

BCD UP-COUNTER

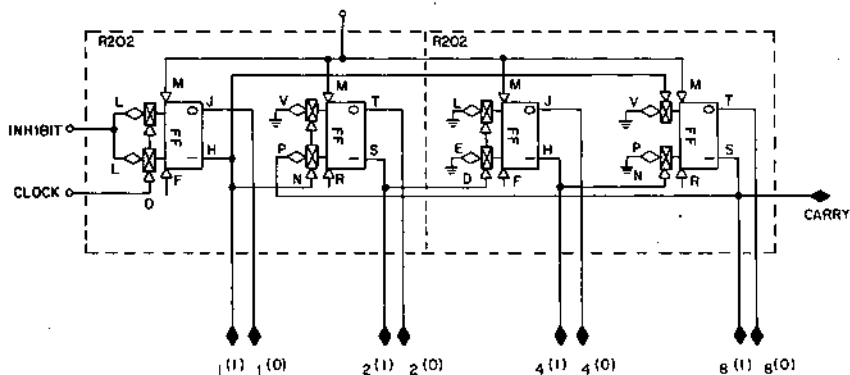
KIT D002

OCTAID
SERIES

The D002 has four binary-coded decimal (8-4-2-1) up-counters. Each counter is operated independently or in series to form a four-digit counter. All inputs conform to standard DEC pulse and level requirements. Each kit includes one printed-circuit board type F723, one H800 connector block, and two R202 decade modules per decade.



MODULE LOCATION DIAGRAM (WIRING SIDE)



BCD Up-Counter

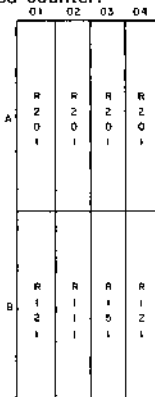
| | |
|---------------|----------|
| Single Decade | \$ 62.50 |
| Quad Decade | \$137.50 |

BI-DIRECTIONAL DECADE COUNTER

KIT D004

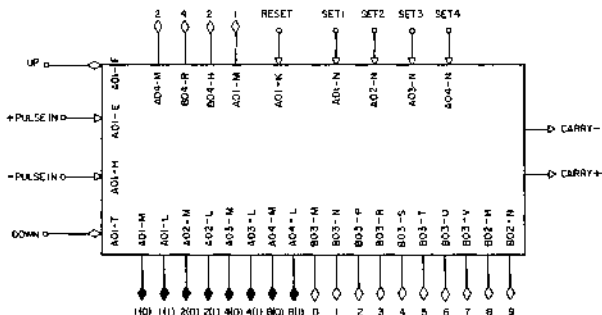
OCTAID
SERIES

The D004 is primarily a one-digit 8-4-2-1 up-down counter that can optionally be used for decimal decoding and 8421-2421 conversion. The counter is level-controlled. All blocks are wired for the counting, decoding and conversion functions. If decoding or conversion functions are not desired, the associated modules need not be ordered. The basic up-down counter kit includes two printed-circuit boards (F861 and F862), four R201 flip-flops, and one R121 gate. To add the decimal decoding function, one R151 binary-to-octal decoder and one R111 gate are included. To add the 8421-2421 conversion function,* one R121 gate is included. The following figures show module location; define the inputs, outputs, and control connections for interconnection to other devices; and schematically illustrate the completed counter.



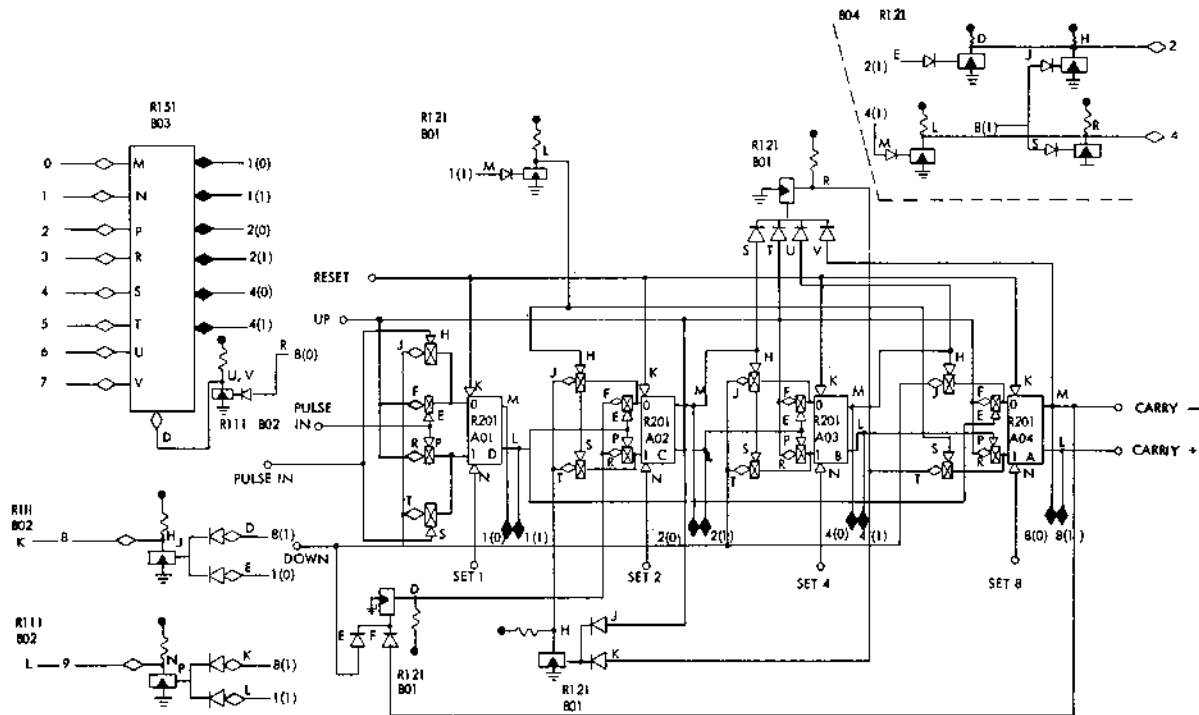
MODULE LOCATION DIAGRAM (WIRING SIDE)

*8421 to 2421 Conversion — Wiring has been provided for 8421 to 2421 conversion for use in a digital-to-analog converter. The most and least significant bits (2 - 1) are derived directly from the 0 sides of the up down counter. The remaining bits (- 4 2 -) are derived from the outputs of two R121 gates connected as NOR gates.



UP/DOWN DECADE DECODER AND CONVERTER INPUTS, OUTPUTS, AND CONNECTIONS

| | | |
|-------------------|-------|----------|
| D004 | _____ | \$123.40 |
| Decoding Option | _____ | \$ 47.00 |
| Conversion Option | _____ | \$ 17.00 |



UP-DOWN COUNTER, DECODER, AND CONVERTER

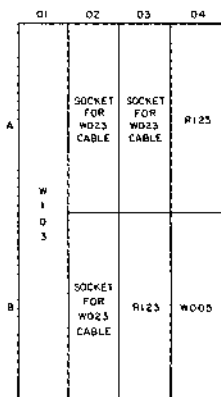
PDP-8/S INPUT BUFFER INTERFACE

KIT D005

OCTAID
SERIES

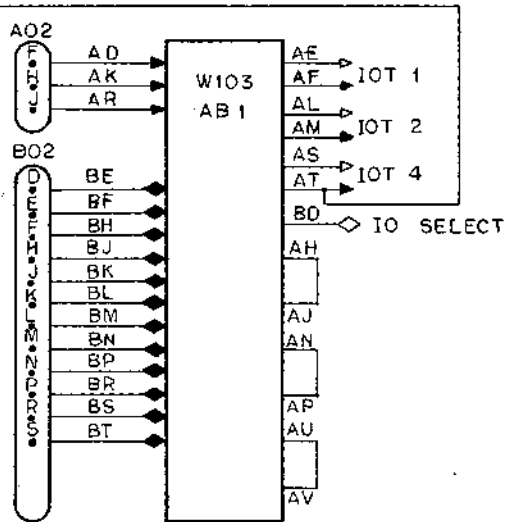
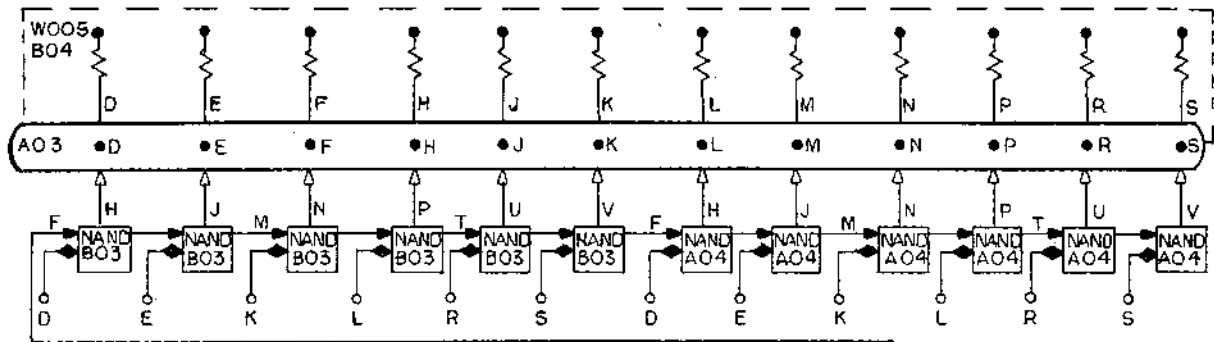
This kit provides selected cable connection sockets, device selection level and pulses, and data input gates for a 12-bit register. The PDP-8/S supplies a device selection code and three I.O. transfer pulses (IOP 1, 2 and 4), which are decoded by a W103 device selector module for local device usage.

A W005 clamped load module provides clamping voltage to the AC register input lines. If, however, there are clamps on these lines in other units it may not be necessary to use these. The complete kit includes two printed-circuit boards (types F002 and F003), one H800W connector block, the W103 and W005, and two R123 gates. An inverter must be provided by the device to be sampled to supply an AC pulse on the Read Buffer, I. O. command.



MODULE LOCATION DIAGRAM (WIRING SIDE)

D005 _____ \$122.00



PDP 8/S INPUT BUFFER INTERFACE

PDP-8/S OUTPUT BUFFER REGISTER

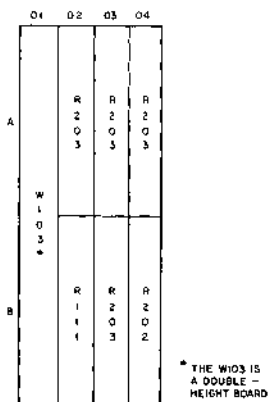
KIT D006

OCTAID
SERIES

This kit provides a convenient means of sampling, storing, and transferring to the outside world the contents of the Central Processor's Accumulator Register during an IOT instruction.

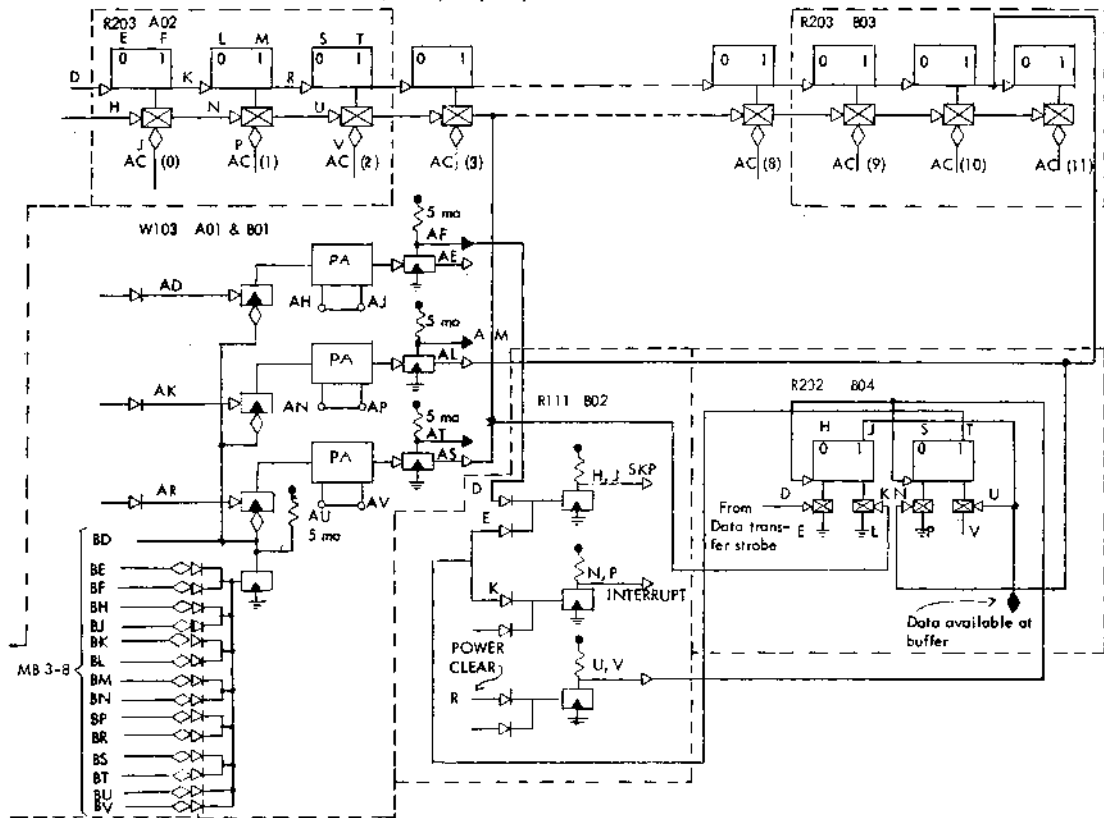
Four R203 triple flip-flop boards are used for storage, making a total of twelve flip-flops. The kit also includes two printed-circuit boards (types F001 and F004), one H800W connector block, and W103 device selector, on R111 gate, and one R202 dual flip-flop. The flip-flops are gated by the corresponding AC bits (0 - 11) being set to the "one" state (positive conditioning levels) and by a positive enabling pulse (supplied by IOP 4 and the chosen device select code). A strobe pulse input is required to the R202 (pin D) when data is strobed out of the R203's.

OUTPUT: The contents of the output buffer register may be sampled or transferred where desired by taking the bit information directly from the output pins of the flip-flops. R202 output (pin J B04) provides a negative level to indicate new data has been deposited in the buffer.



MODULE LOCATION DIAGRAM (WIRING SIDE)

LOCATION NUMBERS FOR R203's ARE: A02, A03, A04, B03.



OUTPUT BUFFER REGISTER

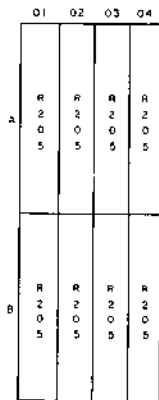
DUAL 8-BIT SHIFT REGISTER

KIT D007

**OCTAID
SERIES**

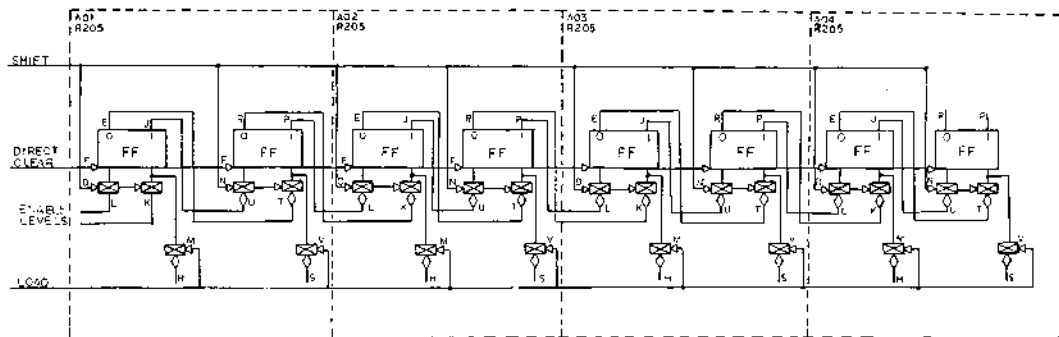
This kit has two independent 8-bit shift registers with the enable inputs of the first flip-flop left floating. By appropriate connection of the floating inputs, operation as a shift register, ring-counter, or switch-tail ring counter can be attained. In addition, the two 8-bit circuits can be operated in series to provide a 16-bit capability. Each kit includes two printed-circuit boards (types F005 and F006), one H800 connector block, and either one or two shift registers. Each shift register includes four R205 flip-flop modules (8 flip-flops) with the "0" and "1" enable inputs connected, respectively, to the "1" and "0" outputs of the preceding stage.

All pulse inputs are bussed together to form a common shift line. A common direct clear line is also brought out for simultaneous clearing of all flip-flops in the shift register. Loading a "1" into the shift register is accomplished by grounding any enable input at least 400 nsec prior to initiation of a load pulse. Individual load pulses are also bussed together to form a common load or strobe input. All pulse and level inputs must conform to the standard DEC configuration.



MODULE LOCATION, DIAGRAM (WIRING SIDE)

| | |
|--------|----------------|
| Single | _____ \$133.00 |
| Dual | _____ \$249.00 |



DUAL 8-BIT SHIFT REGISTER

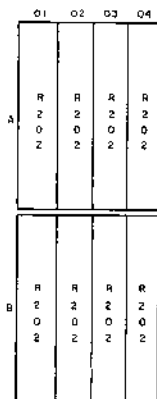
Note: Loading for registers #1 and #2 are identical. For location of inputs and outputs for register #2, substitute row B in place of row A.

DUAL 8-BIT UP-COUNTER KIT D008

**OCTAID
SERIES**

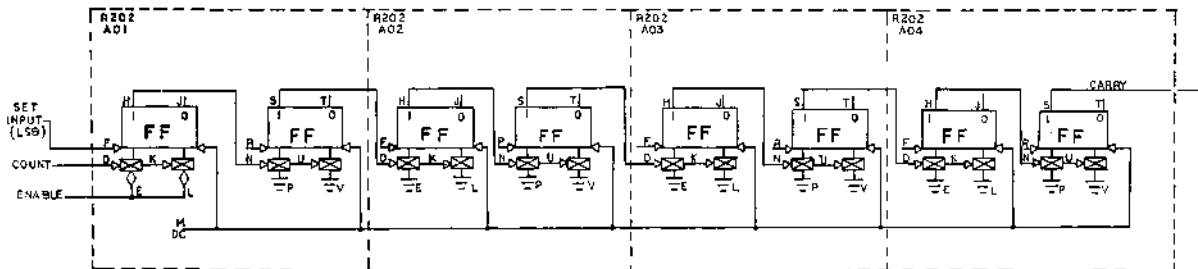
This kit includes two independent eight-bit up-counters (four R202 flip-flops for each counter), two printed-circuit boards (types F007 and F008), and one H800 connector block. Each counter can be operated independently, or should more than eight bits be required, the counters can be connected in series to provide a 16-bit counter.

Each counter has an independent direct clear, count enable, and pulse or count input line. In addition, each bit of either counter can be individually set so that the counter can start counting at some preselected number other than zero. All pulses and levels should conform to DEC standards.



MODULE LOCATION DIAGRAM

| | | |
|--------|--|----------|
| Single | | \$117.00 |
| Dual | | \$217.00 |



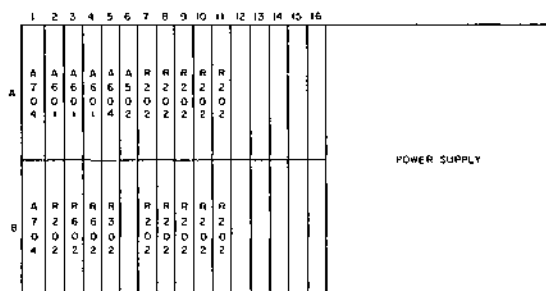
DUAL 8-BIT UP-COUNTER

ANALOG-DIGITAL CONVERTER KITS

KITS C001, C001A, C002

**PANELAID
SERIES**

There are three 10-Bit, successive-approximation, analog-digital converters in the Panelaid™ series. The C001 is supplied with 60-Hertz power, the C001A with 50-Hertz power, and the C002 is available without AC power. All three converters accept any analog value from 0 to -10.23v (full scale) and convert this to a 10-bit absolute value. Each unit has an accuracy of 0.1 percent ($\pm\frac{1}{2}$ least significant bit) and a resolution of 1 part in 1024 (10 millivolts). The maximum conversion rate is 30 kh for low-impedance sources with a maximum input current drain of 1 μ amp. All digital input and output signals are compatible with DEC standard pulses and levels. The C001 and C001A are housed on a H900 mounting panel, while the C002 is mounted on a 1943 panel.



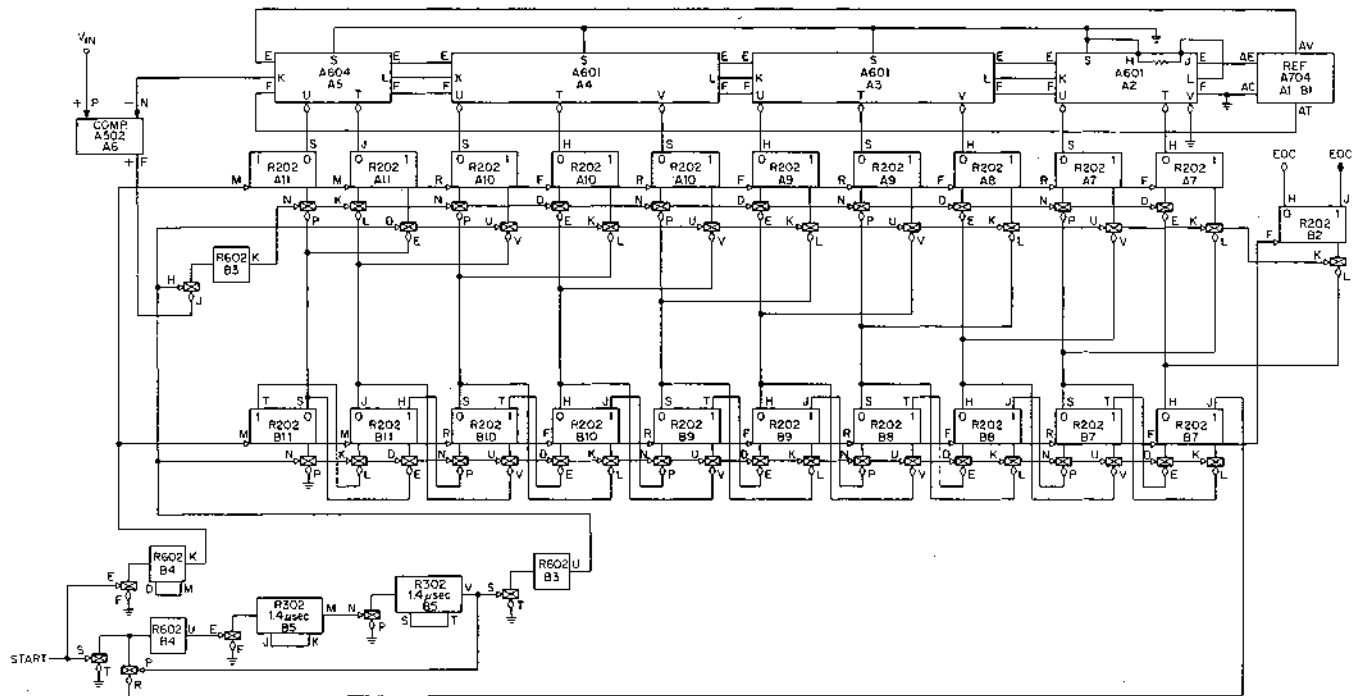
MODULE LOCATION DIAGRAM

PARTS LIST

- 1 — H900 — W — P²³ power supply and mounting panel
- 11 — R202 dual flip-flop
- 2 — R602 dual pulse amplifier
- 1 — R302 dual delay
- 1 — A502 comparator
- 3 — A601 D to A converter
- 1 — A604 D to A converter
- 1 — A704 reference supply
- 1 — E724 Panelaid
- 1 — E725 Panelaid
- 1 — E726 Panelaid
- 1 — E727 Panelaid
- 1 — W980 module extender

*1943 supplied with the C002, H900A-W-P is supplied in C001A

| | |
|------------|--------------|
| \$1,144.00 | — Kit #C001 |
| 1,162.00 | — Kit #C001A |
| 1,079.00 | — Kit #C002 |



10-BIT ANALOG-DIGITAL CONVERTER

50/60 HERTZ BCD REAL TIME CLOCK KIT C003

PANELAID
SERIES

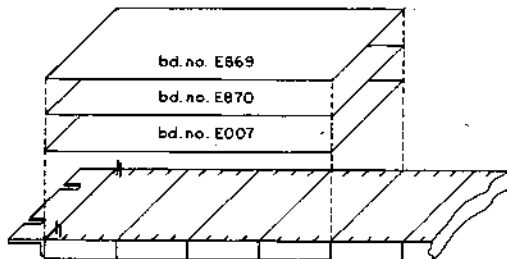
This kit is useful for applications in which it is desired to maintain a time of day reading, or to measure the time lapse of events, to provide time synchronizing signals, etc. The clock has built-in gating to permit connection of switches to preset the clock to the correct time of day; or for elapsed time measurements to clear the clock before use.

| | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 09 | 08 | 07 | 06 | 05 | 04 | 03 | 02 | 01 |
|---|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| | | | | | | | | | xx | | | | xxx | | | |
| A | R 2 0 2 | R 2 0 2 | R 2 0 2 | R 2 0 2 | R 2 0 2 | R 2 0 2 | R 2 0 2 | R 2 0 2 | R 0 1 8 | R 2 0 2 | R 2 0 2 | R 2 0 2 | W 0 1 8 | R 2 0 2 | R 2 0 2 | R 2 0 2 |
| B | R 6 0 1 | R 3 0 2 | W 5 0 1 | W 5 0 1 | W 0 2 3 | W 0 2 3 | W 0 0 5 | R 1 1 1 | R 1 1 1 | R 1 1 1 | R 1 1 1 | R 1 1 1 | W 0 2 3 | W 0 0 5 | R 1 1 1 | R 1 1 1 |
| | | | | | | x | x | x | x | | | | | | | |

- x MODULES OMITTED IF SECOND SET NOT DESIRED
- xx MODULES OMITTED IF CABLE OUTPUTS OF SECOND COUNTER NOT DESIRED
- xxx MODULES OMITTED IF CABLE OUTPUTS OF HOUR AND MINUTE COUNTERS NOT DESIRED

MODULE LOCATION DIAGRAM (WIRING SIDE)

The following figure illustrates the required relative positioning of the three printed-circuit boards to each other when installed on a mounting panel. However, the boards need not occupy these particular socket positions.



RELATIVE BOARD POSITIONS

It is suggested that the PANELAID boards be positioned approximately $\frac{1}{2}$ inch apart and as close to the mounting panel as possible. This facilitates attachment of testing equipment or wiring to other devices.

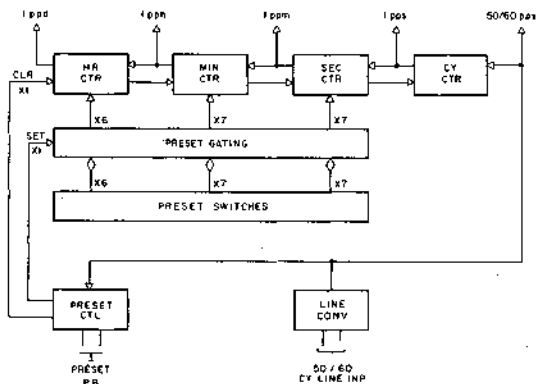
The radix of the hertz counter may be set to either 50 or 60 by jumpers installed on the outer layer board. For a 50-hertz clock a jumper is installed between each pair of lugs with a "50" between them or for a 60-hertz clock a jumper is installed between lugs which have a "60" between them. These lugs are shown on the logic diagram.

CLOCK INPUTS: Should come from a network consisting of a small filament transformer, and a small integrator to filter high frequency noise from the line voltage. A cable socket input is provided. The input network must be supplied by the customer.

PRESET LEVEL INPUTS: Inputs are clamped to -3 volts which cause assertions of "ones" at the input gates. Decade switches used to generate preset levels must provide contact closures to ground to the level inputs to negate bits not to be set; connection to these inputs is via W023 boards in sockets provided.

PRESET PUSH BUTTON INPUT: A momentary contact closure presented between pins S and U of the W051 in B14 will generate the signals to read the contents of the preset switches into the hour, minute and second counters.

OUTPUT CABLING: The "1" side negative outputs of the hour, minute, and second counters are connected to two sockets to enable driving of indicators, connecting to other devices etc.

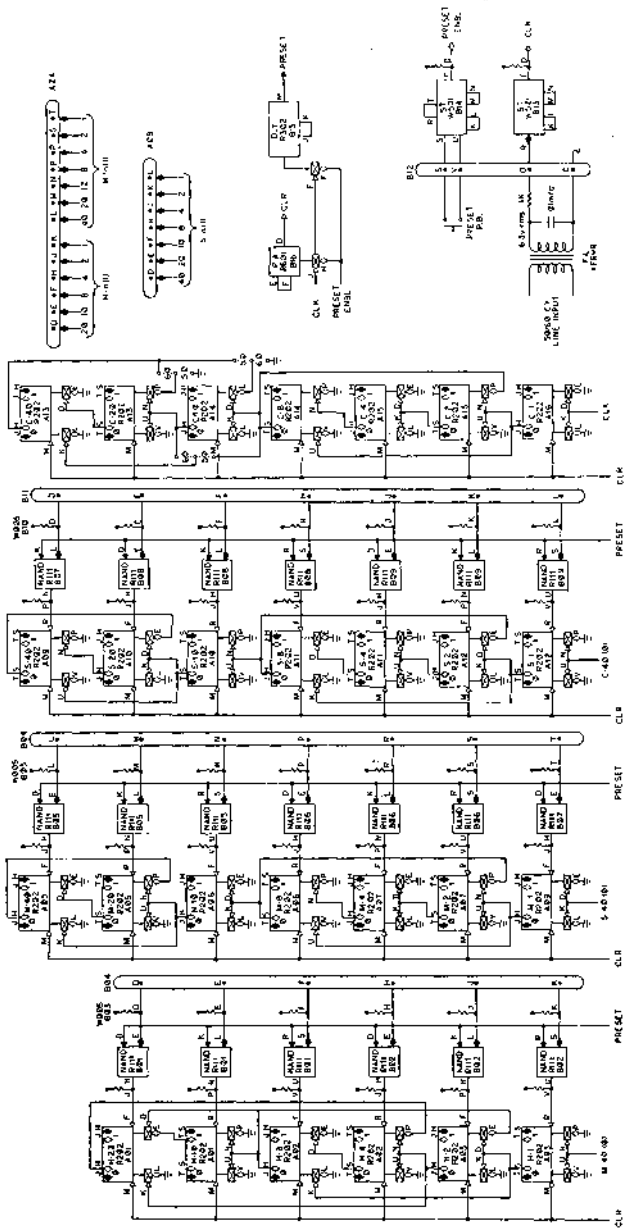


REAL TIME CLOCK BLOCK DIAGRAM

Equipment required and prices; excluding mounting panels, power supplies, and cabling are:

| | |
|----------------------------|--------------------------|
| 1 — E007 PANELAID for C003 | 1 — R302 Dual Delay |
| 1 — E869 PANELAID for C003 | 1 — R601 Pulse Amplifier |
| 1 — E870 PANELAID for C003 | 2 — W005 Clamped Loads |
| 7 — R111 Diode Gates | 2 — W501 Schmitt Trigger |
| 14 — R202 Dual Flip-flop | 2 — W018 Cable Connector |

C003 — \$639.00

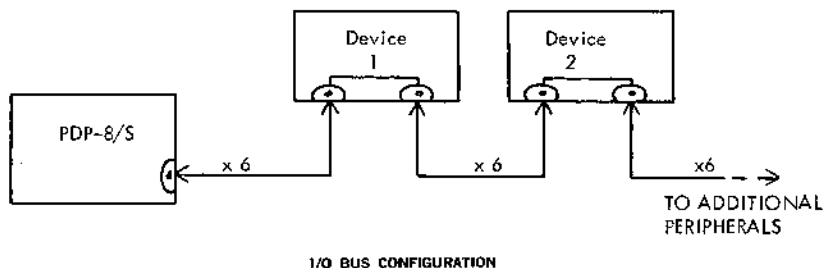


REAL TIME CLOCK

PDP-8/S I/O BUS INTERFACE KIT C005

PANELAID
SERIES

This kit provides an interface for a grouping of six cables that parallel connect each peripheral device. Each device must have associated sockets to facilitate interconnection of peripheral gear and continuation of the I/O Bus cables. Six sockets must be provided for input cables and six for output cables.



The kit includes two printed-circuit boards, each six sockets wide by two sockets high. One board provides all the ground connections, the other all the wiring to parallel the two sockets for each cable.

The PANELAID boards should be positioned as close to the mounting panel surface (and each other) as possible, for easy attachment of test equipment or wiring to input-output devices.

PARTS LIST

- 1 — E001 PANELAID
- 1 — E002 PANELAID

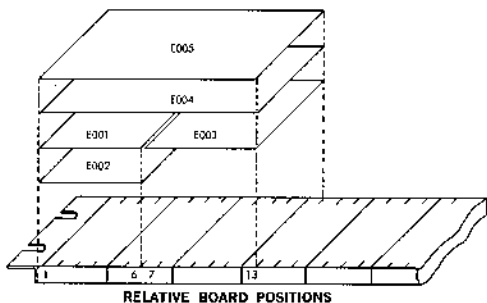
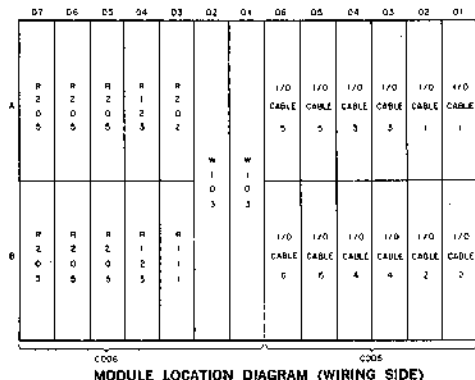
C005 — \$12.00

PDP-8 or PDP-8/S INPUT/OUTPUT BUFFER REGISTER KIT C006

**PANELAID
SERIES**

This kit includes a 12-bit register that may be loaded from the computer's accumulator register (AC); two device-selector modules to decode and generate the control or transfer pulses; input gating to the AC input lines; a flip-flop with one output connected to I/O Skip and Program Interrupt facilities; and a free flip-flop which may be used for enabling or controlling functions. A C005 PANELAID™ interface is used with each C006 to provide connections for the PDP-8 or PDP-8/S I/O Bus cables.

The following figures illustrate the required relative positioning of the C005 and C006 boards when installed on a mounting panel. Although relative board location is critical, the exact positioning of the kit, with respect to the mounting panel, is not.



NOTE:

E001 and E002 are board numbers for kit # C005

E003, E004, and E005 are board numbers for kit #C006

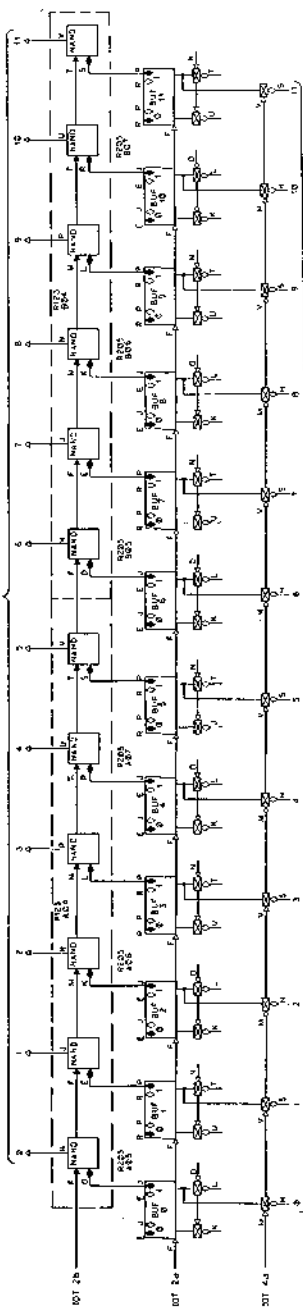
The equipment required and prices, — excluding mounting panels and power supplies are:

- 1 — E001 PANELAID for C005
- 1 — E002 PANELAID for C005
- 1 — E003 PANELAID for C006
- 1 — E004 PANELAID for C006
- 1 — E005 PANELAID for C006

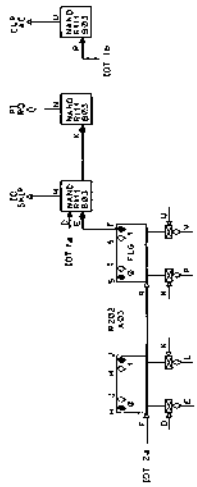
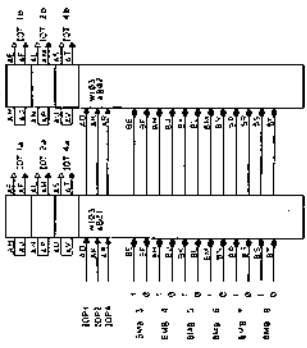
- 1 — R111 Diode Gate
- 2 — R123 Diode Gate
- 1 — R202 Dual Flip-flop
- 6 — R205 Dual Flip-flop
- 2 — W103 PDP-8 Device Selector

C006 — \$397.00

AC INPUT



BAC. (1)



Input/Output Buffer Register

PRINTED CIRCUIT BOARDS

E and F SERIES

The E and F series are the printed circuit back panels used in the OCTAID and PANELAID Kits. These back panels may be ordered separately by those who already have the required Flip-Chip modules and connectors. Where a kit includes more than one board, all boards must be used to perform the indicated functions.

PRICE LIST

| <u>KIT NUMBER</u> | <u>KIT NAME</u> | | <u>PRICE*</u> |
|-------------------|------------------------------------------------|--------------|----------------|
| C001 | Analog-Digital Converter Kits | E724 | \$11.50 |
| C001A | | E725 | 11.50 |
| C002 | | E726 | 11.50 |
| | | E727 | 11.50 |
| | | TOTAL | \$46.00 |
| <hr/> | | | |
| C003 | 50/60 Hertz BCD Real Time Clock | E869 | 16.00 |
| | | E007 | 16.00 |
| | | E870 | 16.00 |
| | | TOTAL | \$48.00 |
| <hr/> | | | |
| C005 | PDP-8/S IO Bus Interface | E001 | 6.00 |
| | | E002 | 6.00 |
| | | TOTAL | \$12.00 |
| <hr/> | | | |
| C006 | PDP-8 and PDP-8/S Input Output Buffer Register | E001 | 6.00 |
| | | E002 | 6.00 |
| | | E003 | 10.00 |
| | | E004 | 10.00 |
| | | E005 | 10.00 |
| | | TOTAL | \$42.00 |
| <hr/> | | | |
| D001A-F | Digital-Analog Converter | F728 | 2.25 |
| | | F843 | 2.25 |
| | | TOTAL | \$ 4.50 |
| D002 | BCD Up-Counter | F723 | 4.50 |

*If the board fits over only one H800 connector block it will be identified by an F and three digits. If the board fits over more than one H800 it will be identified by an E and three digits. Any Octaid kit (D series) can contain only F series boards. However, any Panelaid kit may contain both E and F series boards.

PRICE LIST (continued)

| <u>KIT NUMBER</u> | <u>KIT NAME</u> | | <u>PRICE*</u> |
|-------------------|------------------------------------------------------------------|-------|----------------|
| D004 | Bi-Directional Decode Counter (Converter and Decoder Options) | F861 | \$ 5.70 |
| | | F862 | 5.70 |
| | | TOTAL | <u>\$11.40</u> |
| <hr/> | | | |
| D005 | PDP-8/S Input Buffer Interface | F002 | 4.50 |
| | | F003 | 4.50 |
| | | TOTAL | <u>\$ 9.00</u> |
| <hr/> | | | |
| D006 | PDP-8/S Output Buffer Register | F001 | 2.25 |
| | | F004 | 2.25 |
| | | TOTAL | <u>\$ 4.50</u> |
| <hr/> | | | |
| D007 | Single or Dual 8-Bit Shift Register | F005 | 4.50 |
| | | F006 | 4.50 |
| | | TOTAL | <u>\$ 9.00</u> |
| <hr/> | | | |
| D008 | Single or Dual 8-Bit Up-Counter | F007 | 4.50 |
| | | F008 | 4.50 |
| | | TOTAL | <u>\$ 9.00</u> |
| <hr/> | | | |

PART V: ANALOG - DIGITAL CONVERSION HANDBOOK

PREFACE

The Analog-Digital Conversion Handbook represents the first attempt in the data processing industry to assemble comprehensive information on this subject in a form that makes it immediately useful to beginner or expert. All phases of conversion are covered, from concepts to calibration. Many diagrams supplement the text; and tabular summaries of terms, methods, and performance characteristics are included for comparison and reference. Circuit modules and other equipment manufactured by Digital Equipment Corporation are mentioned specifically, so after choosing the conversion method most appropriate to his needs, the reader can construct his system directly.

The use of circuit modules in constructing analog-digital converters yields several advantages. First, they are flexible. Converter systems have widely varying requirements, from pulse height analysis, where differential linearity is of utmost importance, to time-locked averaging in biomedical work, where resolution is more critical than repeatability or even accuracy. Modules permit the construction of the exact type of converter needed and, should requirements change, the same modules can be used later to build a different kind of system.

Second, modules are economical. Aside from the interchangeability mentioned above, savings are gained in the cost of construction. The typical cost of a digital-to-analog converter is about \$1,000; of an analog-to-digital converter, about \$2,000. If several systems are built, the cost per converter decreases since the same power supplies and mounting panels are used for the additional units. If the speed requirement is exceptionally high, costs will be higher.

A third advantage of using modules is that the completed converter need never go back to the factory for recalibration. Procedures for calibration and adjustment are included in this handbook. Recalibration can be carried out quickly and easily by the user.

Those modules designed exclusively for use in conversion systems are specified in detail in this handbook. The general purpose logic modules also needed are mentioned by name and type number. Complete specifications for these and over 200 other kinds of circuit modules and accessories are contained in another part of this handbook.

CHAPTER I

BASIC ELEMENTS OF CONVERSION

Introduction

This chapter describes the general technique used to convert, to sample and hold, and to multiplex.

For digital-to-analog conversion, just one technique is described. Though there may be some variations, the same technique is generally applicable for all digital-to-voltage or digital-to-current converters.

Analog-to-digital conversion is somewhat more complex and thus a variety of different methods is commonly used. In this chapter, the four most common methods are described. Of these, the successive approximation converter is most generally used since it provides good performance over a wide range of applications at a reasonable cost. However, if the converter is to be used only in a single application, various other methods may be preferred for better performance or lower cost.

It is suggested that this chapter be read as a brief development of the principles of conversion, rather than a delineation of specific methods. Detailed descriptions of conversion systems will be given in Chapters 3 and 4.

Digital-to-Analog Conversion

To convert from a digital number to an analog voltage, a resistive divider network is connected to the flip-flop register which holds the digital number (see Figure 1). The divider network is weighted so that each bit of the register will contribute to the output voltage in proportion to its value.

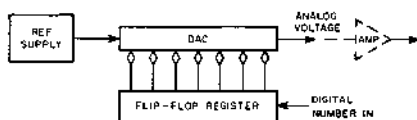


Figure 1. Digital-to-Analog Conversion

The digital input signal determines the analog output voltage, since the divider network is simply a passive element. However, because digital voltage levels are not usually as precise as required in an analog system, level amplifiers are placed between the flip-flops and the divider network. The amplifiers switch the divider network between ground and a

reference voltage supplied by a precision reference supply. The output voltage range is between these two voltage levels. In Digital systems, the range is normally 0 to -10 volts. If the digital-to-analog converter is to drive a long cable or a heavy load, an operational amplifier or emitter follower is usually put on the output of the circuit to lower the output resistance. The digital-to-analog converter and reference supply shown in Figure 1 are basic to a digital-to-analog converter and are described under those headings in Chapter 5.

Analog-to-Digital Conversion

The basis of analog-to-digital conversion is the comparator circuit. This circuit compares an unknown voltage with a reference voltage and indicates which of the two is larger.

SIMULTANEOUS METHOD

Figure 2 shows how a simple simultaneous analog-to-digital converter can be built using several comparator circuits. Each comparator has a reference input signal. The other input terminal of the comparators is driven by the unknown input analog signal, which is between 0 and V volts. The comparator is called "ON" if the analog input is larger than the reference input. Then, if none of the comparators are on, the analog input must be less than $\frac{V}{4}$. If C-1 is on, and C-2 and C-3 are off, the input must be between $\frac{V}{4}$ and $\frac{V}{2}$. Similarly, if C-1 and C-2 are on, and C-3 off the voltage is between $\frac{V}{2}$ and $\frac{3V}{4}$; and if all the comparators are on, the voltage is greater than $\frac{3V}{4}$.

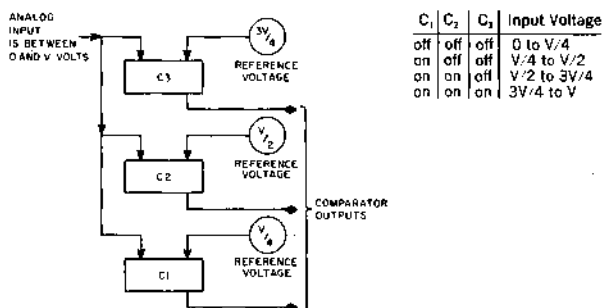


Figure 2. Simultaneous Analog-to-Digital Converter

Here, the voltage range is divided into four parts, which can be coded to give two binary bits of information. Seven comparators would give three bits of binary information. Fifteen comparators would give four bits. In general, $2^n - 1$ comparators will give N bits of binary information.

The simultaneous method is extremely fast for small resolution systems. For large resolution systems (a large number of bits), this method requires so many comparators that it becomes unwieldy and prohibitively costly.

FEEDBACK METHODS

If the reference voltage were variable, only one comparator would be needed. Each of the possible reference voltages could be applied in turn to determine when the reference and the input were equal. But a digitally controlled variable reference is simply a digital-to-analog converter. Thus the generalized analog-to-digital converter shown in Figure 3 is actually a closed-loop feedback system. The main components are the same as a digital-to-analog converter plus the comparator and some control logic. With a digital number in the DAC (digital-to-analog converter) the comparator indicates whether the corresponding voltage is larger or smaller than the input. With this information, the digital number is modified and compared again.

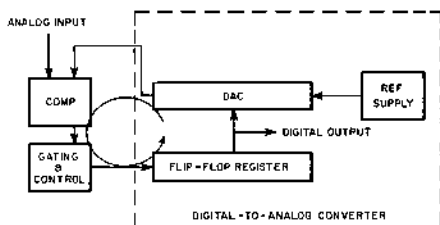


Figure 3. Analog-to-Digital Converter Incorporating Digital-to-Analog Conversion Modules

COUNTER METHOD

Numerous methods may be used for controlling the conversion. The simplest way is to start at zero and count until the DAC output equals or exceeds the analog input.

Figure 4 shows a converter in which the DAC register is a counter, and a pulse source has been added. The gate stops pulses from entering the counter when the comparator indicates that the conversion is complete.

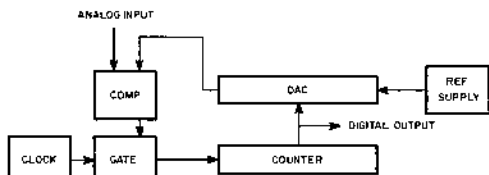


Figure 4. Counter Converter

The counter method is good for high resolution systems: As the number of bits is increased, very little additional circuitry is needed. Multiple inputs can easily be converted simultaneously (as described under Multiplexing later in this chapter). However, conversion time increases rapidly with the number of bits, since an N-bit converter must allow time for 2^n counts to accumulate. The average conversion time will, of course, be half this number.

CONTINUOUS METHOD

A slight modification of the counter method is to replace the simple counter with an up-down counter as in Figure 5. In this case, once the proper digital representation has been found, the converter can continuously follow the analog voltage, thus providing readout at an extremely rapid rate. This method, called continuous conversion, is particularly useful when a single channel of information is to be converted. The converter starts running, and the digital equivalent of the input voltage can be sampled at any time.

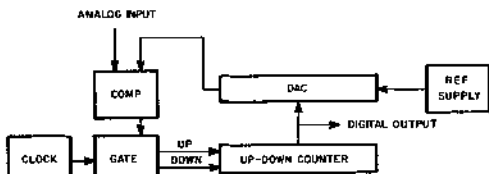
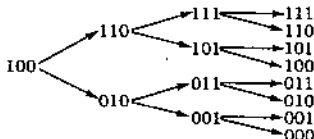


Figure 5. Continuous Converter

The continuous method is less effective for multiple inputs or for inputs that change faster than the converter can change. Each time the input makes a large change, the converter may require as many as 2^n steps to catch up. However, if a rapid rate of change is necessary, extra comparators may be added so that the up-down counter can count in units of 2, 3, 4, or more (see Chapter 3).

SUCCESSIVE APPROXIMATION METHOD

For higher speed conversion of many channels, the successive approximation converter is used. This method requires only one step per bit to convert any number. The successive approximation analog-to-digital converter operates by repeatedly dividing the voltage range in half as follows:



Thus, the system first tries 100, or half scale. Next it tries either quarter scale (010) or three-fourths scale (110) depending on whether the first approximation was too large or too small. After three approximations, a 3-bit digital number is resolved.

Successive approximation is a little more elaborate than the previous methods since it requires a control register to gate pulses to the first bit, then the second bit, and so on. However, the additional cost is small and the converter handles all types of signals about equally fast.

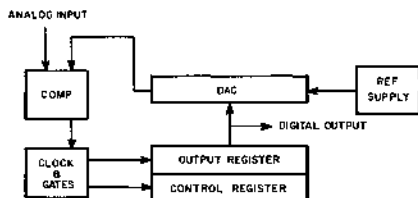


Figure 6. Successive Approximation Converter

The successive approximation method is good for general use. It handles many continuous and discontinuous signals and large and small resolution conversions at a moderate speed and moderate cost.

Sample and Hold

A sample and hold circuit is used with an analog-to-digital converter when it is necessary to convert a signal which changes too rapidly to allow an accurate conversion. A digital signal from some timing device can signal the sample and hold to hold the analog voltage present on its input until a time when the converter has completed its operation. The sample and hold is basically an operational amplifier which charges a capacitor during the track or sample mode, and retains the value of the charge of the capacitor during the hold mode.

The acquisition time of a sample and hold is the time required for the capacitor to charge up to the value of the input signal after the switch is first shorted. The aperture time (see definition, Chapter 2) is the time required for the switch to change state and the uncertainty in the time that this change of state occurs. The holding time is the length of time the circuit can hold a charge without dropping more than a specified percentage of its initial value.

The sample and hold circuit can be represented as shown in Figure 7. When the switch is closed, the capacitor is charged to the value of the input signal; then it follows the input. When the switch is opened, the capacitor holds the same voltage that it had at the instant the switch was opened.

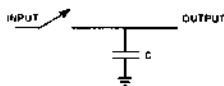


Figure 7 Sample and Hold

It is possible to build a sample and hold circuit just as shown here. Often, the same circuit is used with a high gain amplifier to increase the driving current available into the capacitor or to isolate the capacitor from an external load on the output. In some cases, this sample and hold is made entirely differently; but from a logical point of view, it acts as the ideal component shown.

Figure 8 shows a sample and hold built with an A200 amplifier board and an A121 multiplexer switch.

In Track sample, the hold capacitor is charged up by the operational amplifier; in Hold, the capacitor is switched into the feedback loop. The input resistor and the feedback resistor are switched to ground. Since the input to the amplifier remains within a few microvolts of ground (except during switching), the input impedance is 10,000 ohms to ground both in Track and Hold. The offset input allows a precise dc level to be added to the input so that the output of the sample and hold is shifted by this value.

These principles have been incorporated into the A400 sample and hold.

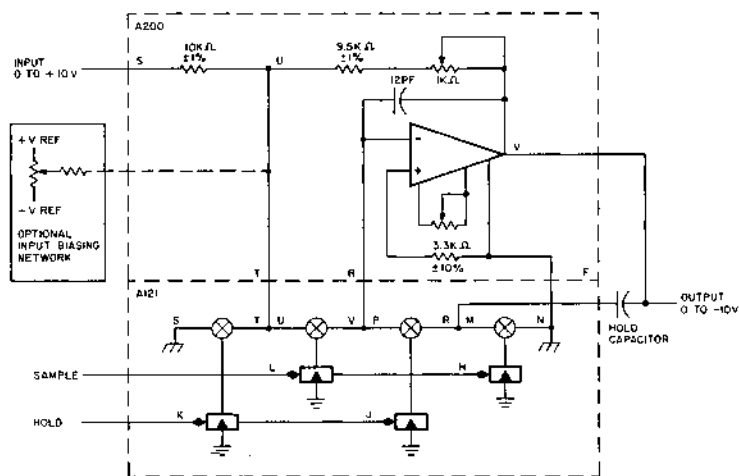


Figure 8. Sample And Hold System

TYPICAL SAMPLE AND HOLD PERFORMANCE

INPUT: 0 to +10 volts
OUTPUT: 0 to -10 volts
ACCURACY: $\pm 0.05\%$ for 10 μs
sample, 5 ms — hold
INPUT IMPEDANCE: 10K Ω
Higher resistances in A200 will increase input impedance at the cost of increased acquisition time, reduced accuracy or both.
OUTPUT IMPEDANCE: $< 10\Omega$

NOTE: For best noise rejection keep amplifier negative input lead short and add two 0.01 mfd capacitors from supply pins to analog ground (pin F) within A200.

Multiplexing

Often it is desirable to multiplex a number of analog channels into a single digital channel or conversely a single digital channel into a number of analog channels. Multiplexing can take place in the digital realm, the analog realm, or in the conversion process.

DIGITAL-TO-ANALOG

In digital-to-analog conversion, a common problem is to take digital information which is arriving sequentially from one device, such as a digital computer, and to distribute this information to a number of analog devices. Usually it is necessary to hold the information on the analog channel even when it is not being addressed from the digital device. There are two ways to multiplex. A separate digital-to-analog converter may be used for each channel as shown in Figure 9.

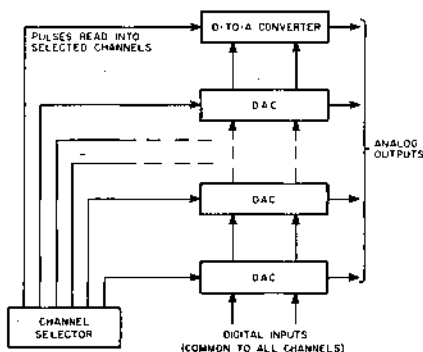


Figure 9. Digital-to-Analog Systems

In this case, the storage device is a digital buffer associated with the d-a converter. Or, a single digital-to-analog converter may be used, together with a set of analog multiplexing switches and a sample and hold circuit on each analog channel. The cost of the first method is slightly more than the cost of the second method, but it has the advantage that the information can be held on the analog output for an indefinite period of time without deteriorating. With the multiple sample and hold technique, however, it is necessary to renew the signal on the sample and hold at periodic intervals.

ANALOG-TO-DIGITAL

In analog-to-digital conversion, it is more common to multiplex the inputs in the analog realm. Here switches, either relays or solid state, are used to connect the inputs to a common bus. This bus goes into a single analog-to-digital converter which is used for all channels (see Figure 10). If simultaneous time samples from all channels are required, a sample and hold circuit can be used ahead of each multiplexer switch. In this way, all channels would be sampled simultaneously and then switched to the converter sequentially. The multiplex switches and sample and holds will introduce some error into the system. However, it is usually less expensive to go to higher quality sample and hold and multiplex circuits than add extra converters.

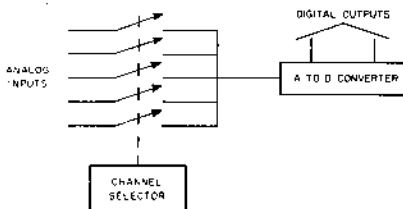


Figure 10. Multiplexed Analog-to-Digital Conversion System

In a simple analog-to-digital converter with a single comparator circuit, it is also possible to multiplex by using a separate comparator for each analog channel. One input of each comparator is tied to the voltage generating device in the converter. The other inputs are tied to the separate analog channels. The comparator to be used can be selected digitally. This method is particularly good when a small number of channels is to be multiplexed since it is quite simple and requires little additional control. For a large number of channels, separate multiplexer switches are usually less expensive and more accurate as they do not put any load on the voltage generating device of the converter.

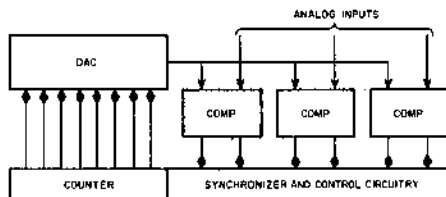


Figure 11. Counter Type Analog-to-Digital Converter with Multiplexed Input

The comparator multiplexing technique is particularly useful with the counter type analog-to-digital converter. This technique is shown in Figure 11. Several comparators are attached to one converter. The counter is cleared; then count pulses are applied. When one of the comparators signals that the digital-to-analog output is greater than the input voltage on that channel, the contents of the counter are read out. Counting is then resumed until the next signal is received.

CHAPTER 2

MEASURES OF CONVERTER PERFORMANCE

Accuracy

Since the end result of conversion is the representation of a given value in different terms, it is important to know how accurate the representation is. In systems where accuracy requirements are not too stringent, say in the order of 1 percent, an overall accuracy specification is usually sufficient. In cases where the desired accuracy is 0.1 percent or greater, it is necessary to isolate the various sources of error; and since a converter is a hybrid device, both digital and analog sources must be taken into account.

In high accuracy systems particularly, accuracy figures given in the general specifications may not include isolated sources of error, e.g., noise. Thus, it is important to know the various types of errors, their causes, how they are measured and specified, and when they are important. Figure 12 shows a breakdown of various types of errors.

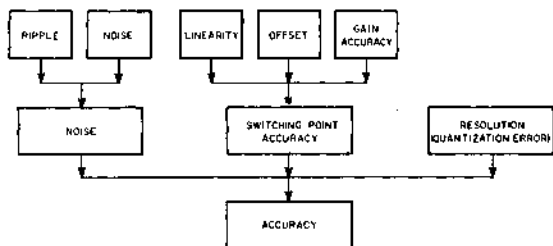


Figure 12. Measures of Cumulative Error

DIGITAL ERROR SOURCES

When a continuous signal is quantized, there is an error which is equal in magnitude to the smallest quantum. For a linear converter, the smallest quantum is the least significant bit. In most converters the quantization error is centered so that it is equal to $\pm\frac{1}{2}$ the least significant bit, written as $\pm\frac{1}{2}$ LSB.

In a continuous converter or digital voltmeter, accuracy may not be as important as avoiding chatter. That is, if the input is right on the dividing line between two quantization states, the output should not oscillate. If hysteresis is introduced so that the quantization error is just under ± 1 LSB, then oscillations will normally be avoided and the accuracy will not be greatly impaired.

The digital-to-analog converter reproduces exactly all the digital input information which it accepts. Hence digital error is not included in its accuracy specifications. However, if the input has more bits than the converter, there will be a quantization error in the readin process which should be taken into account. If desired, a $\frac{1}{2}$ LSB offset can be built into the converter so that the readin will round off, rather than truncate, more precise digital information.

ANALOG ERROR SOURCES

The dc accuracy of the converter (or switching point accuracy) depends on the offset, the gain calibration, and the linearity. Nonlinearities are due to the variation in gain (or common mode effect) in going from the smallest input to the largest input. Some of these will be long-term, because of the common mode effect of the comparator circuit in the analog-to-digital converter, for example. Some will be shorter term, because of discontinuities in the divider network or insufficient settling time of the comparator. The offset and the gain can be adjusted in the calibration until their effects are essentially negligible.

The measurement of analog error in a digital-to-analog converter is easily made by putting in a digital number (the same word length as the converter) and observing the output. In an analog-to-digital converter, the analog error is difficult to locate since the quantization error is always present. However, the point where the output oscillates approximately equally between two neighboring digital numbers is fairly well-defined. This point, called the switching point, can be measured and compared with the theoretical value.

The ripple on the reference supply and other sources of noise are often measured separately since one or the other can sometimes be neglected in the final result. The two can be separated by measuring the ripple in the reference supply and subtracting it from the measured noise, or by running the input source in the converter from the same reference, thereby giving a direct measurement of all noise sources except the reference supply ripple. In a digital-to-analog converter the noise and ripple can be measured by observing the output with a scope. In an analog-to-digital converter they can be measured by observing the input range which causes the output to oscillate between two states.

DIFFERENTIAL LINEARITY

Differential linearity is the variation in the size of the required voltage change that causes an analog-to-digital converter to go from one switching point to another. That is, it is the variation in the size of the states and is generally quoted as a percent of the size of the states. It is a part of the overall linearity discussed above, but deserves special mention because of its importance when an analog-to-digital converter is being used in histogram applications. For example, when plotting the number of inputs versus the digital state, if one of the states is twice as big as its neighbor, it will tend to accumulate twice as many counts. Naturally, a very misleading output results.

Differential linearity is one of the few accuracy characteristics which is affected by the conversion technique. The differential linearity tends to be best when the converter goes

through all the states sequentially as in the counter type converter described in Chapter 1 or the ramp variation described in Chapter 3. In an approximation converter, such as the successive approximation type, the large transients which result in going from, say, half scale to quarter scale require a long time to settle down, and any hysteresis in the comparator circuit causes relatively large variations in the state size. However, the differential linearity of an approximation converter can be improved by running it at very low speed. Differential linearity is also affected by variations in the divider networks (although they are relatively small). It can be avoided by using a ramp converter.

The shorter the converter word length, of course, the better the differential linearity will tend to be. However, this gain may well be compromised, since small resolution could result in the loss or the smoothing of very sharp peaks in the histogram.

Techniques commonly used to overcome difficulties with differential linearity are: changing the offset on the converter (or equivalently the bias on the input signal) and changing the word length of the converter. Switches can be mounted on the converter for this purpose, or the change can be made programmable so that the controlling device can make the change automatically.

DISTRIBUTION OF ERROR

How much of the total error should be in the digital circuitry and how much in the analog portion? For converters in the range of up to 10 or 11 bits, the digital error generally accounts for about $\frac{1}{3}$ to $\frac{1}{2}$ of the total. Thus, a typical 10-bit system would have a quantization error of $\pm\frac{1}{2}\text{LSB}$ and an analog error of $\pm 0.1\%$.

If the accuracy requirement is low, the word length may be the major source of error. The total error may then be treated simply as round-off. If the accuracy requirements are stringent, it is desirable to minimize all sources of error, analog and digital. The digital error is quite simple to minimize by extending the number of bits within practical limits. A converter with an overall error of 0.1% and a word length of 20 bits would be unjustified.

Requiring monotonicity is one way to assure that all the bits are meaningful. This means that all states must exist and they must be in the correct order. In terms of converter operation, as the number going into the digital-to-analog converter is increased, the output voltage must also increase; it should never dip back down at any point. Similarly, if the input voltage to an analog-to-digital converter is increased, the digital output should stay at the same value or increase and should not skip over any states.

The converter is most likely to lose monotonicity when switching between digital states such as 0111 and 1000. If the weighting of the bits is not quite correct, in a digital-to-analog converter the higher state might correspond to a lower voltage, and in the analog-to-digital converter the output might jump directly from 0110 to 1000.

Measures of Speed

DIGITAL-TO-ANALOG CONVERSION

The maximum conversion rate is theoretically limited only by the minimum time between readings to the converter flip-flops, and can easily be as high as 10 megacycles. However, such a figure may be misleading. The desired ratio of settling time to non-settling time usually determines the maximum usable conversion rate.

The settling time of a converter is measured from the time the digital reading is performed to the time when the analog output has settled to within the specified limits of accuracy. How the output approaches its final value depends on the output circuit, as discussed below.

The divider output will have high frequency transients before it begins to settle. If the output is going to a low frequency device, the transients can be ignored. In some applications, it is more desirable to smooth the transition between states than to minimize the total time, in which case the oscillations can be damped with the capacitor or a low pass filter.

If the output is from an amplifier circuit, the settling time will be determined by the maximum rate of change of the amplifier. Thus, the first reading may take longer to settle than subsequent readings, which usually do not change the converter by such a percentage of the full scale.

ANALOG-TO-DIGITAL CONVERSION

Conversion time is measured from when a request is given to when a digital output is available. In converters like the successive approximation type, where all conversions are completely independent, time must be allowed for completion of entire steps in the conversion process. In the continuous converter, the conversion time is usually just that time required to synchronize the request and get the number.

The conversion rate is usually the inverse of the conversion time. In some systems, an amplifier or comparator recovery time is required between conversions; thus the rate is lower. However, comparators manufactured by Digital Equipment Corporation do not have a recovery time. The conversion rate will also be slower if logical operations must be carried out between conversions. In some cases, such as the counter converter performing a number of simultaneous conversions or the synchronous sequential converter, the conversion rate is actually faster than the inverse of the conversion time.

If the input signal is changing with respect to time, it is very important to know when the signal had the value given by the output. The uncertainty in this time measure is called the aperture time (sometimes also called window or sample time). The size of the aperture and the time when the aperture occurs vary depending on the conversion method.

Figures 13 through 16 illustrate how the aperture varies with different conversion techniques. In each case, the upper portion of the figure shows how the converter arrives at an output. The lower portion of each figure shows how the input might be reconstructed from the digital data.

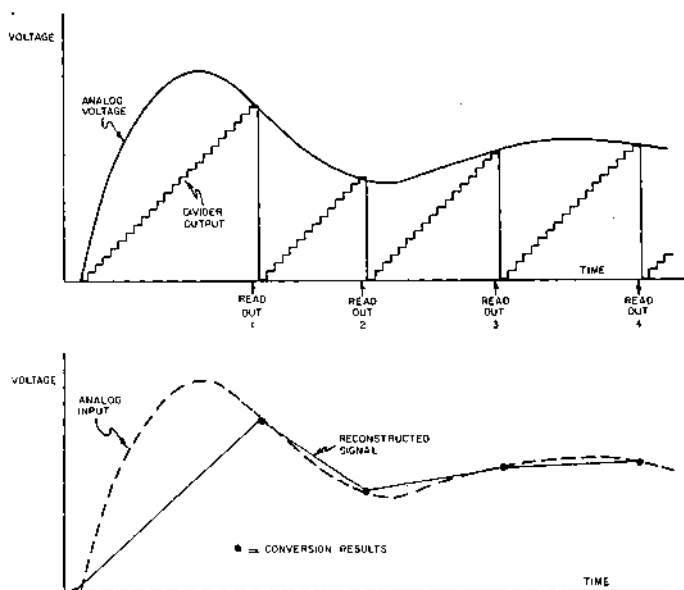


Figure 13. Counter Converter

In the counter converter (Figure 13) the aperture occurs at the end of the conversion. This is not constant with respect to the beginning of the conversion, but it may be calculated from the digital output.

For the continuous converter (Figure 14) the aperture is the time for the last step. Here the assumption is made that the input signal does not change more than ± 1 LSB between conversion steps. To meet this requirement, the maximum rate of change of the input voltage must not exceed the maximum rate of change of the converter. This is $V_{ref}/2^n \Delta T$ where V_{ref} is the full scale voltage, N is the number of bits, and ΔT is the time per step. The maximum rate of change of the sine wave is $2\pi V_{ref} f$, or $\pi V_{ref} f$. Thus, if the converter is to follow the input, the maximum frequency components in the input must satisfy the following equation:

$$\pi V_{ref} f = V_{ref} / 2^n \Delta T$$

and if the peak-to-peak voltage is assumed equal to the converter reference, then the maximum frequency is:

$$f = \frac{1}{2^n \Delta T \pi}$$

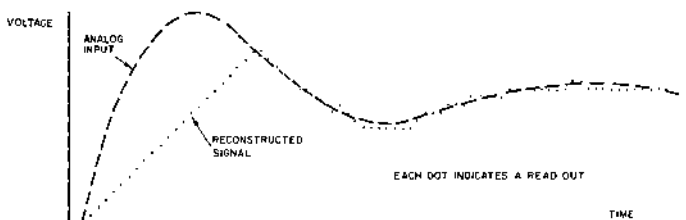
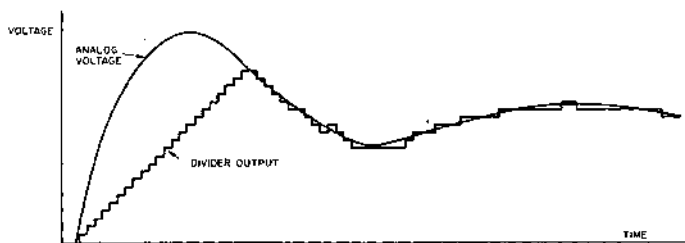


Figure 14. Continuous Converter

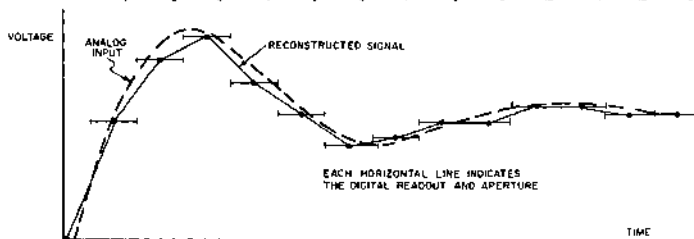
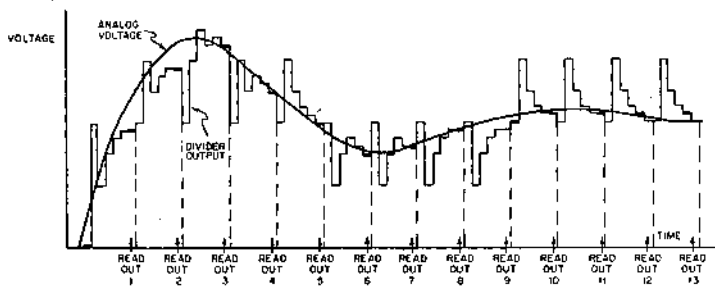


Figure 15. Successive Approximation Converter

For a successive approximation converter (Figure 15) the digital output corresponds to some value the analog input had during the conversion. Thus, the aperture is equal to the total conversion time. Aperture time of the successive approximation converter can be reduced by using the redundancy techniques outlined in Chapter 3 or by using a sample and hold circuit. The sample and hold is illustrated in Figure 16.

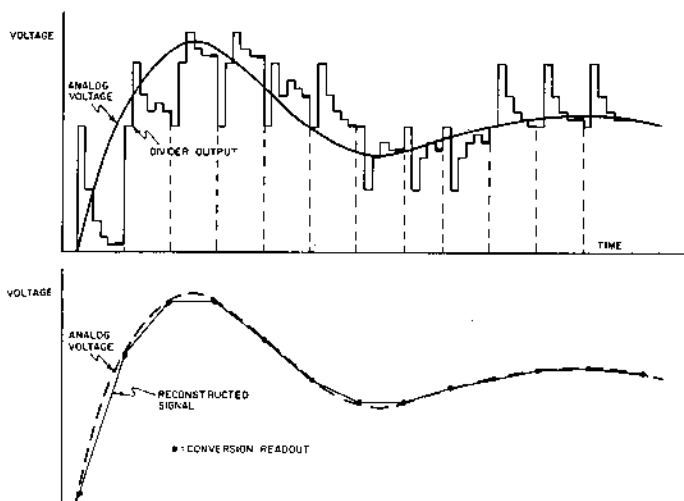


Figure 16 . Successive Approximation Converter with Sample and Hold

SELECTING A CONVERSION METHOD

Chapters 1 and 2 have summarized several methods of conversion and the performance characteristics that may be expected from them. These criteria for choosing a specific conversion method are condensed in Table 1. The table is organized like the handbook with applicable chapters called out for quick reference to detailed descriptions of the methods.

The decision to choose one converter over another is principally a matter of speed, aperture, cost, and whether multiplexing or a single continuous input is to be used. Exact conversion times, aperture times, and cost depend on the number of bits, type of circuitry,

TABLE 1 ANALOG TO DIGITAL CONVERSION TECHNIQUES

| Method | Best for Multiplexed or Continuous Input? | Conversion Time* 5 Bits (μsec) | Conversion Time* 10 Bits (μsec) | Aperture Time* 5 Bits (μsec) | Aperture Time* 10 Bits (μsec) | Constant Time of Aperture? | Relative Cost | Remarks |
|----------------------------------------------|-------------------------------------------|-----------------------------------|------------------------------------|---------------------------------|----------------------------------|----------------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| BASIC METHODS (Chap. 1 & 4) | | | | | | | | |
| Simultaneous | Both | Not Applicable | | | | Yes | Depends on resolution | Excellent for low resolution systems — operates in about 100 nanoseconds |
| Counter | M | 24 av. | 1792 av. | 1.5 | 3.5 | No | Low | Allows many conversions simultaneously |
| Continuous | | | | | | | | |
| Continuous Input | C | 1.5 | 2 | 1.5 | 2 | Yes | Low to Medium | Extremely high speed for continuous input but falls behind on sharp rate of change |
| Discontinuous Input | C | 24 av. | 1024 av. | | | Yes | Medium | |
| Successive Approximation | M | 7.5 | 36 | 7.5 | 36 | Yes | Medium | General purpose — good speed dollar |
| VARIATIONS ON BASIC METHODS (Chap. 3) | | | | | | | | |
| Ramp | M | 16 av. | 512 av. | 1 | 1 | No | Depends on resolution | Good differential linearity — low cost for low resolution systems |
| Section Counter | M | 18 | 112-224 | 1.5 | 3.5 | No | Low to medium | Used with digital voltmeter |
| Continuous with add. comp. | | | | | | | | |
| Continuous Input | C | 1.5 | 2 | 1.5 | 2 | Yes | Medium to High | Similar to continuous but has faster responses to discontinuous or high speed signals |
| Discontinuous Input | C | 6-12 av. | 32-512 av. | 1.5 | 2 | Yes | High | |
| Successive Approximation with Redundancy | M | 9 | 27 | 1.5 | 3 | Yes | Medium to High | Good speed per dollar in high resolution systems. Small aperture, good differential linearity |
| ADVANCED (Chap. 3) | | | | | | | | |
| Subranging | M | 3-4 | 10-20 | 3-4 | 10-20 | Yes | High | Excellent for 5 to 8 bits |
| Subranging with Redundancy | M | 2.5 | 6-9 | 1.5 | 3 | Yes | High | Excellent for 7 bits or more |
| Seq. Approx. (Non-Synchronous) | M | 7.5 | 25 | | | Yes | High | May make errors. Requires sample and hold |
| Seq. Approx. (Synchronous) | C | 1.5-9† | | 1.5 | | Yes | High | †Time between conversions total time |
| Quantizing | | | | | | | | |
| Continuous Input | Both | 2 | 3 | 2 | 3 | Yes | High | Excellent for both multiplexed and continuous inputs. Automatically follows fast input with low resolution and slow input with high resolution |
| Discontinuous Input | Both | 6 | 18 | 2 | 3 | Yes | High | |

*See text

and variations in system design. The speeds given in the table were derived assuming that the system was designed for maximum speed per dollar. Actual speeds will usually be within a factor of 2 for basic conversion methods and within a factor of 5 for the others.

The basic conversion methods, as described in Chapters 1 and 4, will satisfy most requirements. If Table 1 confirms the choice of one of the basic methods, the reader can go directly to Chapter 4 for specific information on the equipment required. The other methods are variations of basic methods and advanced techniques primarily for increased speed. They are described in general terms in Chapter 3.

Signed Digital Numbers

In the following chapters, the most significant bit represents -5 volts, the next most significant bit, -2.5 volts, and so on. Thus, the all ZERO state corresponds to 0 volts and the all ONE state corresponds to 1 LSB less -10 volts. This conversion can be reversed simply by using the opposite side of the flip-flop to drive the divider.

If only the most significant bit is reversed, the numbers are signed, 2's complement, as shown below. Since more numbers are negative than positive, the negative numbers are used for 0 to -5 volts and the positive numbers go from -5 to slightly less than -10 volts.

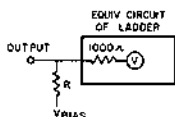
| <u>Voltage</u> | <u>Unsigned</u> | <u>Signed</u> |
|----------------|-----------------|---------------|
| 0 | 000000 | 100000 |
| | 000001 | 100001 |
| | ⋮ | ⋮ |
| | 011110 | 111110 |
| | 011111 | 111111 |
| -5 | 100000 | 000000 |
| | 100001 | 000001 |
| | ⋮ | ⋮ |
| < -10 | 111110 | 011110 |
| | 111111 | 011111 |

In 1's complement, the weighting of the sign bit is reduced so that $+0$ equals -0 . (Thus, it cannot be used in a system with redundancy, a variable word length or any other feature which does not give a constant one to one correspondence between voltage and number.) Weighting is done by increasing the resistance of the MSB (most significant bit), and for a system of 9 or 10 bits the ladder potentiometer is sufficient. For low resolution systems, add a small resistor (about 16 ohms for an 8-bit system, 32 ohms for 7 bits, etc.) in series with the MSB input. It need not be precise (since the potentiometer will adjust for it) nor have a low temperature coefficient (since a large change in this resistor will have a small effect on the output voltage). Use the standard DAC adjustment procedure and look for a straight line instead of a square wave on the most significant bit.

Bipolar Voltages

BIPOLAR D TO A OUTPUTS

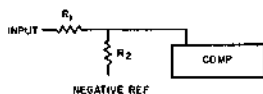
Binary weighted DAC modules made by Digital have an output impedance of 1000 ohms. The external load can reach 2000 ohms without any noticeable effect on the linearity of the system. Thus the output can be made bipolar with a large resistor to a positive bias voltage. The equivalent circuit is shown below.



With a -10 volt reference driving the digital-to-analog converter, the output voltage swing is reduced to $\frac{\pm 5R}{R + 1000}$ volts. The output voltage swing is centered when the bias voltage equals $+R/200$. The bias voltage, of course, should be stable and noise free.

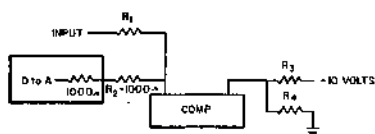
BIPOLAR A TO D INPUTS

If multiplexing is being done or if the input signal cannot drive a heavy load, an amplifier should be used for signal conversion as described in Chapter 5. In other cases, a simple divider can be used in front of the comparator. The basic circuit is shown below.



The impedance level should be kept low since the comparator will draw some current even at balance (a fraction of a microampere). The input, as seen by the comparator, should be as near as possible to the full 0 to -10 volt range.

An alternative to the above scheme is to buck the input against the digital-to-analog converter in the feedback loop, as follows:



The range seen by the comparator is reduced, but common mode effects are avoided since balance is always at the same point. R_1 should be less than 1000 ohms, and R_3 plus R_4 should be about 500 ohms or less.

Table of Voltages

| Octal Numbers | | Voltage |
|---------------------|----------|---------------|
| Signed 2's Comp. | Unsigned | (Negative) |
| 4000 | 0000 | 0. |
| 4001 | 0001 | 0.00244140625 |
| 4002 | 0002 | 0.0048828125 |
| 4004 | 0004 | 0.009765625 |
| 4010 | 0010 | 0.01953125 |
| 4020 | 0020 | 0.0390625 |
| 4040 | 0040 | 0.078125 |
| 4100 | 0100 | 0.15625 |
| 4200 | 0200 | 0.3125 |
| 4400 | 0400 | 0.625 |
| 5000 | 1000 | 1.25 |
| 6000 | 2000 | 2.5 |
| 0000 | 4000 | 5. |
| 2000 | 6000 | 7.5 |
| 3000 | 7000 | 8.75 |
| 3400 | 7400 | 9.375 |
| 3600 | 7600 | 9.6875 |
| 3700 | 7700 | 9.84375 |
| 3740 | 7740 | 9.921875 |
| 3760 | 7760 | 9.9609375 |
| 3770 | 7770 | 9.98046875 |
| 3774 | 7774 | 9.990234375 |
| 3776 | 7776 | 9.9951171875 |
| 3777 | 7777 | 9.99755859375 |
| — | 10000 | 10. |

CHAPTER 3

SPECIAL ANALOG-TO-DIGITAL CONVERSION TECHNIQUES

The analog-to-digital conversion techniques described in Chapter 1 are the most commonly used methods but not necessarily the only ones. There is an extremely large variety of techniques, not all of which have been investigated. Some of the other methods are described in the following section.

Variations In Basic Techniques

SECTION COUNTER

The counter converter is a simple technique for performing conversions. However, if the digital word becomes long, the 2^n steps required to complete the conversion may be too many.

One way to decrease the time at a minimum of cost is to divide the counter into sections. For example, a 10-bit converter could be divided into 2 sections of 5 bits each. At the beginning of the conversion the least significant counter is set to all ones and counts are inserted into the most significant counter until the comparator indicates that the input has been exceeded. The least significant counter is cleared and counted up until the correct value is reached. The maximum number of steps required to complete a conversion is 2^5 for the most significant counter and 2^5 for the least significant counter, giving a total of 2^6 steps. This is a maximum of 64 counts versus 1024 counts for the standard counter converter.

Other types of section counters might use more parts and operate by counting one counter up and the next down. The total conversion time, of course, depends on the number of sections.

The section counter technique is frequently used in digital voltmeters where the output is to be in decimal: Each section of the section counter thus represents one decimal digit.

RAMP METHOD

In the counter converter, each count input is increasing the voltage out of the DAC by one step, effectively generating a ramp out of the DAC. Thus the level amplifiers, reference supply, and divider network could be replaced by an external ramp generator circuit. If accuracy is not too important, the ramp can be made by charging a capacitor with a current source and using the linear part of the exponential. In higher resolution converters, the ramp might be made by using the operational amplifier as an integrator.

The ramp technique is somewhat faster than the counter technique because carry and DAC set up time is not required before gating the next count pulse. The differential linear-

ity, over a short span of a ramp converter, is bound to be fairly good, since the ramp is a continuous signal. Although there may be some noise, the general slope will not change significantly over a short span.

Both the ramp method and the counter technique approach the final value in small steps and from one direction only. This puts considerably less strain on the comparator circuit than a technique such as subranging or successive approximation where the comparator is receiving large input voltage changes in different directions and being asked to resolve small differences. In general, all smooth conversion techniques (the counter, ramp, and continuous converters) generally operate at a considerably faster time-per-step and produce better differential linearity than the approximation methods (subranging, successive approximation, sequential approximation, etc.).

CONTINUOUS CONVERTERS WITH ADDITIONAL COMPARATORS

A continuous converter is an extremely fast and relatively inexpensive device for following a continuous signal. However sometimes the input rate of change exceeds that of the converter. To close this gap determine if the differential error exceeds a specified amount and add or subtract a correction count in a more significant bit. For example, a small amount of logic added to a 10-bit continuous converter could measure large differences between the input and the contents of the converter. If the difference is more than $+8$ counts, it adds a count in the third flip-flop from the least significant end. If the

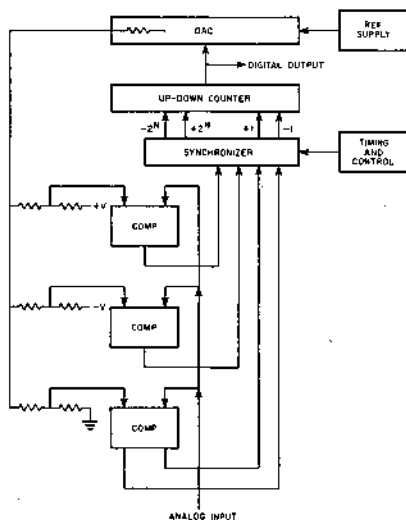


Figure 17. High Speed Continuous Converter

difference is more negative than -8 counts, it subtracts a count from this stage. Thus the converter operates on high frequency signals with reduced accuracy and on low frequency signals with the full accuracy.

A continuous converter with additional comparators is shown in Figure 17. Two comparators and additional gating and synchronizing logic have been added to a basic continuous converter.

SUCCESSIVE APPROXIMATION CONVERTER WITH REDUNDANCY

Redundancy is useful where high resolution and high speed are both required. It can also be used to improve differential linearity and aperture.

The successive approximation converter is extremely efficient; but, since the results of each step are irrevocable, each step must be allowed to settle to within the total system accuracy. For high resolution systems, the settling time can be quite long. With redundancy, the first steps are done with a limited accuracy; then a correction step is inserted to improve the accuracy. Only the correction step and the following steps need to settle to final accuracy. Steps before correction need only settle within $\pm 1/2$ of the correction amount.

The correction can be implemented by adding or subtracting one bit, as in a continuous converter. If the steps preceding the correction are offset, only add circuitry is necessary. For fastest operation, a special divider with redundant inputs can be used so that the addition can be done without generating carries. The digital summing can be done in an output buffer where the carries will not interfere with the analog-to-digital feedback loop.

The correction step can also be used to compensate for changes in the input analog signal during earlier steps, thereby reducing the aperture. It also improves the differential linearity of the converter since a large part of the variation in state size is due to the large transients during the early conversion steps.

Advanced Techniques

SUBBRANGING

This method is very good for converting a large number of input channels since the conversion begins without assuming anything regarding the previous state of the input. It also converts quite rapidly and allows a trade-off between cost and complexity and speed. Thus, if extremely high speed is required, numerous comparators are used and not many steps are required. In the case where less speed is required, perhaps only one comparator circuit would be used.

The subbranging method operates by dividing the total input signal range by the number of subbranges, selecting the appropriate subbrange and then dividing this into subbranges as before, repeating until the desired resolution is achieved.

Figure 18 shows how subbranging works. At the start of the conversion, the only information available about the input signal is that it lies somewhere in the range of zero to the full scale voltage, V_{fs} . The first step of the conversion divides the full scale voltage into

subranges, in this case four. Simultaneously, comparisons are made between the input voltage and the three subrange boundaries, V_1 , V_2 , and V_3 . It can be determined whether the input voltage is higher than or lower than each of these boundaries. If the input signal is lower than all of the boundaries, it must fall in the lowest range. If it is higher than V_1 , but lower than V_2 and V_3 , it must fall in the next to the lowest range, and so forth. Once this information is determined, the selected subrange can be divided into four more subranges and the process repeated.

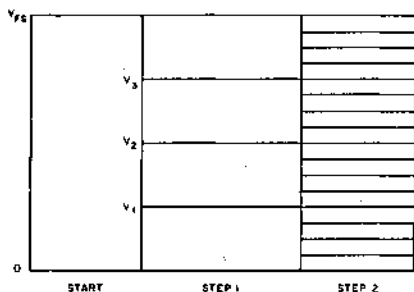


Figure 18 . Subranges for a Converter with Four Subranges Per Step

If there are M ranges per step and S steps, the total resolution of this conversion will be $(\frac{1}{M})^S$. For example, a 12-bit system requiring a total resolution of $\frac{1}{4096}$ could be implemented in 12 steps [$(\frac{1}{2})^{12} = \frac{1}{4096}$], in six steps [$(\frac{1}{4})^6 = \frac{1}{4096}$], in four steps [$(\frac{1}{8})^4 = \frac{1}{4096}$], or in three steps [$(\frac{1}{16})^3 = \frac{1}{4096}$]. The step resolution does not have to be an integer power of two. However, except in a binary coded decimal system where it is useful to make M equal to 10, the saving in control circuitry is usually sufficient to justify increasing the step resolution to the next power of 2.

Figure 19 shows a subranging converter. Here two digital-to-analog converters and a number of comparators are referenced at equally spaced intervals in the range between the value of the two converters. The technique is similar to the simultaneous method. The system starts with the lower DAC (digital-to-analog converter) at zero, the upper one at the maximum voltage. The output of the comparators indicates which range contains the input, say between the reference applied at C_k and the reference applied at C_{k+1} . Then the reference voltage from C_k is applied to the lower DAC, and the reference voltage that was at C_{k+1} is applied to the upper DAC. A new, smaller set of ranges is produced. The process is then repeated.

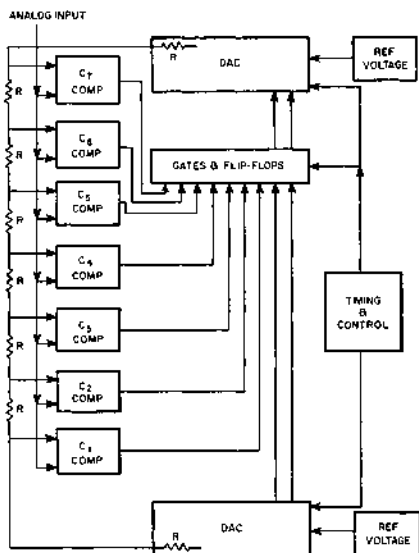


Figure 19. Subranging Converter

If the number of subranges obtained in a single step is equal to the total system resolution, this method becomes the simultaneous method described in the introduction. If the number of subranges per step is reduced to two, this method becomes the successive approximation conversion.

SUBRANGING WITH REDUNDANCY

Redundancy, as described for the successive approximation converter, can be applied in the same manner to a subranging converter. It is particularly useful here as the capacitance of many comparators in parallel causes the settling time to be quite long.

SEQUENTIAL APPROXIMATION

Sequential approximation, also called parallel approximation, uses a separate analog-to-digital converter for each binary bit of information to be obtained. There are two methods of operation, synchronous and non-synchronous.

Figure 20 shows how the non-synchronous type operates. In one example shown at the top of the figure, the analog input comes into a comparator which compares the input with half scale. If the input is larger, the comparator applies a voltage to the most significant bit of each of the DAC circuits down the line. As soon as the first comparator has

settled, the second comparator can start to make its decision. Speed is gained because there is no flip-flop delay in this system. But more important, most comparators will make decisions relatively quickly, since the analog input cannot be very close to the boundaries of more than two subranges (the last one and one other). Thus, the average amount of time required per decision is considerably less than the maximum. In a clocked system, the maximum required time must be allowed for each step. Here, only the average time is allowed.

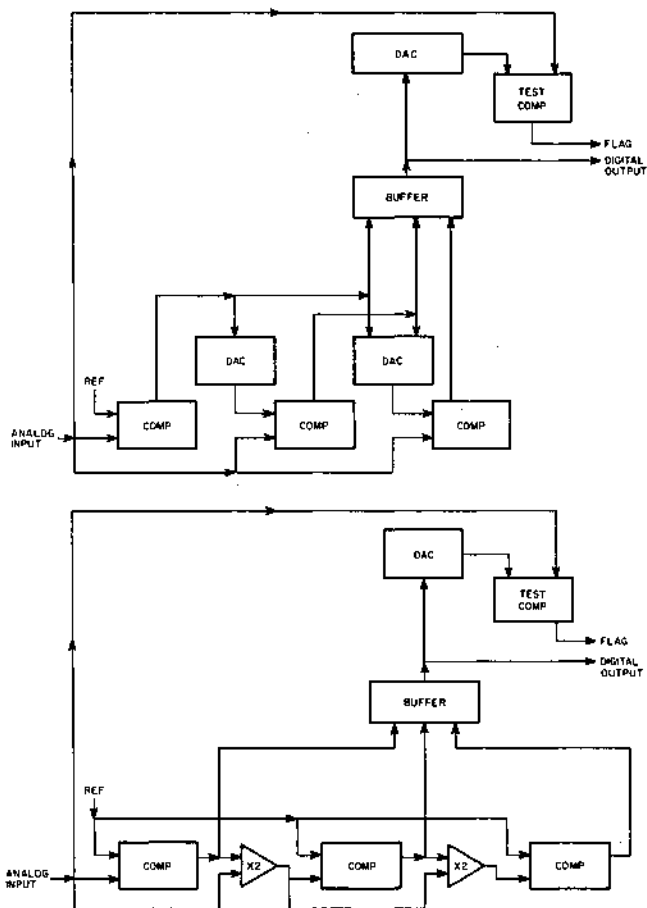


Figure 20. Non-synchronous Sequential Approximation

The converter shown at the lower half of Figure 20 is quite similar except that the individual DAC networks are replaced by operational amplifiers. The analog input goes to the first comparator. If the input is above half-scale, the comparator produces a voltage corresponding to half scale. This is subtracted from the input signal, and the result is multiplied by two and passed on to the next comparator.

In both examples, speed is gained by the fact that full settling time is not needed by those comparators which are not making a critical decision. On the other hand, some difficulties are encountered if the input signal should change slightly before the digital readout has occurred. One of the comparators may change value, but the results may not carry to the end of the chain before readout. Thus, the comparator should have built-in hysteresis so that small noise spikes will not cause an error, and the digital output should always be read into a buffer and double checked with the input.

In synchronous sequential approximation, the time required to perform a complete conversion is essentially the same as in a successive approximation converter; however, the conversion rate is much faster. Erroneous readout is eliminated, since the converter is buffered and synchronous. This type of converter is particularly useful for systems with a single input.

The synchronous or clocked type sequential approximation converter also uses one converter per bit. It differs from the non-synchronous type because there is a delay line between each converter (see Figure 21). The analog information arrives at the first comparator, which makes a decision and stores the information in a shift register for use by later converters. By the time the second converter is set up and ready to make a decision, the same analog information is just arriving at the second comparator. This converter decides on the second bit of the output word, based on exactly the same analog voltage as was at the first converter when the first bit decision was made. This process is continued for however many bits are necessary.

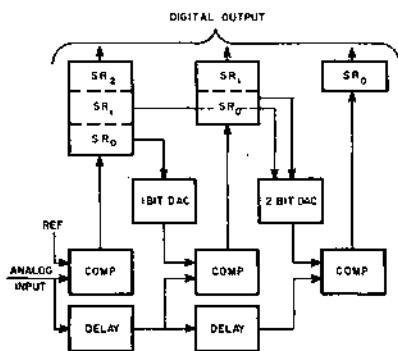


Figure 21. Sequential Approximation (Synchronous)

QUANTIZING ENCODER

The quantizing encoder was developed by Dr. Jerome Cox and Donald Glaser at the Central Institute for the Deaf. It is the most general purpose, high speed converter because it is fast for both continuous and multiplexed inputs.

The quantizing encoder uses one digital-to-analog converter, a number of amplifiers, and a number of comparators. It examines the difference between the input voltage and the DAC output, quantizes the difference to the nearest power of 2, and adds or subtracts this from the DAC. Thus, the quantizing encoder can follow a continuous signal, staying within one bit of the correct value for low frequencies. For high frequencies, it will always be within the nearest possible power of 2 of the correct answer. (Thus, if the input signal should suddenly change, the quantizing encoder will make a similar jump corresponding to the nearest power of 2 change, while the standard continuous converter could increase by only one count.)

For multiplexed input, the quantizing encoder will operate similar to a successive approximation converter but twice as fast. It requires only one step for each two binary bits (or fraction thereof). In addition, since it includes a self-correcting ability, the time per step can be quite fast.

Figure 22 shows how the quantizing encoder could arrive at the result when used as a 4-bit encoder. In the left-hand example, it is used with a multiplex input. At the start

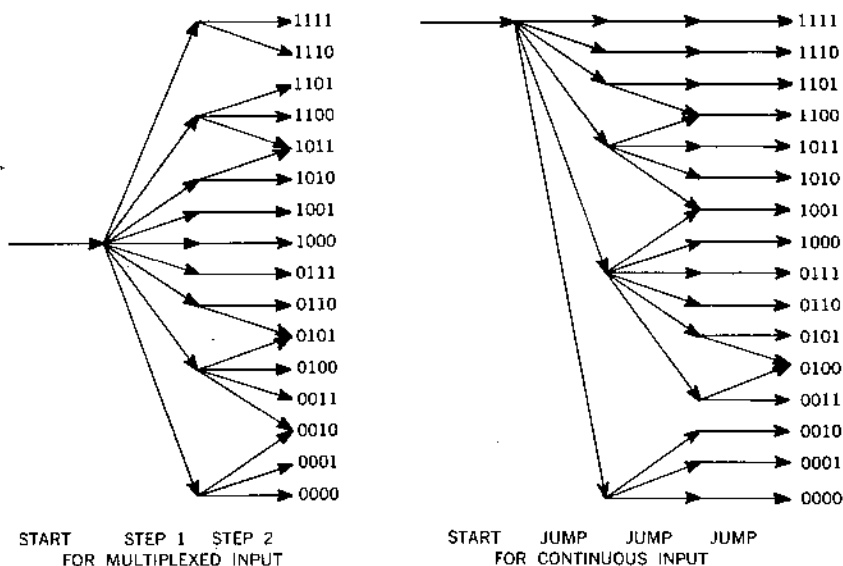


Figure 22. Quantizing Encoder Method

of the conversion the converter is set to mid-scale. At the end of the first step it will go to any of the points shown, and at the end of the second step it always has arrived at the correct answer.

The right-hand example, Figure 22, shows how the converter would react if it were holding its maximum value and the input suddenly dropped to a much lower value. If the new value were within 1 or 2 counts, it would immediately arrive at the exact answer. Otherwise, it would make a power of 2 jump to the nearest correct value.

CHAPTER 4

TYPICAL CONVERTER LOGIC

Digital-to-Analog Conversion

Figure 23 shows a typical digital-to-analog converter. The basic components of this circuit are a flip-flop register, DAC modules, and a reference supply. The digital signals are brought in with a pair of complementary levels for each bit. This information is jammed simultaneously into all the flip-flops and is automatically converted to the appropriate voltage by the divider network.

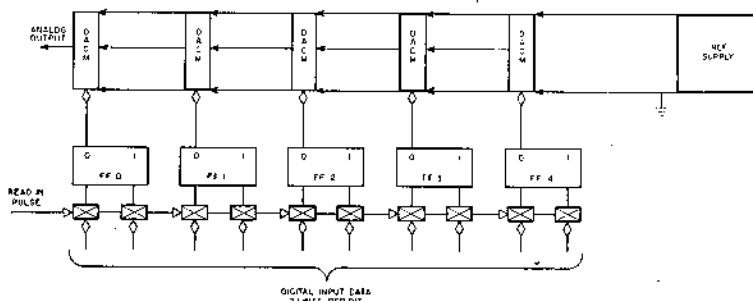


Figure 23. Digital-to-Analog Converter

The settling time of the digital-to-analog converter depends on the number of flip-flops that change, as well as the voltage difference between the two states involved. For example, in switching from a number such as 0111 to a number such as 1000, all of the flip-flops change state. Even though the two final values of the analog voltage are very close, transients occur on the divider output for the following reasons: variation in transition times from flip-flop to flip-flop and from level amplifier to level amplifier; transient current drawn from the reference supply; the fact that the flip-flops have a slower fall than rise time; and the fact that signals must propagate through the divider network. The worst case is switching from mid-scale (1000 . . .) to one count less (0111 . . .). Here the transients are as much as 1 volt.

However, the transients are quite short in duration and return to within $\frac{1}{2}$ LSB of their final value within at most 2.5 microseconds for the medium speed combinations listed in the table. In most cases, these transients will be faster than the load can respond and hence can be ignored. These units will settle to within 0.05 per cent within 2.5 microseconds.

RECOMMENDED MODULES FOR MEDIUM SPEED DIGITAL-TO-ANALOG CONVERTER

| No. of Bits | Flip-Flops | Digital-to-Analog Conversion Module | Reference Supply |
|-------------|----------------|-------------------------------------|------------------|
| Up to 4 | R200 R202 R203 | A601 | A704 |
| 5 | R200 R202 R203 | A601 | A704 |
| 6 | R200 R202 R203 | A601 | A704 |
| 8 | R200 R202 R203 | A601 | A704 |
| 10 | R200 R202 R203 | A604 | A704 |
| 12 | R200 R202 R203 | A604, A605 | A704 |

A small choke can be used between the flip-flop output and the DAC input on the more significant bits to equalize the switching times. This will reduce the transients to about a 0.5 microsecond duration on high accuracy systems. If further smoothing is desired, a low pass filter should be used on the output.

Analog-to-Digital Conversion

SIMULTANEOUS CONVERSION

The simultaneous conversion technique is simple, inexpensive, and extremely fast for a small resolution system. Figure 24 illustrates a simultaneous converter with a resolution of 3 bits. It uses Type W520 as comparator circuits for the input. These units have a resolution of 0.1 volts and are therefore suitable for a simultaneous converter of up to 4 bits. The reference voltages for the level standardizers are made by dividing a ± 10 volt reference with a series of identical resistors. Although the tolerance on these resistors is not wide, in systems of 3 or 4 bits small trimming potentiometers should be put in series with the resistors so that the reference voltages can be adjusted to offset the common mode effects and the zero offset of the comparators. Since the comparators also draw a current through the resistors, the potentiometers can trim the value of the resistors to compensate for this current.

The outputs of the comparators are coded in a Gray code and jammed into a simple flip-flop register, made by cross-coupling inverters and diode gates. A Gray-to-binary decoder on the output produces standard binary notation.

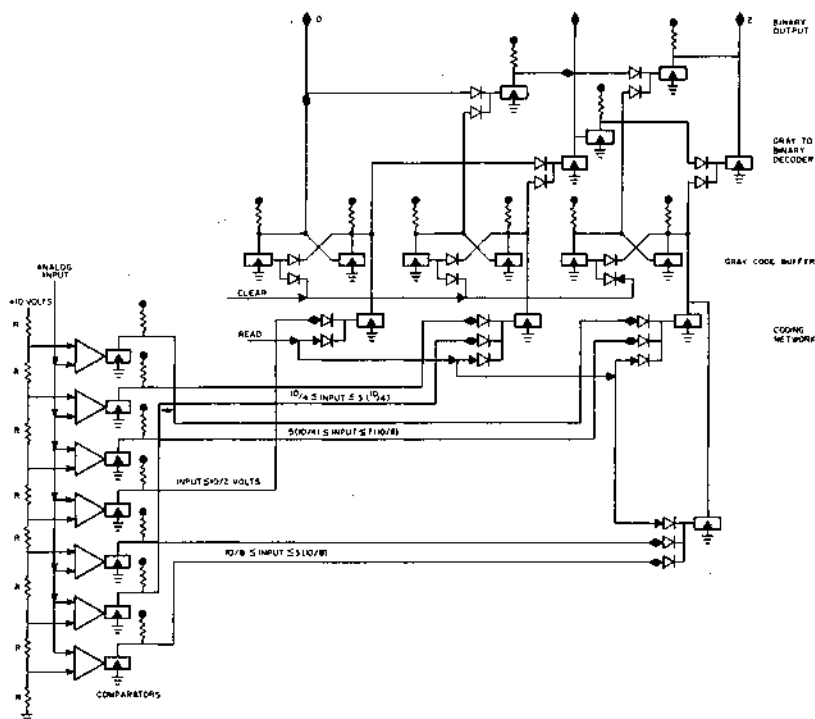


Figure 24. Simultaneous Converter

For medium speed systems, Type R111, R113, R121 and R122 gates can be used with DEC Standard 100 nanosecond pulses. With these gates, pulses can occur 0.5 microsecond apart, thus giving a conversion every 1 microsecond.

There are two factors which limit extending this system to large resolution systems. One factor is cost of so many comparators. The other factor is the current drawn and the input capacitance, which become extremely large if too many comparators are tied in parallel. For this reason it is recommended that the Type W520 be used for systems up to four bits only. Detailed information on the Type W520 is included in the W Series Section of this handbook.

COUNTER METHOD

Figure 25 illustrates a typical circuit for the counter type analog-to-digital converter. The start signal clears the counter and inserts a single pulse in the delay chain. Each time the pulse goes around the chain, one count is added to the flip-flop register. When the divider output is equal to the analog input, the comparator will switch. The next pulse sets the control flip-flop, indicating the end of conversion and inhibiting the pulse from circulating. The circuit shown in Figure 25 used Type R201, R202, R205 flip-flops for the counter. The control flip-flop may be any unbuffered flip-flop such as the Type R200, R202, R203, R204. At the end of conversion, this flip-flop will be set by grounding the ZERO output terminal.

The Pulse Amplifiers Type R602 perform pulse standardization as well as amplification. The clear pulse should be 400 nanoseconds in duration.

The type of delay unit depends upon the number of bits in the counter, since this determines the maximum time required between counts. If an R302 Delay is used, at least two units must be in the loop to provide the required recovery time. The Type R303 does not have a recovery time requirement.

A complete conversion requires 2^N steps, where N is the number of bits in a counter. The average number of steps is 2^{N-1} . Calculations of the time per step must take into account the following:

- Carry propagate time of the flip-flops
- Total transition time of the flip-flops
- Delay of the level amplifiers
- Delay through the ladder network
- Transition time of the comparator and settling time ($0.15 + 0.05N$ microseconds)
- Gating time
- Synchronization time (if required)

If buffered flip-flops are used, the control flip-flop should also be buffered and would be set through the input terminal. Also the comparator signal should not gate the counter input directly. Any noise on either the analog input or the ladder output could cause the comparator input to be in a transient state at the time the out pulse occurs. This could result in a split or partial pulse which might not propagate fully. To avoid this possibility the gating inverter on the counter may be either synchronized or eliminated, since the pulse will be inhibited from continuing through the loop.

CONTINUOUS CONVERSION

Continuous analog-to-digital conversion can be performed using an up-down counter. At each step the counter output is compared with the analog input, and a pulse is added to or subtracted from the counter, as necessary. By proper adjustment of the comparator, it is also possible to inhibit counts when the analog signal is approximately equal to the digital number. The inhibit signal is formed by adjusting the comparator outputs so that they do not switch simultaneously. For ideal operation, the two outputs should be in the same state whenever the digital feedback signal is within $\pm\frac{1}{2}$ part in 2^n of the appropriate input signal.

Synchronization (the use of control flip-flops) is required in all continuous converters. Any noise on the inputs to a comparator could cause the outputs to be in a transient state at the time they were sampled. Thus, if the signals are not synchronized, add and subtract pulses could enter the counter at the same time.

A continuous converter is illustrated in Figure 26. This system uses the R series unbuffered flip-flops with level change carry propagate. The illustration consist of four basic parts: the up-down counter, the DAC, the comparator, and the synchronizer and control logic. Two control pulses are formed by a clock and a delay unit. The synchronizer pulse sets the up-sync flip-flop if the enable level from the comparator indicates that the feedback signal is smaller than the input signal. Similarly, the down-sync flip-flop is set if the analog input is larger than the feedback input. Two sets of diode gates are used to inhibit counting which would cause the counter to overflow.

The outputs of the set flip-flops are exclusive ORed together to assure that no count signals will be generated if both flip-flops are set. After these signals have had time to set up, the clock generates a count pulse which samples the levels and produces a count up pulse or a count down pulse. At the same time the up- and down-sync flip-flops are reset so that the enable signals can be read in the next-time. All of the synchronizer and control logic should be from the same speed line. The flip-flops illustrated here are Type R202s, the clock is a Type R401, the delay a Type R302, and the inverters and diode gates are 2 megacycle logic.

The counter can be a lower speed logic than the synchronizer if desired. In this case, the up and down count pulses should be stretched with Type R602 Pulse Amplifiers to produce pulses of appropriate duration. In the illustration using Type R202 Flip-Flops, the outputs are buffered since the flip-flop outputs drive a capacitor diode gate level input, a capacitor diode gate pulse input, and a diode gate input, as well as providing the signals to the DAC. The inverters used for buffering are 10 megacycle units which have a minimum of capacitance. Readout from the counter register should take place from the output of the inverter buffers so as not to exceed the loading on the flip-flops.

The continuous conversion method is applicable when the maximum rate of change of the analog voltage is less than the fastest possible rate of change in the converter. That is:

$$\left(\frac{\Delta V}{\Delta t} \right)_{\text{input}} \leq \frac{V_{\text{ref}}}{2^N \Delta T}$$

where

$$\left(\frac{\Delta V}{\Delta t} \right)_{\text{input}}$$

is the rate of change of the input analog voltage, V_{ref} is the full scale voltage of the converter, N is the number of bits, and ΔT is the time per step. ΔT is the sum of:

Carry propagate time for the flip-flops

Total transition time of the flip-flops

Delay of the level amplifiers

Delay through the divider network

Transition time of the comparator and settling time
($0.15 \pm 0.05N$ microseconds)

Total transition time for the synchronizer

15 microseconds

Delay through gates and pulse amplifiers if in feedback loop

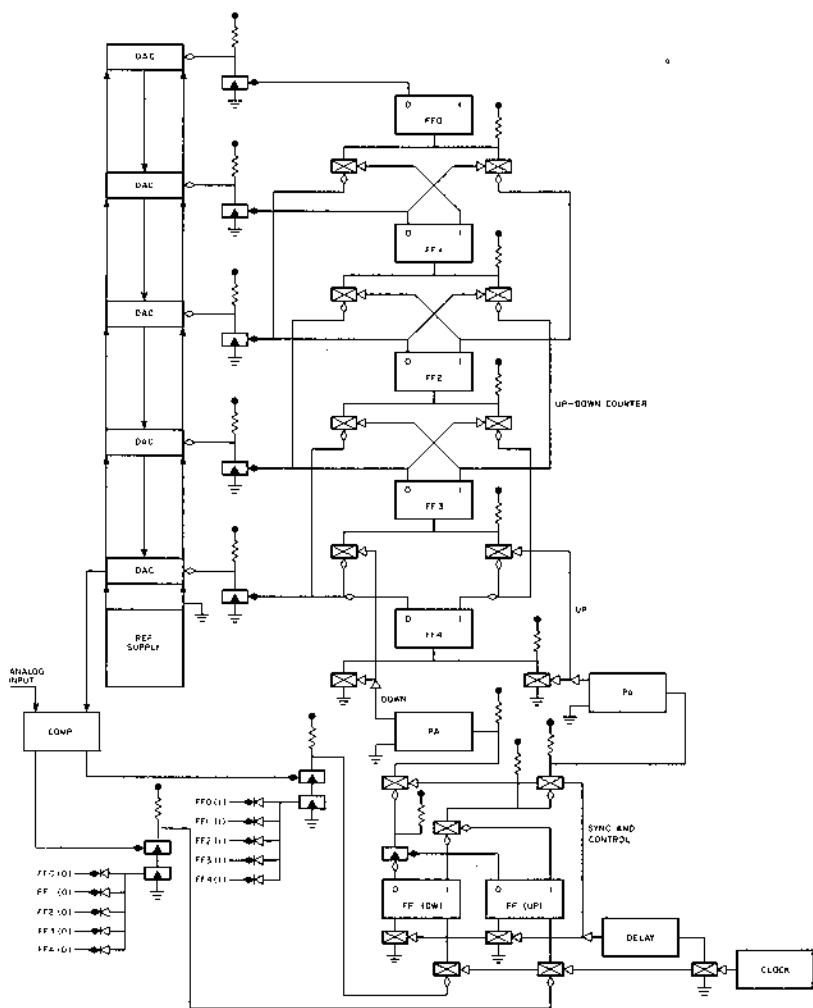


Figure 26. Continuous Converter with Unbuffered Flip-Flop

Carry propagate time may be reduced splitting the carry chain. For example, if flip-flops 2, 3, and 4 are in the ONE state, the count-up signal can be gated to complement flip-flop 1 as well as flip-flop 4. Of course, the normal carry input to flip-flop 1 is not used.

SUCCESSIVE APPROXIMATION CONVERTER

This method repeatedly approximates the input voltage. At each step, the possible range of the input signal is divided in half. The converter uses a digital register with gatable ONE and ZERO inputs, a digital-to-analog converter, a comparison circuit, a control timing loop, and a flip-flop distributor register that determines which step is taking place (see Figure 27). The distributor register is like a ring counter with a single ONE circulating to indicate which step is taking place. At the beginning of the conversion, both the digital register and the distribution register are set with a ONE in the most significant bit and a ZERO in all bits of lesser significance.

At the same time, a pulse enters the delay chain. When this pulse has had sufficient time to make one complete loop through the chain, the digital-to-analog converter and the comparator have settled and the comparator output determines whether the next digital approximation should be larger or smaller. At this time, the next most significant bit of the digital register is set to a ONE, and the most significant bit either remains in the ONE state or is reset to a ZERO, depending on the comparator output. The single ONE in the distribution register is shifted to the next position. This procedure is repeated until the final approximation has been corrected, making a total of N steps, plus settling time for the last flip-flop.

The total time_q required is $N \Delta T$, where ΔT , the time per step, is at least as large as the sum of:

Total transition time for the flip-flops

Delay of the level amplifiers

Delay through the divider network

Transition time of the comparator and settling time

1 microsecond for $N < 5$,

0.2 N microseconds for $5 < N < 8$,

2.4 microseconds for $N = 9$,

3.0 microseconds for $N = 10$

Delay through pulse amplifier and gates

No synchronization time is required for this method since the comparator never controls the action of more than one flip-flop.

The digital register and the distribution register use the Type R202 flip-flops. Due to the set up time of the internal gates, the time per step must be at least 1 microsecond.

The control delay chain uses Type R302 delays and R602 pulse amplifiers.

CHAPTER 5

BASIC CIRCUITS

This chapter includes general information on the use and importance of various characteristics of converter circuits. Detailed performance characteristics are given for specific Digital modules. Definitions of symbols and terminology are included in the appendix.

Any of the appropriate modules described in the Digital Module Catalog can be used for the flip-flop registers and the control and gating logic in a converter. The choice is governed by speed requirements in the system.

DIGITAL - ANALOG CONVERSION MODULES

The A601 (Figure 28) is a three-binary-bit digital-to-analog converter utilizing a star-type divider network and three precision germanium-transistor level amplifiers. It may be connected in series with other converters to form higher resolution converters. The accuracy of the A601 is suitable for up to eight bits of conversion. For higher resolution, it should be combined with the Types A604 and A605.

A $-3v$ input signal at all digital inputs produces ground out. The input load is 1 ma at ground. If all inputs are not required, the most significant inputs should be used, and the least significant ones should be left open circuited. The converter input may be driven from the converter output of another module in order to provide higher resolution. If not driven from another unit, it should be terminated with 1000 ohms to ground. A termination resistor is included in the module. The reference input requires a -15 ma DEC A704 supply. The supply should be adjusted to approximately $-10.01v$ to overcome the saturation resistance in the level amplifiers. High Quality Ground is the ground return for the reference supply and should be connected to the supply terminal and eventually to chassis ground at a noise-free location.

The output is the analog equivalent of the digital input. The most positive output is $0v$. The most negative output is $-10v$ less the value of the least significant bit. The output impedance is 1000 ohms. If a bipolar or reduced output swing is required, the output may be loaded with 1000 ohms or more without affecting the accuracy.

The A604 and A605 (Figure 29) are two-binary-bit digital-to-analog converters for use with the A601 in forming high resolution, high accuracy converters. Inputs and outputs are identical to the A601 except that a terminating resistor is not included. Germanium transistors are used.

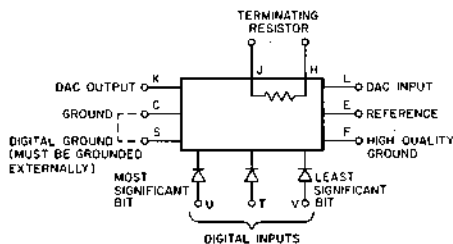


Figure 28. A601 DIGITAL-ANALOG CONVERTER

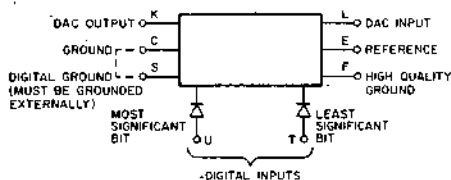


Figure 29. A604, A605 DIGITAL-ANALOG CONVERTERS

| | A601 | A604 | A605 |
|--------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------|------------------------------------------------------------------------|
| ACCURACY: ^a | $\pm 0.25\%$ of expected value or ± 0.5 mv, whichever is greater | $\pm 0.025\%$ of expected value or ± 0.25 mv, whichever is greater | $\pm 0.005\%$ of expected value or ± 0.05 mv, whichever is greater |
| TEMPERATURE COEFFICIENT: | ± 100 ppm/ $^{\circ}$ C max (from $+10^{\circ}$ C to $+45^{\circ}$ C) | ± 25 ppm/ $^{\circ}$ C (from $+10^{\circ}$ C to -45° C) | ± 10 ppm/ $^{\circ}$ C (from $+10^{\circ}$ C to $+45^{\circ}$ C) |
| OUTPUT IMPEDANCE: | 1000 ohms $\pm 0.1\%$ | 1000 ohms $\pm 0.1\%$ | 1000 ohms $\pm 0.1\%$ |
| SETTLING TIME: | 300 nsec | 300 nsec | 1.5 μ sec |

^aAt 25° C includes tolerance of ± 1.5 v on the ± 10 v and -15 v supplies.

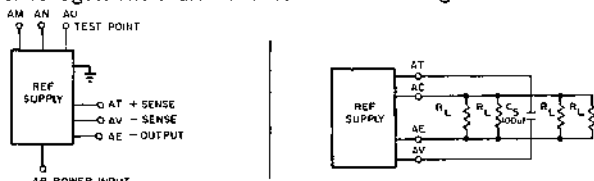
The following combinations of modules are recommended.

| Resolutions (bits) | % of Full Scale | Analog Accuracy (% of Full Scale) | Units (quantity-type) |
|--------------------|------------------|-----------------------------------|------------------------|
| up to 8 | down to 0.39% | 0.25% | 3-A601 |
| 9-10 | 0.195% to 0.098% | 0.082% | 1-A604, 3-A601 |
| 11 | 0.049% | 0.038% | 2-A604, 3-A601 |
| 12 | 0.024% | 0.014% | 1-A605, 2-A604, 2-A601 |
| 13 | 0.012% | 0.01% | 2-A605, 2-A604, 2-A601 |

Reference Supplies

The reference supply determines the voltage range of the converter. It is important that the supply be of good quality, since any error in the reference voltage will translate directly into error in the converter. That is, a 0.1 percent ripple in the reference produces a 0.1 percent ripple in the analog output.

Digital manufactures a reference supply: The Type A704, which may be used for systems of 13 bits or less. The supply is mounted on a Digital module and is driven by Digital standard power voltages. The characteristics are shown in Figure 30.



Type A704. Precision Power Supply

| Module Type | Output | Current | Stability | Regulation | Ripple Peak to Peak |
|-------------|--------|---------------|------------------------------------------------|------------------------------|---------------------|
| A704 | -10v | -90 to +40 ma | 1 mv/8 hrs 1 mv/15 to 35°C 4 mv/0 to 0°C | 0.1 mv, no load to full load | 0.1 mv |

| Module Type | Adjustment Resolution | Input Power | Use | Output Impedance |
|-------------|-----------------------|---------------------------|--------------------------------------|------------------|
| | | -15 volts/100 ma 10 ma | Load with 5000 pf at load. | |
| A704 | 0.01 mv | -15 ± 2 volts/ 250 ma | See below for sensing and preloading | 0.0025 ohms |

TYPE A704 PRECISION POWER SUPPLY

REMOTE SENSING

The input to the regular circuits of the A704 is connected at sense terminals at (+) and AV (-). Connection from these points to the load voltage at the most critical location provides maximum regulation at a selected point in a distributed or remote load. When the sense terminals are connected to the load at a relatively distant location, a capacitor of approximately 100 microfarads should be connected across the load at the sensing point.

PRELOADING

The supplies may be preloaded to ground or -15 volts to increase the current available in either direction. -125 ma maximum can be obtained by connecting a 270Ω ±5%, 1 watt, resistor from the -10 v pin AE reference output to pin AC ground.

Figure 30. Reference Supply Specifications

Comparators

The comparator is an unusual circuit because it is a hybrid, partially analog and partially digital. Basically, it is a very high gain difference amplifier. The outputs "saturate" quickly so that they do not exceed standard levels. (For Digital equipment these are 0 and -3 volts.) The comparator, Type A502, has an input range of 0 to -10 volts. When the input differential is large, the dual outputs are complementary Digital levels.

The time required for the comparator to switch states depends on the desired system resolution and the conversion method. That is, the comparator takes longer to respond to a 10-millivolt differential input than for a 100-millivolt differential input. A 7-bit system, for example, seldom requires information about 10-millivolt differentials. Similarly, the comparator switches faster in a counter or continuous converter system, where the differential input is being reduced gradually, than in a successive approximation converter, where the differential voltage may go from 5 volts to 0 in one step.

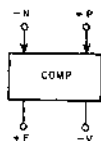
FACTORS AFFECTING COMPARATOR ACCURACY

As the input to the comparator circuit varies from 0 to -10 volts, the switching point may vary also. That is, one of the inputs may have to go somewhat more negative than the other before the outputs switch. A similar effect occurs with changes in temperature. In the Type A502, the switching point does not move more than 5 millivolts as the input voltage changes from 0 to -10 volts and the temperature changes over a range of 20°C (around room temperature). Power supply fluctuations of the Type 728 or an equivalent supply change the switching point by less than 0.6 millivolts.

Both outputs will not switch simultaneously unless the amplifier is in perfect balance. If the switching point changes mentioned above affect both outputs equally, the effect is referred to as a shift in the common switching level. If one of the outputs is affected more than the other, there is an offset between the two sides of the amplifier.

USE OF THE COMPARATOR

Illustrations of the use of the comparator are included in Chapter 4. In other uses, it must be remembered that the comparator is a hybrid circuit. If the differential input is small, but balance is not quite right, the outputs may not be complementary. If there is a small amount of ripple on the input, the outputs may oscillate. Normally this effect is of no concern because the errors have already been taken into account in the common mode and resolution specifications. However, if the results are to be read into more than one flip-flop, output oscillations can cause different information to be read into the different flip-flops. Thus, the outputs must be synchronized before being read into more than one flip-flop. Similarly, the comparator level changes should not be used as information unless it is certain that transient signals (such as those that occur when a DAC switches) will not cause false outputs.



Type A502 Comparator

Specifications:

Input Range: 0 to -10 volts

Input Impedance: 1 microampere, 125 picofarads (The input current depends on the relative polarity of the two inputs. The more positive input may draw up to 1 microampere and the more negative input may supply up to 1 microampere. The maximum current difference between states is 1 microampere.)

Outputs: Two outputs, 0 and -3 volt levels

Output Loading: 7 units base load at dc, 1 unit for maximum speed

Resolution: 1 millivolt at dc

Common Mode & Temperature: 5-millivolt maximum equivalent input offset for 10-volt common mode change and 20°C change

Speed:

Depends on application, principally on the ratio of the voltage difference before passing through the switching point (V_i) to the voltage afterward (V_A). Speed is affected to a lesser degree by the length of time the input difference is at V_i , by the magnitude of V_A , by the source impedance, and by the load. Typical speeds in an analog-to-digital converter system where the source is a ladder network and level amplifiers, and the load is a 1 unit base load, are listed below. (These speeds include allowances for extra divider settling times at high accuracies.) For more information on specific applications, see Chapter 4.

| V_i/V_A | V_A in mv | Time in μsec |
|-----------|-------------|-------------------------|
| -512 | 10 | 3.0 |
| -128 | 40 | 1.6 |
| -32 | 160 | 1.2 |
| -2 | 20 | 0.6 |
| -2 | 80 | 0.5 |
| $-1/512$ | 10 | 0.15 |

Adjustment:

Two potentiometers control zero set and common balance. See Chapter 6 for adjustment.

Power: -15 volts/55 ma; $+10$ volts (A)/0; $+10$ volts (B)/21 ma.

Figure 31. Comparator Specifications

When the comparator is used in a digital voltmeter or a continuous converter, it is usually desirable to have built-in hysteresis which is just slightly less than $\pm\frac{1}{2}$ LSB. The hysteresis avoids converter chatter (switch back and forth between two states) when the input voltage lies on a boundary between the two states. It is possible to introduce some hysteresis into the A502 by adjusting the common switching level and offset control so that the two outputs do not switch simultaneously. In a continuous converter, counting would then take place only when the two outputs were of opposite polarity. No action would take place when both outputs had the same polarity. The same type of logic would be applied in a digital voltmeter, the exact action depending on the conversion method used to arrive at the results.

Multiplexer Switches

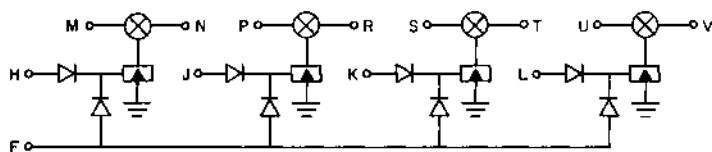
ANALOG MULTIPLEX SWITCHES

An analog multiplex switch is like a relay, in that two points are opened or shorted on command from an external source. Digital manufactures a relay switch, Type A111, for low speed operations, and a solid state switch, Type A121, for high speed operations. The control inputs to these switches are 2-input AND gates, each with a separate control input and all with one input in common. If the control inputs are driven from binary to octal decoders, up to 512 switches can be placed in parallel. The accuracy and speed limitations are the switch capacitance and the amount of leakage current back through the switches.

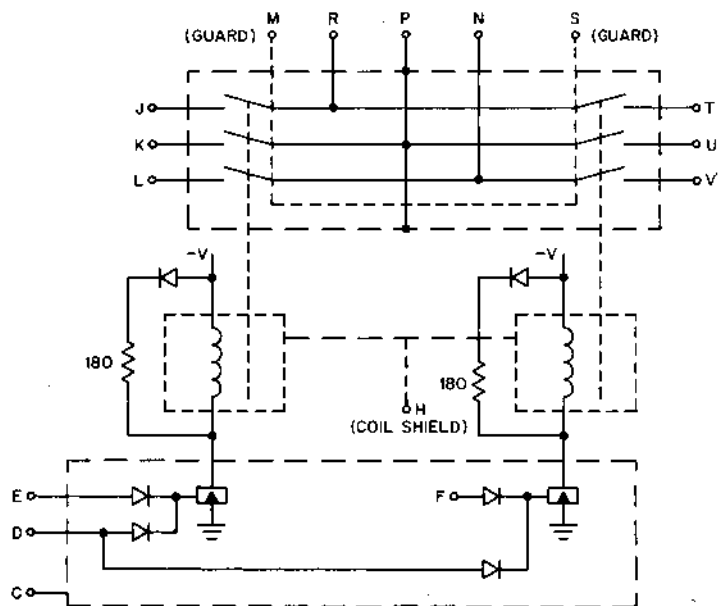
The switches can be tied in parallel, cascaded to give double level multiplexing for large systems, or used in other applications such as the sample and hold circuitry.

USE OF THE TYPE A121 SWITCH

In the off position, most types of A121 switches can have up to 15 volts across them, ranging from +10 volts to -5 volts referenced to ground.



A121 Solid State Switch



A111 Relay Switch

Figure 32. Multiplexer Switches

Multiplexer Switch Specifications

| TYPE NUMBER | A121 | A111 |
|-----------------------------|------------------------------------------|-----------------------------------------|
| Type of Switch | Solid state | Relay |
| Number of Circuits | 4, single pole, independent | 2, double pole, outputs bussed |
| Control | | |
| Signals | Digital levels | Digital levels |
| Enable | -3v | -3v |
| Load | 1.3 ma load shared among grounded inputs | 3 ma load shared among ground inputs |
| Signal | | |
| Max. voltage | +10 - 5 | ±10v |
| Max. current | +1 ma | 1 ma |
| "On" offset (max.) | 0 | |
| "On" resistance (max.) | 450Ω | 0.2Ω |
| "Off" resistance, leakage | 10 na | 5 x 10 ⁶ Ω |
| Speed | | |
| 50% input to .01% of output | Delay + sync + charging time | Delay + bounce setting |
| Turn on delay | 100 nsec | 0.9 msec |
| Turn off delay | 50 nsec | 0.06 msec |
| Bounce setting | | 0.3 msec |
| Life | | 10 ⁹ operations at low loads |

TABLE 8 USEFUL LOGS

| t/T | $1 - e^{-t/T}$ | $e^{-t/T}$ |
|-----|----------------|------------|
| 3 | 0.95021 | 0.04979 |
| 4 | 0.98168 | 0.01832 |
| 5 | 0.99326 | 0.00674 |
| 6 | 0.99752 | 0.00248 |
| 7 | 0.99909 | 0.00091 |
| 8 | 0.99966 | 0.00034 |
| 9 | 0.99988 | 0.00012 |
| 10 | 0.99995 | 0.00005 |

The switch is turned on when the two control level inputs are negative voltage (or open). When changing the state of the switches, care should be taken that two switches tied to a common node are never turned on simultaneously. If the control levels come from 10-megahertz flip-flops which are all changed simultaneously and which are decoded by 5-megahertz binary octal decoders, the switching is fast enough so that there is no danger of shorting. If low speed circuitry is used to drive the switch, or if the controlling flip-flops are not all changed simultaneously, one of the enabling inputs should be grounded before the state of the switches is changed. This will put all of the switches in the off position and assure that there will never be a make before break situation. If the switches are turned on

simultaneously, no damage will occur if the voltage ratings are observed, but large signal and transients will occur. It should be noted that the fall time of the output waveform of a single multiplexer switch is almost entirely determined by the load impedance and may be quite long for high load impedances.

RELAY MULTIPLEXER TYPE A111

The Type A111 contains two double pole switches which can be used for differential multiplexing. The switch outputs are connected to an output bus. The speed of the relay is determined by the delay in turn-on plus the bounce settling time. For the Type A111 this delay is 1.2 milliseconds. There are two control level inputs for each relay; one of these is common to both relays on the module, and one is independent. The relay is turned on when both of its control inputs are negative.

Analog Amplifiers

Amplifiers are sometimes used at the input of an analog-to-digital converter to shift the input range, scale the input range, provide a differential input, or isolate the input signal from the converter. Amplifiers are used on the output of digital-to-analog circuits to shift or scale the output range, to reference the output signal to the external ground, and to lower the output impedance. The last two features are important when the two pieces of equipment are separated by a distance that makes noise pickup likely. In this case, it is best to put the amplifiers at the driving source end, that is, at the output of the divider network in a digital-to-analog conversion or at the signal source for analog-to-digital.

The most useful amplifier for these applications is the operational amplifier. Its high input impedance and high gain make it a building block just as a flip-flop or nor gate is a digital building block.

Usually an operational amplifier is designed to roll off at 6 db per octave. This ensures less than 180 degrees additional phase shift so that the amplifier will not oscillate. This also produces a simplification in calculating the dynamic aspects of putting an amplifier in the system, although for a rigorous analysis, much more detail about the characteristics of the amplifier must be known, and the calculations are far more complex.

The approximation of infinite input impedance and infinite gain can be used in designing with good quality operational amplifiers with negligible error.

Figure 33a shows the amplifier operating as a simple inverter. The gain is R_2/R_1 . The input impedance is R_1 , and is returned to virtual ground (within microvolts of true ground). The gain accuracy and stability is that of R_1 and R_2 . The output impedance depends on the difference between open loop gain and closed loop gain. Typically, the closed loop gain is not very high, less than 100, and the open loop gain is in the order of 10^4 . Under these circumstances, the output impedance is less than one ohm.

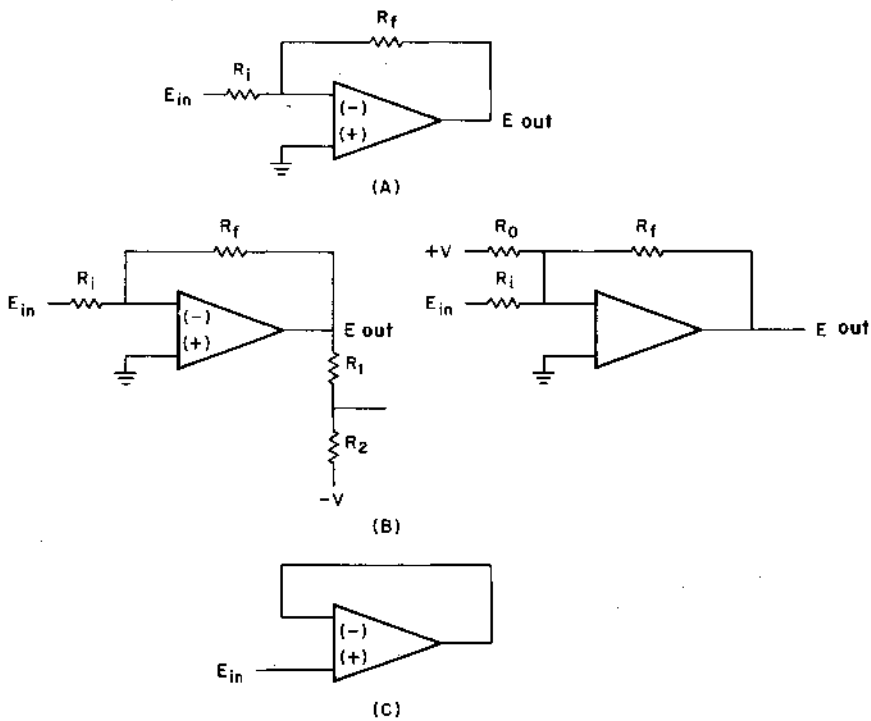


Figure 33. Typical Amplifier Configuration for Scaling and Biasing Digital-to-Analog or Analog-to-Digital Inputs

Figure 33b shows how a signal may be offset with a negative or positive reference voltage. In b, the positive reference is summed with the input voltage, E_{in} . The amplifier will keep the turning point at ground so that a sample calculation of resistances and currents is all that is required to determine the offset. Since the summing point is at ground, each input is independent of the other. If a half scale offset is required,

$$\frac{+V}{R_o} = \frac{2R_i}{E_o}$$

the input signal current applied thru R_i will be superimposed on the above dc level. Figure a utilizes a gain of two and a times $\frac{1}{2}$ alternator. If the input voltage swings from -5 volts to $+5$ volts, the alternator output will vary from zero to -10 volts.

Figure 34c shows a non-inverting "potentiometric" amplifier configuration. The output will equal the input and the gain will approach $+1$. The current drawn by the non-inverting input will be nearly zero. The input impedances achieved can approach 500 megohms.

Scaling, offsetting and differential input to an analog-to-digital circuit follow exactly the same method. The input resistor would be R_1 minus the appropriate output impedance of the driving signal.

When amplifiers are required on converters, it is generally best to use the same type of amplifier as is being used in the analog portion of the circuitry to keep the performance characteristics the same. When an amplifier is being used internally in the converter, such as between a group of multiplexer switches and an analog-to-digital converter, a higher performance amplifier is required, since it will be asked to take full scale changes and settle within a very short time.

The A200 consists of a DEC amplifier (part #1505379) mounted on an A990 amplifier board and includes a gain trim and balance potentiometer. Mounting holes are provided for input and feedback networks and roll off capacitor. The amplifier is supplied to Digital by Analog Devices and is identical with the Analog Devices 102 A.

| | |
|-------------------------------|--------------------------------------|
| Open Loop Gain: | 2×10^6 |
| Rated output voltage (a20 ma) | $\pm 11\text{v}$ |
| Frequency response | |
| Unity gain, small signal | 10 mc |
| Full output voltage | 300 kc |
| Slewing rate | $30\text{v}/\mu\text{sec}$ |
| Overload recovery | $200 \mu\text{sec}$ |
| Input voltage offset | Adjustable to Zero |
| Average vs temp. | $20 \text{uv}/^\circ\text{C}$. |
| Vs supply voltage | $15 \text{uv}/\%$ |
| Vs time | $10 \text{uv}/\text{day}$ |
| Input current offset | $\pm 2 \text{na}$ |
| Average vs temp. | $0.4 \text{na}/^\circ\text{C}$. |
| Vs supply voltage | $0.15 \text{na}/\%$ |
| Input impedance | |
| Between inputs | 6 megohm |
| Common mode | 500 megohm |
| Input voltage | $\pm 15 \text{volts}$ |
| Max common mode | $\pm 10 \text{volts}$ |
| Common mode rejection | 20,000 |
| Input | $8 \mu\text{volts}$ |
| Power | |
| Voltage | $\pm 15 \text{ to } 16 \text{volts}$ |
| Current at rated load | 35 ma |

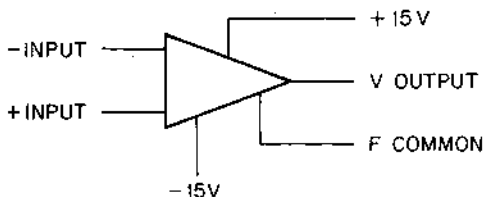


Figure 34. A200 Operational Amplifier

CHAPTER 6

INTERCONNECTION AND CALIBRATION

Grounding and Shielding

If the converter system operates with eight bits or more, care should be taken with the system wiring to avoid noise pickup and ground potential differences between the analog equipment and the converter. Since the digital voltages are low level, the major noise source within the converter is fast-switching transients, particularly pulses. Their effects can be minimized by isolating the analog portions (the divider network, level amplifier, reference supply and comparator) from the digital portions of the converter. Pulse-generating devices, such as clocks and pulse amplifiers, should be farthest away from the major analog components.

Single wires can be used within a mounting panel or between two panels if no noise sources are nearby. Coaxial cable is best, of course, for long leads. However, a twisted pair is usually sufficient, even in high accuracy systems, if pulse lines and other fast transients are avoided. The shield conductors of the coaxial or twisted pair should be tied down at one end only, and this end should go to a good ground, not near a pulse transformer or other high frequency device.

On the precision level amplifiers, there is a separate input for the high quality ground. These inputs can be tied together and fastened to chassis ground at a good solid point. In general, excessive analog ground loops should be avoided.

Similarly, in large systems sense wires from the reference voltage supply should be brought to a point near the load so that the supply will regulate the voltage as seen by the load, not the voltage as generated at the power supply. If the load is distributed, capacitors at the main load points will reduce transients caused by the rapid switching of the DAC's. A separate ground-shield is brought out on the Type A111 Multiplexer Switch. It isolates the analog signal from noise transients generated by the multiplexer control signals. Any solid ground source can be used here, but this analog signal is not a ground reference for the system.

Signals from a high impedance output are more sensitive to noise pickup than those from a low impedance output. Thus, if a digital-to-analog converter is to drive long leads where noise could be picked up, the output should be buffered with an amplifier having a low output impedance.

The size of the ground potential differences which can occur between the converter and the analog input or output signal should also be minimized. If it is not possible to place the two pieces of equipment close to each other with the grounds tied tightly together, a

heavy ground strap can be run between them. Alternatively, the ground potential differences can be subtracted out. In an analog-to-digital converter this is done by using a differential amplifier at the input, or by using two standard operational amplifiers. In the latter case, one of the amplifiers is used to invert the ground; then the signal and inverted ground are summed. In digital-to-analog conversion, the ground from the signal destination is brought back to the converter, inverted with an operational amplifier, and summed with the signal.

CAUTION

The multiplexer switches are low impedance switching circuits. Precautions should be taken against possible shorting of the analog inputs and outputs of these circuits to any other low impedance source, including ground. Such shorting could damage either the circuits or the signal sources.

CALIBRATION

EQUIPMENT NEEDED

The adjustment and calibration procedures outlined here are designed to be as simple as possible. Three pieces of equipment are needed, as follows:

1. A digital module extender.
2. An oscilloscope with a high gain ac-coupled vertical amplifier and a dual trace amplifier.
3. A reference for determining proper gain setting. Can be a standard voltage or a reference from the analog equipment.

GENERAL PROCEDURE

There are six kinds of calibration needed for basic conversion systems. They apply to digital-to-analog converters and to three types of analog-to-digital converters: the counter, continuous, and successive approximation types. Other conversion systems require basically the same kind of adjustments, with certain steps added or omitted depending upon the circuits used. In this chapter, the six general procedures for calibration are presented as follows:

Steady State Calibration

DAC Networks

Comparators (analog-to-digital conversion only)

Offset and Gain

Speed

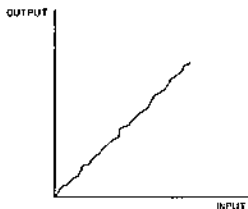
Noise and Ripple

Digital-to-Analog Adjustment

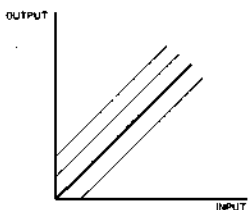
Analog-to-Digital Adjustment

Calibration should follow in the same order as the procedure given. In steady state calibration particularly, the DAC, offset, and gain adjustments carried out in that order make it unnecessary to repeat previous adjustments for fine trimming. The effects of these adjustments can be seen easily if output is plotted against input. Normally, with the digital number 0 in, the output should be 0 volts out, and vice versa. Similarly, maximum input should yield full scale output. Intermediate points should fall on a straight line between these two points.

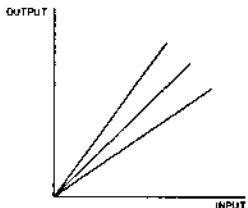
An uncalibrated converter, however, produces the non-linear plot shown below.



By adjusting the DAC networks, the irregularities are removed from the curve and it becomes a straight line. Next a small amount of offset is added to the network, shifting the curve up and down, as shown below, until the zero input gives a zero output.



Finally the gain is adjusted until a relatively large input produces the correct output. The slope of the curve will change as follows:



DIVIDER ALIGNMENT

The DAC is aligned to compensate for variations in resistors in the divider network and for variations in the output impedance of the level amplifiers. The output voltage from the bit to be calibrated is compared with the output voltage resulting from all of the bits of lesser significance. The difference is trimmed so that it is equal to one least significant bit. A simple setup for making this adjustment is shown in Figure 35. The clock, delay one-shot, and inverter simulate a digital input to the converter. Here they are shown switching the inputs between 00100000 and 00011111. Thus, the bit under test is the third bit, and the adjustment is made with the trimpot on that bit.

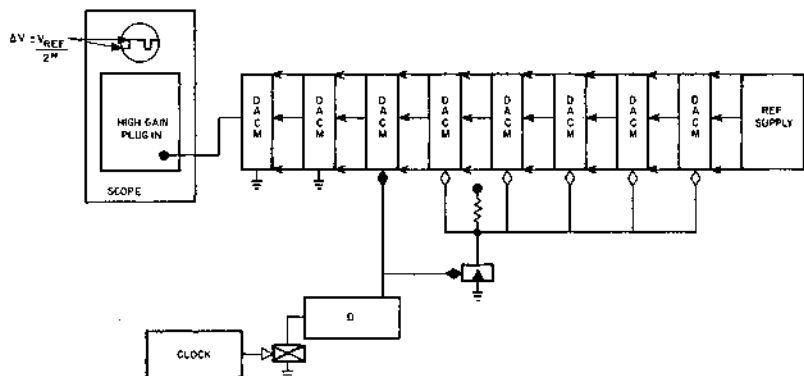


Figure 35. DAC Adjustment

The output should be monitored by an oscilloscope with a high gain, ac coupled vertical amplifier. The amplitude of the output should be one least significant bit voltage contribution. Since this alignment also adjusts for variation in output impedance of the DAC's, the level DAC's should be aligned in the same relative order as in the final system. Any unused bits of lesser significance should be connected to $-3v$. in the test setup just as in the system. Inputs to DAC's in more significant positions may be either grounded or connected to -3 volts, as long as they remain constant throughout the alignment.

In starting the alignment, it is advisable to check a non-adjustable bit first to make sure that the setup is correct. Using this method, the adjustment of bits of lesser significance is independent of the adjustment of bits of more significance. Therefore, the least significant adjustable bit should be checked first, then the next in order, and so on toward the most significant bit. The alignment is then completed in one step, without the need of going back to realign any portion.

The sensitivity to the trimpot motion depends on the number of bits being used. In a 10-bit system, where the voltage differential being observed is approximately 9.8 millivolts, the motion of the least significant potentiometer is barely seen on the scope. Working toward the most significant bit, the adjustment range will become larger and larger until it may be possible to invert the relative values of the outputs. To avoid such inversion, note whether the longer portion of the rectangular wave corresponds to the more negative part of the signal or to the more positive part of the signal. Be sure that this relationship continues the same for all of the bits.

Since the DAC's use fine resolution wire-wound trim pots, ascertain that they are in a stable position and that the slider arm is not resting on a single wire where it could jump away, possibly in the wrong direction. After trimming, tap the pot once or twice with the end of a screwdriver and, if the output changes, retrim to the stable position closest to the ideal value.

There are two advantages of this particular method of alignment. As the trimpot is changed, the dc level will move up and down. However, since the levels are being observed simultaneously, and only the difference is being monitored, the scope can be put on ac and the picture will stay in the center of the scope face. Also, since the adjustment is made on the differential between two states, a 10 per cent error in the adjustment will give an error in the system of only 10 per cent divided by 2ⁿ.

An ohmmeter should not be used to adjust the ladder network, since it will not take into account the output impedance of the level amplifiers. Do not try to adjust the output with a voltmeter since the dc level shift would require switching between the two states, and the measurements would be extremely confusing and time-consuming.

NEED FOR REALIGNMENT

Realignment should not be necessary under normal conditions. The system should be checked if the modules have been subjected to a drastic change of temperature or to a mechanical shock sufficient to change the trim pot settings. Realignment should be done if one of the DAC modules is changed.

THE COMPARATOR TYPE A502

The comparator can be adjusted easily with a dual trace oscilloscope and a clean-SN dc source applied simultaneously to the inputs.

The two outputs of the A502 are viewed simultaneously on a dual trace oscilloscope. With both traces synchronized to a single point, the two signals will appear as roughly complementary square waves. For most applications the comparator should be balanced; that is, both outputs change simultaneously when the relative polarity of the inputs changes. For continuous converters or digital voltmeters, however, such adjustment would cause the converter to oscillate around a dc level. In this application it is desirable to delay switching of the outputs until the input analog signal is almost 1/2 LSB away from the divider input. The small amount of hysteresis introduced prevents converter chatter.

ADJUSTMENT FOR BALANCE

The comparator should be adjusted so that the two outputs are perfect complementary square waves. Adjust the upper potentiometer to make the two waveforms complementary. Adjust the lower potentiometer for equal positive and negative portions of the square wave. These controls are somewhat interdependent, so it is necessary to repeat the adjustments until the optimum symmetry is observed. The resolution can be increased by reducing the size of the input sine wave and repeating the adjustment.

COMPARATOR WITH HYSTERESIS

Begin the adjustment with a difference voltage, applied to the input, that is equal to the amount of hysteresis desired. Proceed to adjust the comparator as above, under Adjustment For Balance.

The comparator adjustment can change with time, temperature, or a mechanical shock severe enough to jar the potentiometers. The need for readjustment depends on the accuracy required and the environment. Usually a monthly check is more than sufficient. Testing can be done by taking the comparator out of the converter and employing the above method or by testing the overall system, as described in the next chapter.

OFFSET AND GAIN

Offsetting and gain adjustments should be made on the assembled system. In a digital-to-analog converter, a digital number is put in and the output is observed with a voltmeter. In an analog-to-digital system, a voltage is put in and the switching points are observed. Offset and gain adjustment are necessary to compensate for the open-circuit voltage drop of the DAC's, which can be as high as 10 millivolts in precision converters. In an analog-to-digital converter offsetting is also necessary to center the quantization error; that is, if the state zero corresponds to 0 volts and the state one corresponds to 10 millivolts, the converter should switch between states zero and one at an input of 5 millivolts.

OFFSET

The calibration should begin with the offset. A positive voltage can be applied through a large resistor (usually on the order of 1 to 10 megohms) to the digital-to-analog converter output. The size of the bias resistor, or the amplitude of the bias voltage can be varied until the offset is correct. For digital-to-analog conversion, zero in gives zero out. For analog-to-digital, an input of $\frac{1}{2}$ LSB produces the first switching point.

The offset voltage source can be the standard ± 10 volts (for systems of up to 10 bits). The percentage variations in the voltage supply for the offset signal are scaled according to the amount of bias obtained. That is, a 10 percent ripple on the bias supply produces a 10 percent ripple in the offset; so if the offset is 10 millivolts, a 10 percent ripple would be 1 millivolt.

GAIN

The gain adjustment on a digital-to-analog converter is made by setting the digital number to half-scale or full-scale and adjusting the reference voltage supply until the output has

the correct value. The Type 1562 has one trimming potentiometer for this adjustment. The Type A204 has both a fine and a coarse adjustment. In checking the output voltage, remember that the output impedance of the divider network is about 1000 ohms. Thus, loading the output with one megohm would reduce the output voltage by 0.1 percent. This adjustment should be done with the same load as in the final system.

The gain adjustment for an analog-to-digital converter differs only in that the common mode effect of the comparator must be taken into account. The comparator has been balanced with a 5 volt common mode. The offset has been applied so that the lowest switching point is correct. Therefore, the reference adjustment which gives the correct half-scale switching point is different from that which gives the correct full-scale switching point. Generally, maximum accuracy is desired in the lower part of the scale, so the mid-scale point should be used. Alternatively, the reference may be adjusted for the best fit between half-scale and full-scale points. In calculating the switching points for these measurements, be sure to remember the quantization offset that has been introduced. This adjustment should be made at low speed (10 to 20 microseconds per step).

SPEED ADJUSTMENTS

NOISE AND RIPPLE

When the DAC's switch, a transient current is drawn from the reference supply. Normally this supply is loaded with a capacitor to reduce noise (see power supplies, Figure 30), but it may also be desirable to place small capacitors at the reference inputs of the individual DAC's and possibly also between the high quality ground and the chassis ground. The voltage at the load can be monitored on a scope with a high-gain dc-coupled plug-in unit.

Care should be taken that the noise being observed is actually there and not introduced through the scope or by a ground lead attached to the wrong point. The reference and the ground tend to move together. If the input signal source is referenced to this ground, it also moves. Thus, the scope should generally be disconnected from ground at the power and connected to the converter ground at a good solid point, and the cable running to this scope should be prevented from introducing additional noise.

ANALOG-TO-DIGITAL ADJUSTMENTS

As mentioned previously, the speed and accuracy of an analog-to-digital converter are inter-related. That is, if the converter is run too fast, the DAC's and the comparators do not have enough time to settle to final value. In the range of 6 to 10 bits, even a tenth of a micro-second per step can make a considerable difference in the system accuracy. Thus, the speed may be adjusted for the maximum allowable time and hence the maximum accuracy, or it may be adjusted for the minimum time required to give the required accuracy.

Test for speed should be made by checking the major switching points. For most converters (including the counter, continuous, and successive approximation types) these are around one-fourth, one-half, and three-fourths of full scale, as shown below.

| <u>Area Being Checked</u> | <u>From</u> | <u>To</u> |
|---------------------------|-------------|------------|
| $\frac{1}{4}$ | 0011...110 | 0011...111 |
| | 0011...111 | 0100...000 |
| | 0100...000 | 0100...001 |
| $\frac{1}{2}$ | 0111...110 | 0111...111 |
| | 0111...111 | 1000...000 |
| | 1000...000 | 1000...001 |
| $\frac{3}{4}$ | 1011...110 | 1011...111 |
| | 1011...111 | 1100...000 |
| | 1100...000 | 1100...001 |

For a more detailed check, the switching points around $1/8$, $7/8$, $1/16$, etc., might also be included.

DIGITAL-TO-ANALOG ADJUSTMENTS

The digital-to-analog converter output contains transients when many bits are changed simultaneously, such as in going from 01111 to 10000. These transients are caused by variation in flip-flop transient times and propagation time through the divider.

Transients can be reduced by adding a small choke in series between the flip-flop and level amplifier, or by loading the flip-flop with a resistor to -15 volts. Further reduction can be made with a low pass filter on the output (remember that the digital-to-analog output impedance is 1000 ohms.)

CHAPTER 7

TESTING AN ANALOG-TO-DIGITAL CONVERTER

The adjustment and calibration procedures detailed in the previous chapter should result in a converter that operates correctly over the whole range. To make sure the converter meets specific accuracy requirements, testing may be desired, and simple operating checks should be repeated at regular intervals to assure continued correct operation.

If the converter is part of a general purpose computing facility, complete testing can be performed easily under program control. If, on the other hand, the converter is part of a specialized system or is to be tested before installation in such a system, manual or semi-automatic testing is necessary and will probably cover only the worst cases. For most converters (counter, continuous, and successive approximation) the worst cases are seen at the major switching points; namely, one-fourth, one-half, and three-fourths full scale (see Chapter 6).

The following sections describe tests that can be performed to measure the various converter characteristics either manually or by computer. The equipment required depends on the tests to be performed. Some of the tests require very specialized equipment, while others can be performed with quite simple equipment.

MONOTONICITY

This simple test requires a minimum of precision equipment. It does not guarantee a specific accuracy but gives a good indication. If a converter with a star/type divider passes a monotonicity check, the relative error in the DAC will be small, probably less than ± 1 LSB.

DIGITAL-TO-ANALOG — Monotonicity can be checked by driving the converter from a counter and observing the output on a high gain scope. The output should be a staircase pattern.

ANALOG-TO-DIGITAL — The input can be any noise-free power supply (such as a battery) and a potentiometer of less than 2000 ohms. In testing high resolution systems, potentiometers should have a coarse and fine control with overlapping ranges. Starting at zero, increase the input voltage and check that each state exists and that these states are in the correct order. A similar computer-controlled test can be done using a saw tooth generator as the input signal.

STEADY STATE ACCURACY

DIGITAL-TO-ANALOG — Set an input to a known digital number and observe the output with a high accuracy meter. Compare with the theoretical value.

ANALOG-TO-DIGITAL — The input can be a high accuracy voltage reference or a stable, ripple-free, variable power supply with a high accuracy meter. When the converter is run at a rapid rate, the indicator lights will show quite clearly where the switching points are.

The input voltage at the switching point is measured and compared with the theoretical value. Computer controlled checking can be done in a similar manner using a precision programmable reference as the input signal.

NOISE

DIGITAL-TO-ANALOG — Noise can be measured on a scope with a high gain, ac-coupled plug-in unit.

ANALOG-TO-DIGITAL — The noise appears as a band around the switching point, where the converter output is oscillating between two neighboring states.

INTERMITTENT ERRORS

Intermittent errors can be caused by pickup or loss of a bit in the digital section or by noise picked up in the analog section. The test for intermittent errors should be done with automatic or semi-automatic equipment where the converter is run at full speed for an extended period of time. The equipment should be installed in its final configuration so that the transmission of the information is included in the test. It is important to check the states where there is only a single 0 or a single 1 for possible pickup or loss of information in the digital transfer.

In a general purpose system which includes two-way conversion, an intermittent error check can be run in a closed loop. The computer can generate a pattern wave of digital numbers which are converted to analog, then reconverted to digital. The results are checked to see that the two numbers agree within their specified tolerance.

DIGITAL-TO-ANALOG — In a general-purpose system, limits for two specific numbers can be set up with two comparators, and the state of the comparators can be sampled by the computer after the corresponding number has been brought in. Where other numbers are read in, the comparator outputs would not be sampled, of course. For semi-automatic testing, a similar system might be set up with a counter driving some of the bits of the converter and toggle switches driving other bits.

ANALOG-TO-DIGITAL — In a general purpose system, a dc voltage input would be applied and the computer would monitor it to make sure that all the readouts produced the same number or two adjacent numbers.

To test semi-automatically, set a dc voltage input that is as far as possible from any switching point and insert the equivalent number into a bank of toggle switches. The Type R121 AND/NOR Gate can be used to compare the output with the toggle switches. A clock and a few gates can be set up so the converter runs at its maximum rate and stops if the toggle switches and the analog-to-digital converter do not agree.

SETTLING TIME (DIGITAL-TO-ANALOG)

In most applications, the digital-to-analog converter is asked to go through small changes at a time. The worst case transients occur when all the flip-flops change, that is, when the states change from 0111 to 1000.

The settling time with respect to large transients is most important when the converter output is being multiplexed. It can be observed by looking at the signal on a single channel with a high gain scope.

In a system where the multiplexing is done digitally, or where there is only a single channel, the response to large transients is only important when a group of conversions is started; after which the converter will be changing in relatively small steps. If an analog-to-digital converter had been constructed with the same modules, then the response to large transients can be inferred from previous operation. For example, in a successive approximation converter, the settling time for a quarter-scale step must be less than the time per step of the converter.

To observe the settling time more directly, a comparator can be used with one input set to the desired threshold of the dc value of the digital-to-analog converter. The Digital-to-Analog can be switched back and forth, and the comparator output can be monitored on the scope.

RESPONSE TO TRANSIENTS (ANALOG-TO-DIGITAL)

Transient response is extremely important in a converter with multiplexed inputs. The response can be tested in the same way that switching point accuracy is tested. Alternate the input between a test channel and an offset channel. Vary the voltage on the test channel until a switching point is found, and compare this with the switching point that was observed in the steady state test. If the output is observed visually on indicator lights, the voltage on the offset channel should be one which gives all zeros or all ones, so that the alternate voltage can be read clearly.

If the output is being monitored by a computer, the steady state and transient switching points can be measured simultaneously by performing several conversions before changing the channel. The first conversion will give the transient results, the last conversion will give the steady state results. A check should be made with the offset and test channels at nearly opposite ends of the voltage range. Do not use end points, as the converter saturates and overshoot would not be detected. The first decision point should be tested. In a successive approximation converter, for example, the first decision is whether the input is above or below half-scale.

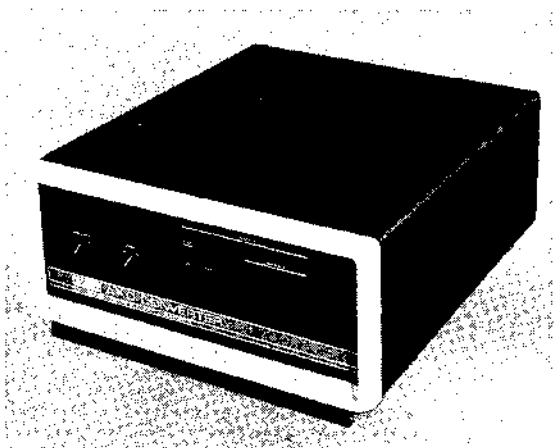
In a single channel system, the transient response is only important for the first conversion. It can be checked manually, running the converter from a push-button and changing the input voltage manually. The general approach would be the same as for a multiplexed system.

Operating Checks

Operating checks are made to assure that the equipment has not been damaged, wires have not been pulled off, or other catastrophic failures have not occurred. If properly set up, the check also detects drift, so that the converter will never actually reach a point where it needs realignment. Generally the test should be simple and should be a part of the overall preventative maintenance routine for the equipment. In a general purpose computing facility with both types of conversion systems, a closed loop test can be run very simply by plugging the digital-to-analog converter into the analog-to-digital converter and comparing the results that come back with the original number.

If a converter is being tested separately, a simple test can be made on the worst case points. If precision equipment is not readily available for the test, the converter can be checked against a divided-down value of its own internal reference.

GENERAL-PURPOSE ANALOG-TO-DIGITAL CONVERTER AND MULTIPLEXER CONTROL



Digital is now offering its general-purpose analog-to-digital converter (ADC-1) and multiplexer control (AMX-1) as separate units or as a combined converter-multiplexer (CMX 1). Optional equipment includes input amplifiers to obtain high impedance or "standardize" the input signal, sample and hold circuitry, and interfacing for the PDP-8, PDP-8/S, or PDP-9 computers.

ADC-1 CONVERTER SPECIFICATIONS

The ADC-1 converts an analog voltage to a binary number. Three convenient switches are mounted on the INDICATOR/CONTROL PANEL; a POWER ON/OFF switch is a 117-volt input power disconnect. The ADC switch is a normally open pushbutton that initiates an A/D conversion whenever the switch is activated. The WORD LENGTH control is a rotary switch used to select the word length, the conversion accuracy, and the conversion time. The WORD LENGTH switch selects the following characteristics:

TABLE 1. CONVERSION ACCURACY AND TIME AT SELECTED WORD LENGTHS

| Word Length (No. of bits) | Max Switching Point Error* | Conversion Time (μ sec) |
|---------------------------|----------------------------|------------------------------|
| 6 | $\pm 1.6\%$ | 9.0 |
| 7 | $\pm 0.8\%$ | 10.5 |
| 8 | $\pm 0.4\%$ | 12.0 |
| 9 | $\pm 0.2\%$ | 13.5 |
| 10 | $\pm 0.1\%$ | 18.0 |
| 11 | $\pm 0.05\%$ | 25.0 |
| 12 | $\pm 0.025\%$ | 35.0 |

* $\pm 1/2$ LSB for quantizing error.

A completely wired back panel includes an A/D Converter, interfacing for the PDP computers, an optional multiplexer control with up to 64 input channels and amplifier output, and provisions for a sample and hold amplifier (A400).

If the converter is used with a PDP computer, conversions are initiated by an IN/OUT Transfer instruction. If the converter is used separately, a CONVERT A-D PULSE is necessary to initiate conversion.

ACCURACY: See Table 1.

CONVERSION TIME: See Table 1.

APERTURE TIME: Same as conversion time.

CONVERTER RECOVERY TIME: None.

INPUT: 0 to -10v standard. Input scaling may be specified using the amplifier option.

INPUT LOADING: ± 1.2 amp and 125 pf for 0 to -10v input signal.

OUTPUT: Binary number of 6 to 12 bits, with negative numbers represented in 2's complement notation. A 0v input gives a 4000₁₀; a -5v input a 0000₁₀ and a -10v (minus 1 LSB) input gives 3777₁₀ number.

CONTROLS: Power ON/OFF switch, ADC switch, binary readout indicators and a seven position rotary switch which selects word length and conversion rate are provided.

The convert A/D pulse input requires a negative pulse (0 to -3v) of at least 150-nsec duration. The pulse loading is 1 ma at ground.

AMX-1 MULTIPLEXER CONTROL SPECIFICATIONS

The AMX-1 includes from 1 to 16 A121 multiplexer switch modules, depending upon the number of channels required by the user. The user may select any multiple of four channels to a maximum of 64.

In the random address mode, the control routes the analog signal from any selected channel to the A/D Converter input. In the sequential address mode, the multiplexer control advances its channel address by one each time an indexing command is received. After indexing through a predetermined number of channels, the address is returned to zero. When using the sequential operation, the conditioning levels for random addressing are ignored.

Three convenience switches are mounted on the INDICATOR/CONTROL PANEL: a POWER ON/OFF switch, a CLR switch, and an INDEX switch. The POWER ON/OFF switch is a 117-volt input power disconnect. The CLR switch is a normally open pushbutton that clears the multiplexer address register and selects channel zero whenever the switch is activated. The INDEX switch is also a normally open pushbutton that increments the channel address by one each time the switch is activated.

A completely wired back panel includes the multiplexer control with up to 64 input channels and amplifier output, interfacing for the PDP computers, an optional 6 to 12 bit general-purpose A/D Converter, and provisions for a sample and hold amplifier (A400).

If the multiplexer is used with a PDP computer, control is carried on by In/Out Transfer instructions. If the multiplexer is used separately see specifications.

Multiplexer Address Input—six lines accept DEC standard levels of 0 and -3 volt, with 0v for assertion. Load is 1 ma at ground.

At the completion of the conversion process, two complementary A/D DONE levels initiate external reading of the converted data. This level remains in the A/D DONE state until an external clear flag pulse is generated or another convert A/D pulse is given. If used with a PDP computer, the flag is cleared when the read buffer command is given.

The clear flag pulse requires a negative pulse (0 to -3v) of at least 100-nsec duration. The pulse loading is 1 ma at ground.

POWER: Module power is supplied through one H701 power supply and one H704 regulated power supply. Input power; 117 volts at less than 1/2 amp.

OPERATING TEMPERATURE RANGE: 0°C to 50°C

MECHANICAL: Panel Width: 19 inches
Panel Height: 8 1/4 inches
Depth: 19 1/2 inches

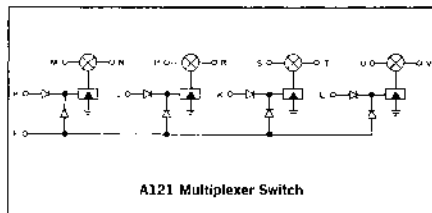
Random Address Control—the channel select pulse input requires a negative pulse 0 to 3v of at least 100-nsec duration. The pulse loading is 1 ma at ground.

The channel address levels must be brought to their final values at least 400 nsec before the channel select pulse occurs.

Sequential Address Control—the index pulse has the same characteristics as the random address control.

Operate Time—the time required to switch from one channel to another is 10 μ sec to within 1 millivolt of the final voltage. This time is preset within the control and starts when a set or index command is received.

Indicators—binary readout indicators; six are provided.



POWER: Module power is supplied through one H701 power supply and one H704 regulated power supply. Input power: 117 volts at less than 1/2 amp.

CONTROL:

Signals Digital levels, -3 volts for assertion.
 Load 1.3 milliampere load shared between its grounded inputs.

SIGNAL:

Input Operating Signal voltages $\pm 10\text{v}$ to -5v
 Output voltage 0 to -10v
 Output current 5 ma
 Input Impedance 6 Mohm (min)
 Output Impedance 1 ohm (max)
 Input Current Offset ± 2 ohm (max)
 Input Voltage Offset ± 1 mv. (max)
 "Off leakage" 10 na. (max)
 Capacitance 10 pf (max)

SPEED:

10% input to .01% output 10 usec

MECHANICAL:

Panel Width: 19 inches
 Panel Height: $8\frac{1}{4}$ inches
 Depth: $19\frac{1}{2}$ inches

The CMX-1 combination with computer interface is available as the AF01A (PDP-8, 8/S) AF01B (PDP-9) interface. As such, it is considered a computer peripheral, and check out and installation is included in the price.

The computer interface options also may be purchased as modules and cables from this catalog and installed by the customer who takes responsibility for check-out.

Modules required for PDP-8 and 8/S interface:

| | |
|------------|------|
| 1 | R111 |
| 2 | R123 |
| 2 | W103 |
| Bus Cables | |

Modules for PDP-9 Interface:

| | |
|------------|------|
| 3 | W103 |
| 1 | W500 |
| 1 | R202 |
| 1 | R107 |
| 4 | R123 |
| 2 | W640 |
| Bus Cables | |

| | |
|--------------------------------|--------------|
| A/D Converter (ADC 1) | — \$2,000.00 |
| 64 Channel Multiplexer (AMX 1) | — \$2,250.00 |
| Plus \$16.25 per channel | |
| Converter-Multiplexer (CMX-1) | — \$3,300.00 |
| Plus \$16.25 per channel | |
| Options | |
| Input Amplifier | — \$ 300.00 |
| Sample and Hold | — \$ 500.00 |
| AF01A, AF01B | — \$4,500.00 |

A SERIES

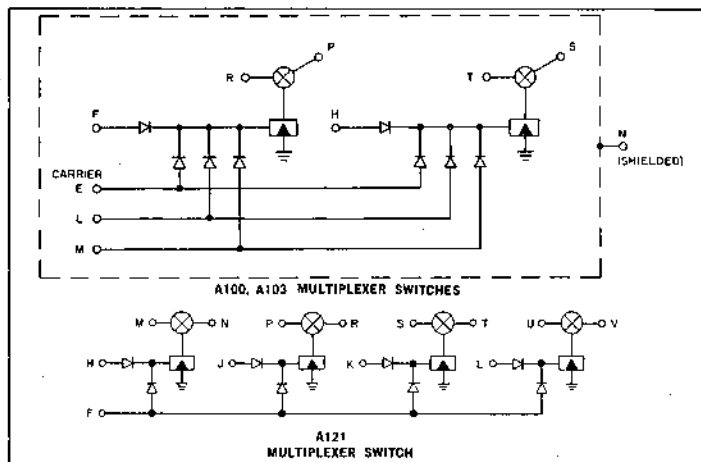


MULTIPLEXER SWITCHES

TYPES A100, A103, and A121

A

SERIES



A100

A103

A121

| Control | Digital levels and 5-mc square wave | | |
|-------------------------------------------|-------------------------------------|-------------|-------------|
| Signals | -3 v (5-mc square wave pin E) | | |
| Enable | -3v | | |
| Load | 1¼ ma shared among grounded inputs | | |
| Signal | | | |
| Max voltage | 12v | 30v | 10v |
| Max current | 1 ma | 1 ma | 1 ma |
| "On" offset (max.) | 200 µV | 300 µV | 0 |
| "On" resistance (max.) | 50Ω | 50Ω | 480Ω |
| "Off" leakage, capacitance | 2 na, 10 pf | 2 na, 10 pf | 2 na, 10 pf |
| Carrier cross talk (with light filtering) | 10 mv p-p | 10 mv p-p | 0 |
| Speed | Delay + sync + charging time (RC) | | |
| 50% input to tolerance output | | | |
| Turn on delay | 400 nsec | 400 nsec | 600 nsec |
| Turn off delay | 200 nsec | 400 nsec | 1000 nsec |
| Synchronization | 100 nsec | 100 nsec | 100 nsec |

The A100 and A103 multiplexer modules contain two, single-pole, high-speed, solid-state switches. The switch drive is transformer-coupled so that the switch may be completely isolated from ground. The switch is turned on when the three control inputs are at -3v (or open-circuited) and the carrier is receiving a 5-mc square wave. The square wave can be made using a 10-mc clock and a 10-mc flip-flop. Since the switches are low impedance, care should be taken to avoid shorting signal terminals to ground

or to each other, or simultaneously turning on two switches which have a common connection. There is a shield on Pin N that should be grounded. In newer modules, this connection is made internally. Better performance results if Pin N is also grounded externally.

The A121 multiplexer module contains four single pole, high-speed, insulated-gate FET switches. The switch is turned on when its two inputs are at -3 volts.

A100 — \$100.00

A103 — \$ 78.00

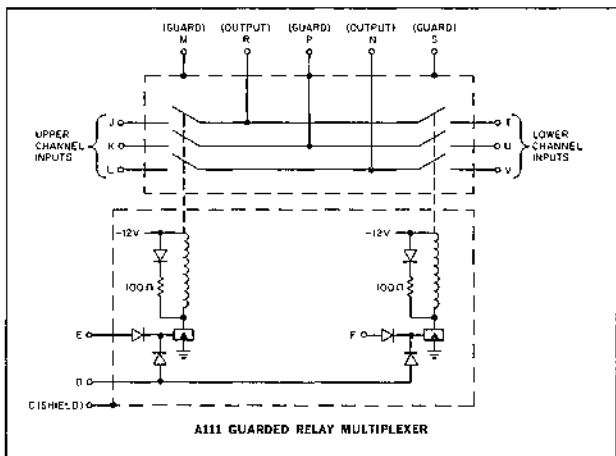
A121 — \$ 65.00

GUARDED RELAY MULTIPLEXER SWITCH

TYPE A111

(Standard height, double width)

A
SERIES



At low levels, multiplexing of analog signals must usually include guarding and shielding provisions to control noise pickup. Fortunately, transducers having low-level outputs are often slow speed devices like thermocouples, so that the limited speed of a relay multiplexer is not a serious problem, and the superiority of relay contacts for ultra-low-offset switching can be fully utilized. The two James Microscan 3-pole relays in the A111 are specially designed for this purpose, and are mounted on a double-clad circuit board which shields the analog from the digital circuitry and provides guarded contact wiring. The large size of the special relays used requires that two module slots be allowed for each A111 module.

INPUTS: Each relay driver requires 3 ma drive at ground, shared among grounded inputs. A

shield on the component side of the board covers the driver circuitry and is connected to pin C. Another shield covering the area under the relay coils is connected independently to pin C. Contacts close when inputs are at $-3v$.

OUTPUT: Signal Contacts — 10v and 1 ma, max. Contacts switch within 1 msec. Life expectancy — 10^9 operations. Limits can be extended to 30v and 10 ma below 25 cps at short duty cycles. **Guard Contacts** — Designed for high voltage, high current transients. Guard contacts close before signal contacts close, open after signal contacts open.

POWER: +10 v(A)/0 ma; -15v(B)/85 ma.

OPERATIONAL AMPLIFIER*

TYPE A200

A SERIES

The A200 is an operational amplifier mounted on an A990 amplifier board. Provisions are made on the board for the mounting of potentiometers for gain trim and balance. Mounting holes are also provided for input and feedback networks, and rolloff capacitor.

| | |
|-------------------------------------------|--------------------------|
| OPEN LOOP GAIN: | 2x10 ⁶ |
| RATED OUTPUT | |
| Voltage: | ±11v |
| Current: | 20 ma |
| FREQUENCY RESPONSE | |
| Unity gain, small signal: | 10 MHz |
| Full output voltage: | 300 kHz |
| Slewing rate: | 30v/ μ sec |
| Overload recovery: | 200 μ sec |
| INPUT VOLTAGE OFFSET (Adjustable to Zero) | |
| Average vs. Temperature: | 20 μ v/ $^{\circ}$ C |
| Average vs. Supply voltage: | 15 μ v/% |
| Average vs. Time: | 10 μ v/day |
| INPUT CURRENT OFFSET: | |
| Average vs. Temperature: | ±2 na |
| Average vs. Supply voltage: | 0.4 na/ $^{\circ}$ C |
| Average vs. Supply voltage: | 0.15 na/% |
| INPUT IMPEDANCE | |
| Between inputs: | 6 megohm |
| Common mode: | 500 megohm |
| INPUT VOLTAGE | |
| Maximum: | ±15 volts |
| Maximum common mode: | ±10 volts |
| Common mode rejection: | 20,000 |
| POWER | |
| Voltage: | ±15 volts |
| Current at rated load: | 35 ma |

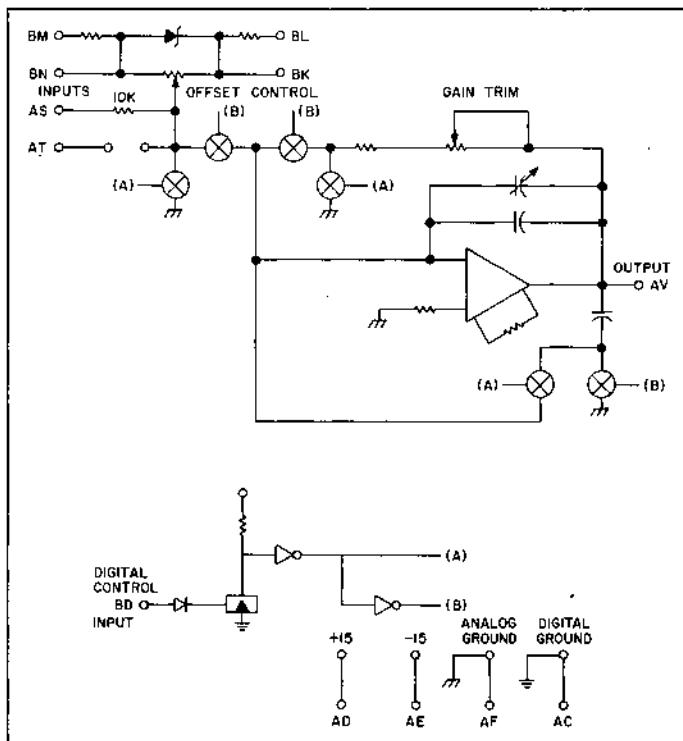
*REFER TO A990 FOR CONNECTIONS

SAMPLE AND HOLD AMPLIFIER

TYPE A400

(DOUBLE HEIGHT, DOUBLE WIDTH)

A
SERIES



The A400 is an accurate sample and hold amplifier capable of tracking a full scale excursion in 12 micro-seconds to 0.025% accuracy. In the hold mode, the droop (a decay) is less than 1 millivolt per millisecond. Two analog inputs are provided. Pin AS is connected to a 10K Ω resistor which provides for unity gain. Pin AT is connected to a point which allows for the insertion of different resistors to effect a gain change. The resistor connected to this point must be a precision 1% resistor with a temperature coefficient of 25 ppm.

An optional internal offset network which uses the ± 15 volt supply can be included. Connections are made according to the following table:

| PIN | TO OFFSET OUTPUT | |
|-----|------------------|-----------------|
| | NEGATIVE | POSITIVE |
| BK | NO CONNECTION | -15 VOLT GROUND |
| BL | +15 VOLT SUPPLY | NO CONNECTION |
| BM | NO CONNECTION | -15 VOLT SUPPLY |
| BN | +15 VOLT GROUND | NO CONNECTION |

Offsets of up to 6 volts can be achieved in this manner. The digital control input (BD) requires the standard -3 volt level to sample (track) and ground to hold.

The A400 can be used to sample fast time varying

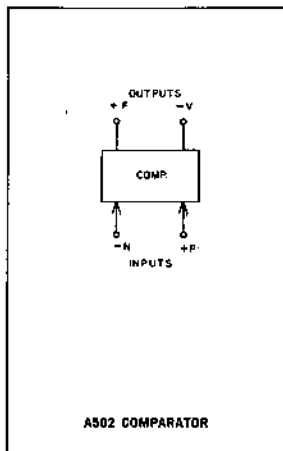
wave forms and produce a time invariant output sufficient for analog to digital conversion. Several sample and holds may be used to simultaneously sample a number of inputs and be multiplexed into an A to D converter. The A-400 is mounted on a double height double width board. Therefore, the unit requires 4 card slots (2 x 2).

| | |
|--------------------------------------|------------------------------------|
| TRACK TIME TO 0.025%: | 12 μ sec |
| APERTURE: | Less than 150 nanosec |
| DROOP: | Less than 1 volt/sec |
| GAIN: | 1.000 (Adjustable to 0.025%) |
| INPUT IMPEDANCE: | 10K Ω \pm 0.1% (AT) |
| FULL SCALE INPUT: | \pm 10 Volts |
| OUTPUT CURRENT: | 10 MA |
| TEMPERATURE COEFFICIENT (IN SAMPLE): | 20 μ volt/ $^{\circ}$ C Offset |
| TEMPERATURE COEFFICIENT (IN HOLD): | 0.10 Volt/Sec/ $^{\circ}$ C |
| POWER REQUIREMENTS: | \pm 15 Volts/50 MA |

| | |
|-----------------|----------|
| A400 | \$330.00 |
| Optional Offset | 50.00 |

COMPARATOR TYPE A502

A SERIES



The A502 Comparator is a high speed difference amplifier which compares two input voltages and indicates which of the two is the more negative. The comparator has a resolution of 1 mv, and an input range of 0 to $-10v$. The maximum combined error due to a change in the common input voltage from 0 to $-10v$ and a $20^{\circ}C$ temperature change is 5 mv equivalent input offset. Two potentiometers allow adjustment of the zero set and common balance.

As seen in the module diagram, when the input polarity of pins N and P are $-$ and $+$, respectively, then the output polarity of pins F and V are $+$ and $-$, respectively.

The comparator switching time is less than 250 nsec for a ± 10 mv square wave. The switching time is also less than 250 nsec when one input is at $-5.00v$ and the other is switched from ground to $-5.02v$. For finer resolution, the switching time is increased. When the comparator is driven from a high impedance, fast switching source, such as a digital-to-analog converter, time should also be allowed for

transients to settle. The analog-digital conversion application notes show illustrations of various combinations of divider networks and comparators in typical converter applications.

INPUT: 0 to $-10v$. The input draws up to $1 \mu a$, depending on the relative polarity of the two voltage inputs. The maximum current difference between positive and negative input voltages is $1 \mu a$. The difference input capacitance is 75 pf.

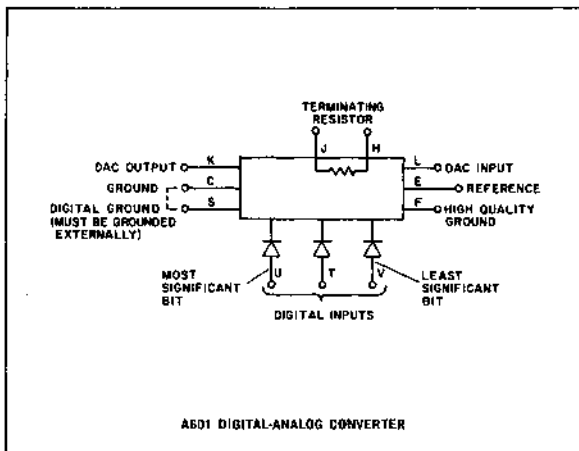
OUTPUT: The outputs produce standard levels of ground and $-3 v$. Each output will supply 5 ma (2 ma at maximum speed) at ground, and 14 ma (2 ma at maximum speed) at $-3 v$.

POWER: $+10 v(A)/21$ ma; $-15 v(B)/55$ ma.

NOTE: See "WIRING" section of reference supplies data sheet.

DIGITAL-ANALOG CONVERSION MODULE TYPE A601

**A
SERIES**



The A601 is a three-bit digital-to-analog conversion module utilizing a star-type divider network and three precision germanium-transistor level amplifiers. It may be connected in series with other converters to form higher resolution converters. The accuracy of the A601 is suitable for up to eight bits of conversion. For higher resolution, it should be combined with the Types A604 and A605.

ACCURACY*: $\pm 0.25\%$ of expected value or ± 0.5 mv, whichever is greater

TEMPERATURE COEFFICIENT: ± 100 ppm/ $^{\circ}$ C max from $+10^{\circ}$ C to $+45^{\circ}$ C

OUTPUT IMPEDANCE: 1000 ohms $\pm 0.1\%$

SWITCHING TIME: 300 nsec

SETTLING TIME: The settling time is determined by the capacitive loading at the output. Approximately 10 nsec/pf should be allowed in addition to the switching time.

DIGITAL INPUT: DEC standard levels. A -3 v input signal at all digital inputs produces ground out. The input load is 1 ma at ground. If all inputs are not required, the most significant inputs should be used, and the least significant ones should be left open

circuited. **Converter Input**—The converter input may be driven from the converter output of another module in order to provide higher resolution. If not driven from another unit, it should be terminated with 1000 ohms to ground. A termination resistor is included in the module. **Reference Input**—The reference input requires a -15 ma DEC Type A702 or A704 Supply. The supply should be adjusted to approximately -10.01 v to overcome the saturation resistance in the level amplifiers. **High Quality Ground**—This is the ground return for the reference supply and should be connected to the supply terminal and eventually to chassis ground at a noise-free location.

OUTPUT: The output is the analog equivalent of the digital input. The most positive output is 0v. The most negative output is -10 v less the value of the least significant bit. The output impedance is 1000 ohms. If a bipolar or reduced output swing is required, the output may be loaded with 1000 ohms or more without affecting the accuracy.

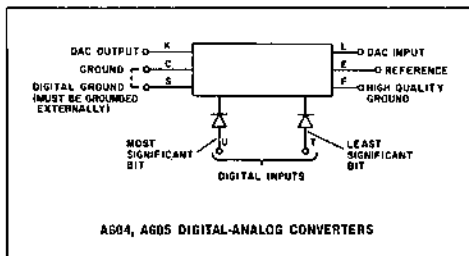
POWER: $+10$ v/1 ma; -15 v/40 ma; -10 v/ref -9 ma.

* At 25° C includes tolerance of ± 1.5 v on the $+10$ v and -15 v power supplies.

See **CAUTION** on A606 specifications.

DIGITAL-ANALOG CONVERSION MODULES TYPE A604, 605

A SERIES



The A604 and A605 are two-bit digital-to-analog conversion modules for use with the A601 in forming high resolution, high accuracy converters. Inputs

and outputs are identical to the A601 except that a terminating resistor is not included. Germanium transistors are used.

| | A604 | A605 |
|--------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| ACCURACY:* | $\pm 0.025\%$ of expected value or ± 0.25 mv whichever is greater | $\pm 0.005\%$ of expected value or ± 0.05 mv. whichever is greater |
| TEMPERATURE COEFFICIENT: | ± 25 ppm/ $^{\circ}\text{C}$ (from $+10^{\circ}\text{C}$ to $+45^{\circ}\text{C}$) | ± 10 ppm/ $^{\circ}\text{C}$ (from $+10^{\circ}\text{C}$ to $+45^{\circ}\text{C}$) |
| OUTPUT IMPEDANCE: | 1000 ohms $\pm 0.1\%$ | 1000 ohms $\pm 0.01\%$ |
| SWITCHING TIME: | 300 nsec | 1.5 μsec |

* At 25°C includes tolerances of ± 1.5 v on the $+10$ v and -15 v supplies.

SETTLING TIME: The settling time is determined by the capacitive loading at the output. Approximately

10 nsec/pf should be allowed in addition to the switching time.

The following combinations of modules are recommended.

| Resolutions (bits) | % of Full Scale | Analog Accuracy (% of Full Scale) | Units (quantity-type) |
|--------------------|------------------|-----------------------------------|------------------------|
| up to 8 | down to 0.39% | 0.25% | 3-A601 |
| 9-10 | 0.195% to 0.098% | 0.082% | 1-A604, 3-A601 |
| 11 | 0.049% | 0.038% | 2-A604, 3-A601 |
| 12 | 0.024% | 0.014% | 1-A605, 2-A604, 2-A601 |
| 13 | 0.012% | 0.01% | 2-A605, 2-A604, 2-A601 |

These modules have been factory aligned; however, for maximum accuracy, the assembled system should be calibrated as a whole. Offset compensation has been made for standard digital-to-analog conversion. Additional offset may be added for analog-to-digital conversion.

Note: See "WIRING" section of reference supplies data sheet.

POWER: A604: $+10$ v/1 ma; $+15$ v/30 ma; -10 v ref/ -10 ma. A605: $+10$ v A/1 ma; -15 v/30 ma; -10 v ref/ -9 ma.

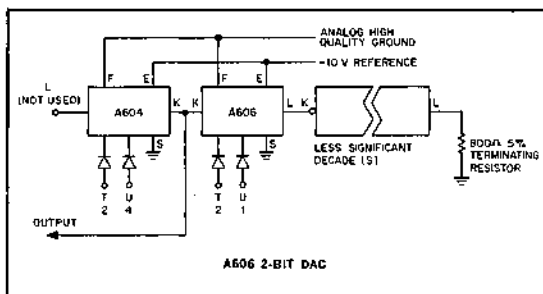
See **CAUTION** on A606 specifications.

A604 — \$62.00

A605 — \$78.00

DIGITAL-ANALOG CONVERSION MODULE TYPE A606

A SERIES



TRUTH TABLE:

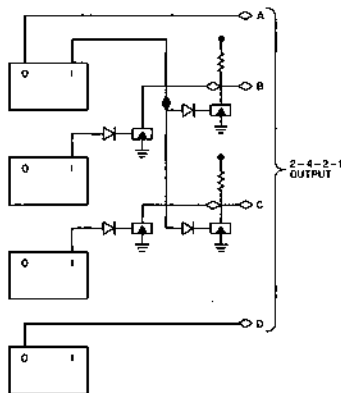
| Decimal Number | | | | | A | B | C | D |
|----------------|---|---|---|---|---|---|---|---|
| | B | 4 | 2 | 1 | 2 | 4 | 2 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| 3 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 4 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 5 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| 6 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 7 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |
| 8 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 9 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |

This module is similar to the A604 but with different values of ladder resistors. It is designed to be used in conjunction with an A604 to form one decade of BCD Digital to Analog conversion. The digital inputs of the decade must be 2-4-2-1 weighing (a conversion scheme from an 8-4-2-1 flip-flop register to a satisfactory 2-4-2-1 code is shown). Overall accuracy and other characteristics are the same as for A604, except as shown in the logic diagram.

POWER: +10v(A)/1.0 ma; -15v/30 ma; +10v ref./-9 ma.

CAUTION

Care should be taken when using power supplies with separate +10v and -15v on-off controls. If this is the case, the -15v must be turned off first and on last; otherwise, damage to the DACs may result.



8-4-2-1 FLIP FLOP REGISTER

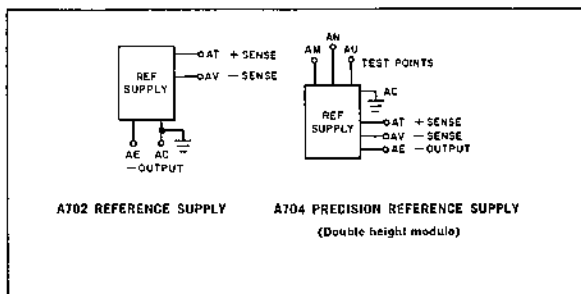
A606 — \$62.00

REFERENCE SUPPLIES

TYPES A702, A704

A

SERIES



| Module Type | Output | Current | Temperature Coefficient | Regulation | Ripple Peak to Peak |
|-------------|--------|----------------------------|---------------------------------------------------|------------------------------|---------------------|
| A702 | -10 v | ± 60 ma | 1 mv/°C | 30 mv, no load to full load | 10 mv |
| A704 | -10 v | -90 to +40 ^o ma | 1 mv/8 hrs 1 mv/15° to 35°C 4 mv/0° to 50°C | 0.1 mv, no load to full load | 0.1 mv |

| Module Type | Adjustment Resolution | Input Power | Use | Output Impedance |
|-------------|-----------------------|---------------------------------|-----------------------------------------------------------------|------------------|
| A702 | 5 mv | -15 v/100 ma +10 v (B)/10 ma | Load with 500 μ f at load. May also be preloaded if desired | 0.5 ohms |
| A704 | 0.01 mv | -15 ± 2 v/250 ma | See below for sensing and preloading | 0.0025 ohms |

REMOTE SENSING: The input to the regulating circuits of the A704 is connected at sense terminals AT (+) and AV (-). Connection from these points to the load voltage at the most critical location provides maximum regulation at a selected point in a distributed or remote load. When the sense terminals are connected to the load at a relatively distant location, a capacitor of approximately 100 μ f should be connected across the load at the sensing point.

PRELOADING: The supplies may be preloaded to ground or -15v to change the amount of current available in either direction. For driving DEC Digital-Analog Converter modules, -125 ma maximum can be obtained by connecting a 270 $\Omega \pm 5\%$ 1 watt resistor from the -10v pin AE reference output to pin AC ground (A704 only).

PIN CONNECTIONS: The A704 is a double-sized module. The top pin letters are prefixed A.

Wiring: Digital-analog and analog-digital converters perform best when module locations and wiring are optimized. All Digital-Analog Converter modules should be side-by-side, with Type 932 bus strip used to bus pins E and pins F together on all converter modules. In an analog-digital converter, the comparator should be mounted next to the converter module for the bits of most significance. The reference supply module should be mounted nearby, and if the A704 is used, its sense terminals should be wired to pins E and F of the most-significant-bits converter module. The high quality ground must be connected to the common ground only at pin AC of the reference supply module, and this point should also be the common ground for analog inputs to analog-digital converters. Do not mount A-series modules closer than necessary to power supply transformers or other sources of fluctuating electric or magnetic fields.

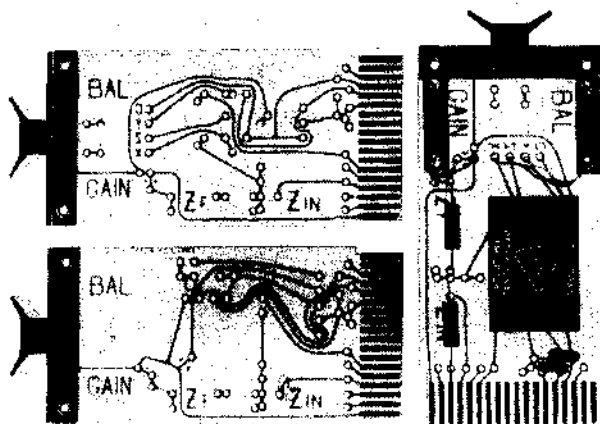
A702 — \$ 58.00
A704 — \$184.00

AMPLIFIER BOARDS

TYPES A990, A992

A

SERIES



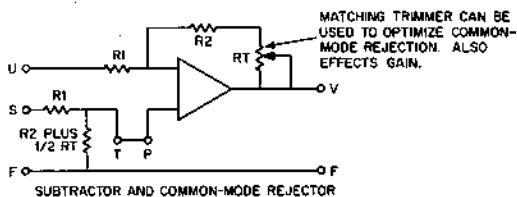
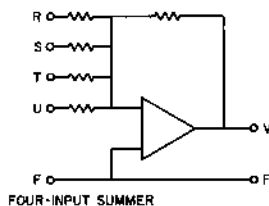
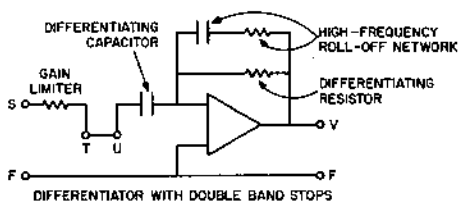
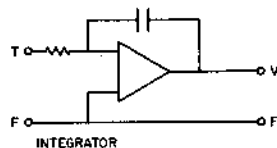
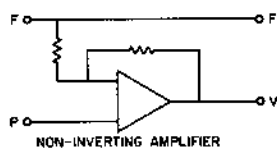
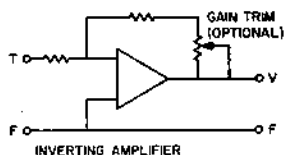
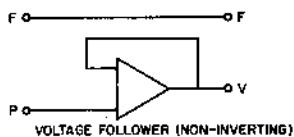
Many types of commercially available operational amplifiers can be mounted in the holes provided on these predrilled etched boards. Mounting holes and printed wires provide for balance trim, gain trim, and feedback networks required to build such common operational devices as voltage followers, inverting or non-inverting amplifiers, integrators, differentiators, summers and subtractors. Most amplifiers listed in the table below require $\pm 15\text{v}$ regulated supplies which are readily available from the amplifier manufacturers. Notable exceptions are Analog Devices' Models 101, 103, and 104 which may be used with standard DEC $+10\text{v}$, -15v supplies at some sacrifice in voltage range ($+5$, -10v) and noise.

POWER: Positive at pin D, negative at pin E, common at pin F for all types. Space is provided for mounting bypass capacitors used with some high frequency amplifiers.

TRIMMING: Mounting holes on $1''$ centers at the handle end accept wirewound potentiometers for balance and feedback (gain) trimming. Gain rheostat may be connected in series with feedback components to allow precise adjustment of gain using inexpensive 1% feedback resistors. Board is etched to allow for use without gain trimming, and one printed conductor must be cut at caret marks to put a rheostat in the circuit. Gain rheostat stray capacitance to ground is driven by amplifier output.

| Amplifier Supplier | Types accepted by A990 | Types accepted by A992 (boosters too) |
|--------------------|------------------------|---------------------------------------|
| Analog Devices | 101, 102, 104, etc. | 103, 106, 107, etc. |
| Burr-Brown* | 1500-46, 1500-68 | — |
| Data Device Corp. | — | most types, except boosters |
| Nexus | Case K or Case L | Case Q |
| Philbrick | — | Case PP |
| Union Carbide | — | most types |
| Zeltex | — | Case A |

*Except Burr-Brown differential output and chopper stabilized types. Perforated board W994 or other blank module may be used to mount non-standard configurations.



PART VI: COMPUTER CATALOG

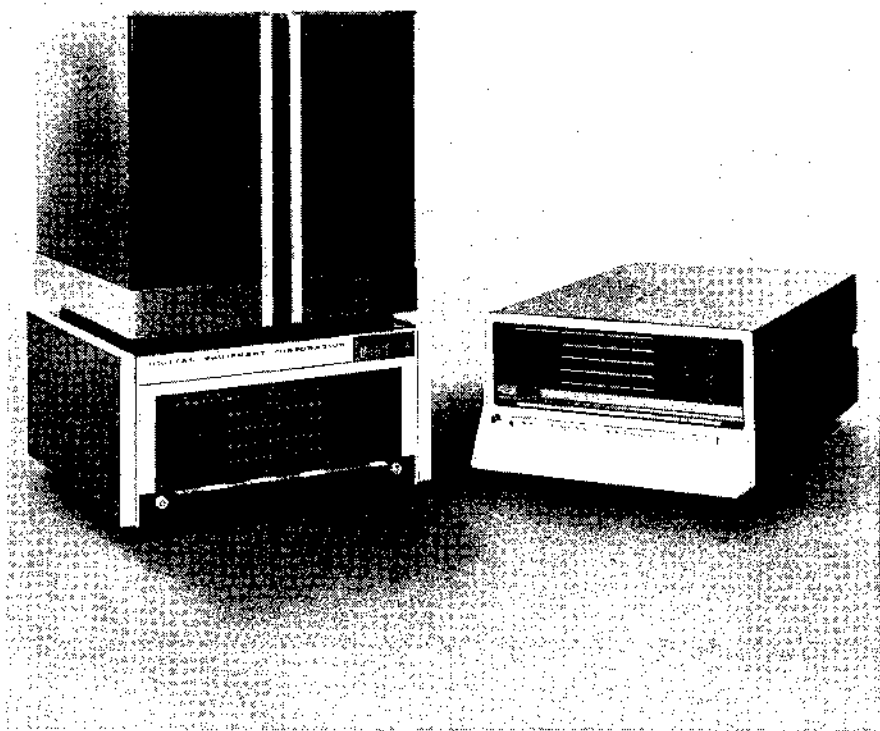


PDP COMPUTERS

PDP general-purpose digital computers are used for a wide variety of data processing and control functions. PDP's are constructed of highly reliable FLIP-CHIP digital circuit modules, and include built-in provisions for marginal checking. The resulting overall reliability has earned PDP's a reputation for trouble-free performance. An exceptionally varied line of input-output devices are available, and versatile facilities are provided in the computers to handle these and other devices.

A complete, well-documented package of programming aids accompanies each PDP computer. The package includes a FORTRAN compiler, a symbolic assembler, on-line debugging routines, an editor, and utility, arithmetic, and maintenance routines. Editing and on-line debugging programs use the same symbolic language as the assembly systems. This means that debugging is carried out in the same language as the program being debugged, eliminating the creation and reassembly of new symbolic tapes each time an error is found.

The arithmetic subroutines include a floating point package. Input-output subroutines are prepared for most of Digital's standard optional devices. Extensive maintenance routines are provided. Supporting these programming aids are free training courses at Digital and membership in DECUS, the Digital Equipment Computer Users Society. DECUS provides a means for users to exchange ideas and programs through regularly scheduled symposia. A library of fully documented programs is maintained.



PDP-8

The PDP-8 is a general-purpose, stored-program computer, featuring a 1.5 microsecond random access core memory, a fast arithmetic processor, and a buffered input-output control. These features combine to make the PDP-8 one of the most popular on-line computers for physics and biomedical analysis and process control. The PDP-8 is also used in large systems as a control element and as a training computer.

The PDP-8 is easy to install, maintain, and use, with comprehensive software, customer-tested in over 500 installations. The basic system includes 4096 words of 12-bit ferrite core memory, keyboard-printer and tape reader-punch, eight auto-index registers, wired-in analog-to-digital converter, program interrupt, data interrupt, and indirect addressing.

A partial list of central processor options includes the Extended Arithmetic Element for high speed, double precision arithmetic; Memory Modules and Control for increasing memory size in increments of 4096 words to 32,768 words; a Data Channel Multiplexer providing direct memory access for seven external devices; and a Serial Drum for storage of 65,536 to 262,144 words.

The applications success of the PDP-8 has led Digital to develop a series of computers based on the PDP-8 to meet a number of special needs, resulting in a unique family of small computer products. These include the DISPLAY 8, the LINC-8, the TYPESETTING-8, the MULTIANALYZER-8, and the new PDP-8/S.

SPECIFICATIONS

Word Length: 12 bits

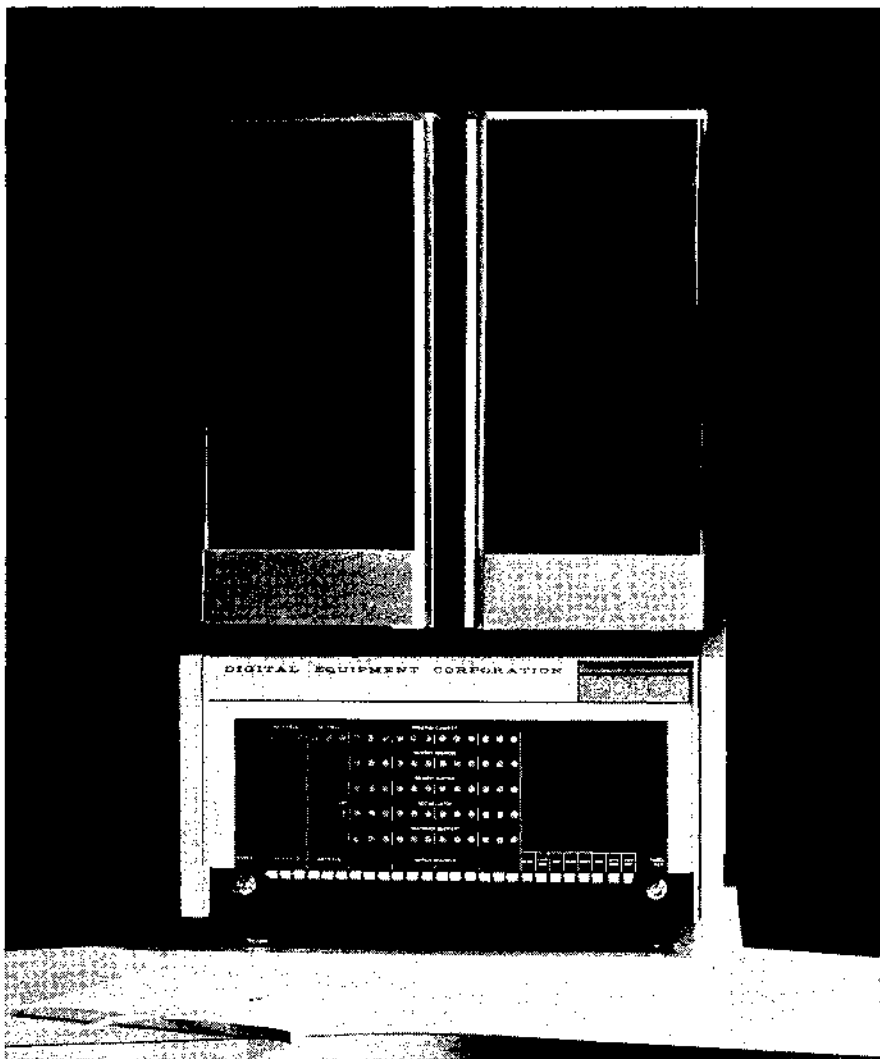
Memory: 4096 to 32,768 words; cycle time 1.5 microseconds

Add Time: 3.0 microseconds

In-Out Transfer Rates: 7,992,000 bits per second

Standard I/O Devices: Printer-keyboard with paper tape punch and reader

Instructions: 49 with standard equipment, expandable to over 100 as optional equipment is added



PDP-8/S

The PDP-8/S is the first full-scale, general-purpose, core-memory digital computer selling for under \$10,000; it is designed for data handling and for controlling complex process systems.

The PDP-8/S has the same size memory, the same input/output capabilities, the same extensive set of standard options as the PDP-8. Both use the same software. The difference between the two machines is in speed and physical size. The PDP-8/S adds in 36 microseconds compared with an add time of 3.0 microseconds for the PDP-8. The basic 12-bit-word PDP-8/S features an 8-microsecond, 4096-word, expandable core memory; a comprehensive software package, including FORTRAN; and an ASR-33 Teletype. Although the PDP-8/S combines a fully parallel core memory and input/output facility with a serial arithmetic unit, the machine appears to be fully parallel to the user. Flexible, high capacity, input/output capabilities of the computer operate a variety of peripheral equipment. In addition to the standard teletype and perforated tape equipment, the system can operate in conjunction with most of the optional devices offered in the PDP-8 family line. Equipment of special design is easily adapted for connection into the PDP-8/S system. The computer need not be modified to add peripheral devices.

SPECIFICATIONS

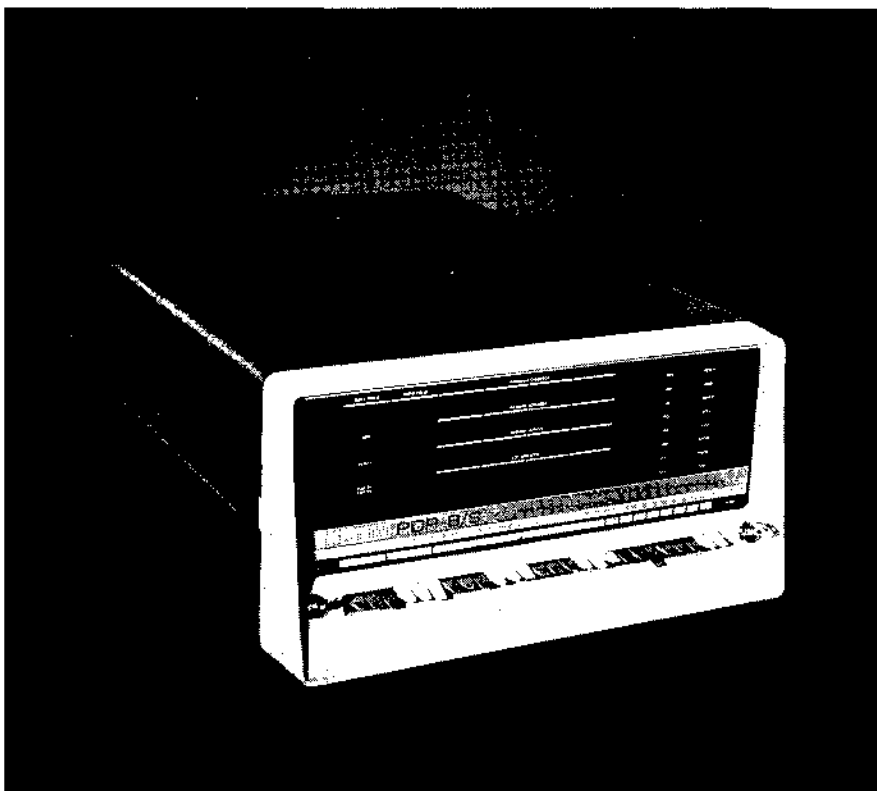
Word Length: 12 bits

Memory: 4096 to 32,768; cycle time 8.0 microseconds

Add Time: 36 microseconds

In-Out Transfer Rate: 1,500,000 bits per second

Standard I/O Devices: Printer-keyboard with paper tape punch and reader



LINC-8

The LINC-8 is a computer-based system designed to control experiments and collect and analyze data in the laboratory. The system combines the features of the PDP-8 and the LINC computers, and allows the researcher to choose between the two programming systems available. The researcher simply uses one of the two consoles in the system. Typical biomedical applications for the new system are: arterial shock wave measurements in-phase triggering of stimuli from EEG alpha waves, processing of single-unit data from the nervous system, EKG processing, and operative conditioning applications.

Other applications for the LINC-8 include research in physics, chemistry, meteorology, oceanography, psychology, radiation, seismology, and acoustics.

The original LINC hardware and software were developed for on-line, real-time laboratory research under grants from the National Institutes of Health and the National Aeronautics and Space Administration. Development began at Massachusetts Institute of Technology and continued at Washington University in St. Louis.

The LINC-8 system includes: a built-in multiplexed analog-to-digital input facility, a relay register, dual digital LINCtape transports, an alphanumeric oscilloscope display and an ASR-33 teletypewriter. The LINC-8 takes advantage of the PDP-8's input/output bus for additional convenience in interfacing other laboratory instrumentation to the LINC-8 system.

With the LINC-8, the researcher has the option of using the LINC software which has been designed to allow the researcher to write his own programs after minimum instruction or he may use the more advanced PDP-8 programming system which includes FORTRAN. The LINC-8 system "talks" with researchers by displaying instructions and results on the oscilloscope display. Displays combine English language with data displays. To familiarize customers with the new system, Digital offers four courses in programming and maintenance of the LINC-8. These are included in the basic system purchase price.



DISPLAY-8

The DISPLAY-8 (Type 338 Programmed Buffered Display) is an integrated cathode-ray-tube system containing its own general-purpose computer. It is capable of precisely displaying points, lines, and characters, and of performing extensive computation using the computer order code and a complete software package.

The computer is a PDP-8. It is fast enough to perform 200,000 additions per second while displaying 300,000 points, 600 inches of vector, or 700 characters flicker free at the same time. The highly flexible character generator produces alphabetic characters or special symbols, similar to those used on electronic circuit schematic, with equal ease.

The 338 can be used as a self-contained display system or as a buffered display station in a large computer system. The 338 can control interfaces to external data sources, such as the central computer in a large system, and can handle real time requests, such as data phone interrupts. The 338 can be programmed to view selected small areas of a large stored drawing: 10 by 10 inch window can be moved randomly about a 6 by 6 foot drawing for detailed examination and modification.

The system contains the following features for general purpose computations: An extensive software package that includes FORTRAN, symbolic assembler, debugging programs, floating point arithmetic, and display maintenance programs; 4096 words of core memory; program interrupt; and keyboard-printer and 10-hertz paper-reader punch. The 338 may be expanded using any standard PDP-8 plug-in units.



PDP-9

The PDP-9 is a stored-program, general-purpose digital computer, designed to handle a variety of on-line and real-time scientific applications calling for more computation power than offered by the PDP-8. The basic PDP-9 features a 2-microsecond add time; 8,192 words of 18 bit (plus optional parity bit) core memory; a real-time clock; a 300-character-per-second paper tape reader; a 50-character-per-second tape punch; and input-output teleprinter (Teletype Model KSR-33). Input/Output can be via programmed transfers, data channel transfers, or direct memory access. The maximum I/O transfer rate is 18,000,000 bits-per-second.

Single address instructions are used, with auto-indexing and one level of indirect addressing permitted. A single memory reference instruction can directly address any location in a block of 8,192 words of memory. PDP-9 has a Direct Memory Access channel plus four built-in Data Channels.

The memory can be expanded in 8,192-word increments to a total of 32,768 words. Mass storage devices, such as DECTape, IBM compatible magnetic tape, disks and drums are available as options for the PDP-9, as are a wide variety of other input-output devices and central-processor additions.

A comprehensive software package including FORTRAN IV, a MACRO Symbolic Assembler, a monitor system, and diagnostic routines is provided with the basic machine. With the modular software package, PDP-9 users can program in a device-independent environment to take full advantage of configurations with mass storage devices and central processor options.

Applications for the PDP-9 include its use in biomedicine, process control, chemical instrumentation, display processing, hybrid systems and data communications. A special configuration, the PDP-9 MULTIANALYZER, has been designed for physics applications.

SPECIFICATIONS

Word Length: 18 bits

Memory: 8,192 to 32,768 words in 8,192 word increments.

Cycle Time: 1.0 microseconds

Add Time: 2 microseconds

In-Out Transfer Rate: Up to 18,000,000 Bits per second

Standard I/O Devices: A 300-character-per-second paper tape reader, a 50-character-per-second paper tape punch and a 10-character-per-second KSR-33 teletype

Options: DECTape, IBM Compatible magnetic tape, drums, CTRS, A/D converters, line printers, card readers, plotters, etc.



PDP-10

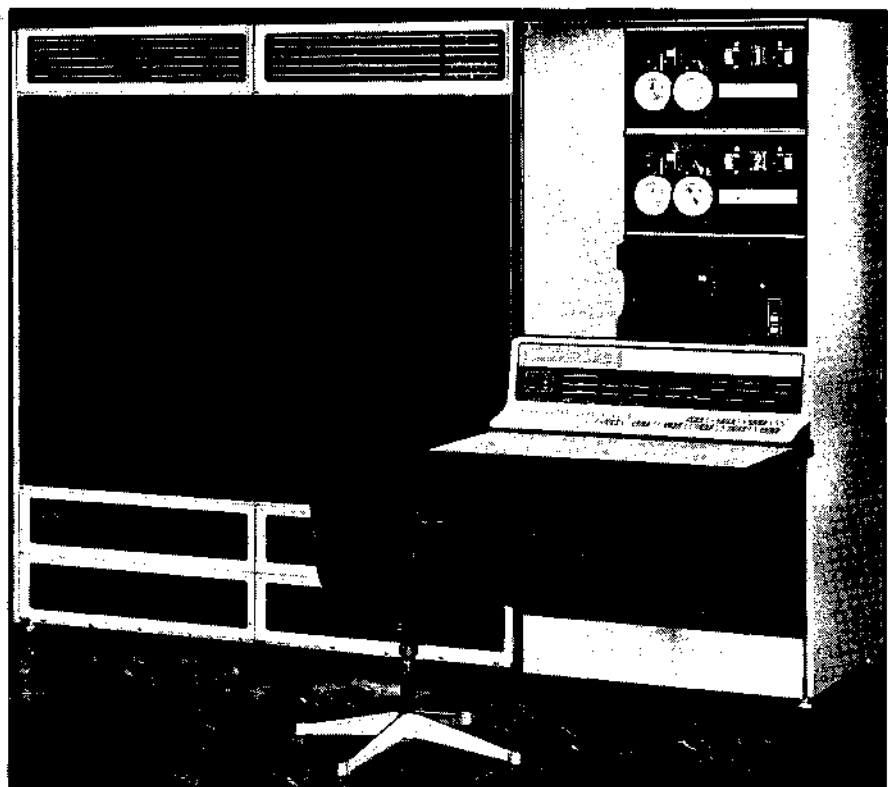
PDP-10 is an expandable, 36-bit computer system available in five configurations (PDP-10/10, 10/20, 10/30, 10/40, and 10/50) and offering optimum power and versatility in the medium price range.

The PDP-10 includes an extremely powerful processor with 15 index registers, 16 accumulators, and 8,192 words of 36-bit core memory, a 300-character-per-second paper tape reader, a 50-character-per-second paper tape punch, a console teleprinter, and a two-level priority interrupt subsystem. PDP-10/20 adds two DECTapes. PDP-10/30 includes 16,384 words of memory and additional I/O devices. PDP-10/40 adds an extended order code and a memory protection and relocation feature. And PDP-10/50 permits swapping between 32,768 words or more of memory and fast access disk file via the multiplexer/selector channel, and includes multiprogramming time-sharing software.

The PDP-10 is designed for on-line and real-time applications such as physics and biomedical research, process control, as a departmental computation facility, in simulation and aerospace, chemical instrumentation, display processing and as a science teaching aid.

The software package includes real-time FORTRAN IV, a control monitor, a macro assembler, a context editor, a symbolic debugging program, an I/O controller, a peripheral interchange program, a desk calculator and library programs. All software systems assure upward compatibility from the standard 8,192 words of memory through the multi-programming and swapping systems at both the symbolic and relocatable binary level.

PDP-10 features a 1-microsecond cycle time, a 2.1-microsecond add time, I/O transfer rates up to 7,200,000 bits per second and a modular, proven software package that expands to make full use of all hardware configurations. Memory can be expanded in 8,192 word increments to the maximum directly addressable 262,144 words.



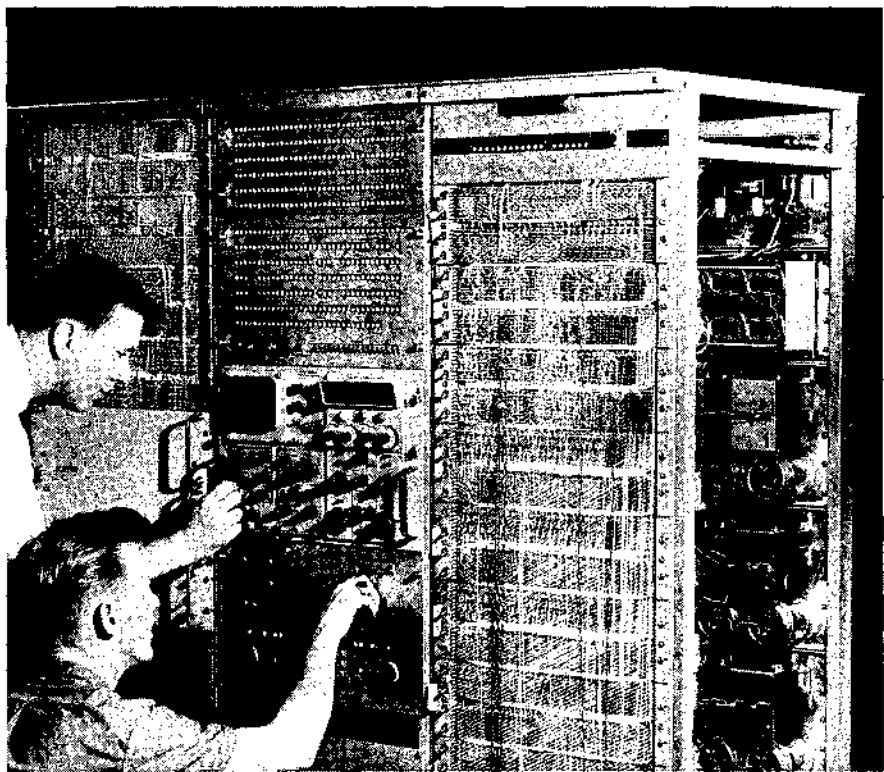
DIGITAL TEST SYSTEMS

DEC designs and manufactures a variety of devices for testing computer components and similar products. The Company uses these products in its own operations and also markets them to a regularly growing list of customers.

DEC memory test products are used by nearly every major manufacturer of core memories (memories such as the ones DEC uses in its computers). This equipment is used to check each stage of the computer memory assembly from the single core to the completed unit.

DEC has recently announced a memory test system, the PMA-8 (Programmable Memory Analyzer-8), which incorporates the PDP-8 as its control element. The speed and versatility of the PMA-8 is a major contribution to the memory testing field.

Automatic Module Testers are another Digital Test System product. Equipment such as the tester shown in the photo, is used by DEC and other companies who manufacture large quantities of their own modules to perform functional tests on completed modules. The tester controlled by a PDP computer, can perform from 10 to 100 different static and dynamic tests on a module in one second.



INPUT-OUTPUT OPTIONS

MAGNETIC TAPE EQUIPMENT

DEctape, a unique fixed address magnetic tape system, allows on-line program debugging or high speed loading and readout. Density is 375 ± 60 bpi; tape speed is 80 ips with a 15 kc character rate. Reads and writes in both directions; redundant tracks allow less than one transient error in 10^{10} characters. Total storage, the equivalent of 4000 feet of perforated tape, is three million bits per reel.

Other magnetic tape systems include automatic and programmed controls and high or low density transports. Formats are IBM compatible at recording densities of 200, 556, and 800 bpi. Transfer rates range from 15 to 90 thousand characters per second. Transports include an electro-pneumatic design of high performance and low tape stress and wear.

MAGNETIC DRUM SYSTEMS

Drums provide auxiliary mass storage with direct access to memory. Sizes range from a 32,768 word drum to 262,144 words.

DISPLAY AND PLOTTING EQUIPMENT

Precision and incremental cathode ray tube displays convert digital data into graphic and tabular form. Light Pen detects plotted points to initiate computer action; Symbol Generator plots alphanumeric or special symbols in four sizes on scope face. Incremental Plotters give hard-copy graphs and histograms.

PRINTERS

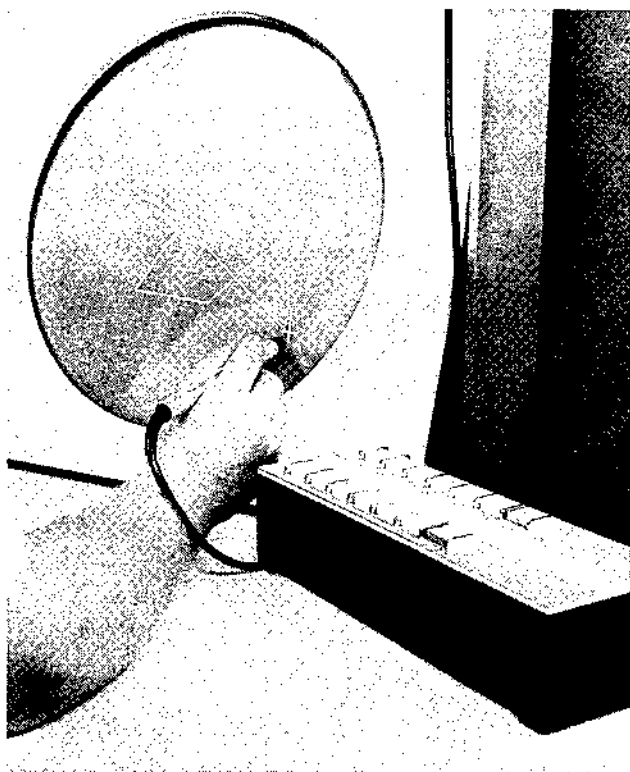
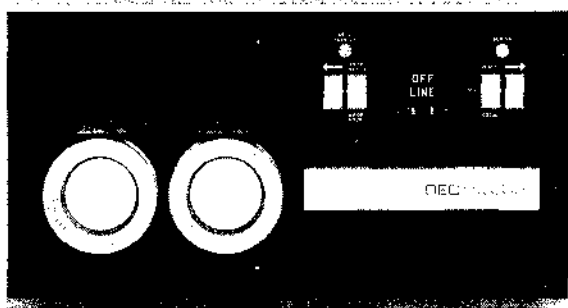
Automatic line printers produce hard-copy output data from 300 to 1000 lines per minute with 120 or 132 column lines and any of 64 characters per column. Teleprinters permit on-line inputs and outputs from the computer console or remote stations at 10 characters per second. Character sets are ASCII.

ANALOG-DIGITAL CONVERTERS

General purpose analog to digital converters offer seven front-panel selections of speed and word length. Maximum speed: 6 bits 1.6%, 9 microseconds. Maximum accuracy: 12 bits 0.025% 35 microseconds. Digital-to-analog equipment has maximum conversion time to an accuracy of one least significant bit of $2 \mu\text{sec}$. Speeds may be limited by the repetition rate of the associated equipment.

PERFORATED TAPE AND CARD EQUIPMENT

Paper tape punches operate at 10 to 63 characters per second; readers at 10,300, and 400. Card punch controls permit operation at 100 or 300 cards per minute; card readers at 100, 200, or 800.



APPENDIX 1

MIL-STD-806B AND DEC SYMBOL COMPARISON

This comparison of MIL-STD and DEC Symbology relates MIL-STD symbols to the DEC logical equivalents or combination of equivalents which perform the same function. Designations of high (H) and low (L) are used instead of "1's" and "0's" to avoid the problem of positive and negative assertion.

DEC R-series FLIP-CHIP modules also are related to the appropriate MIL-STD equivalent. In cases where many input gates are provided (such as flip-flops), only a few of the many methods of input connections are illustrated. Output triggering of flip-flops is not shown, but is one of the possible methods of clearing and setting.

MIL-STD-806B gating symbols use a small circle(s) at the input(s) of the logic element to indicate that a relatively low (L) input signal activates the function. The absence of a circle indicates that a relatively high (H) signal activates the function. The presence or absence of a circle at the output of an element indicates that the output is low (L) or high (H) respectively in the activated state.

DEC's high and low level symbology uses this same principle except for a difference in signal indication. A solid diamond (\blacklozenge) indicates DEC's low (L) signal level (-3 volts), whereas open diamond (\diamond) indicates the high (H) signal level (0 volts or ground). Correspondingly, for pulse signals, a solid arrowhead (\blacktriangleright) signifies a negative (low) pulse, and open arrowhead (\triangleright) a positive (high) pulse.

The MIL-STD-806B logic symbols with their DEC equivalents are listed in Table 1. Logically equivalent AND and OR elements for each system with the appropriate Table of Combinations are included.

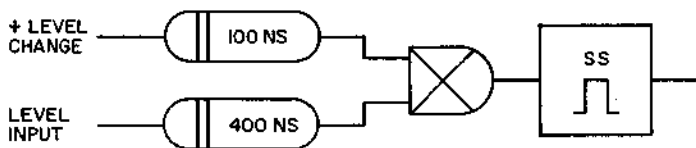
MIL-STD-806B logic symbols, with their DEC counterpart, for flip-flops, one-shot multivibrators, inverters, etc., are illustrated in Table 2. It should be noted that the input connections of the DEC elements correspond to the MIL-STD operation, symbolically described.

In most cases, the DEC element is capable of greater flexibility of operation if maximum use of input/output gating is utilized.

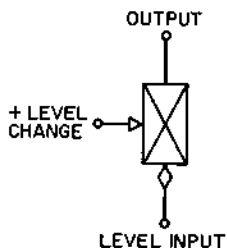
MIL-STD nomenclature for flip-flop inputs is, set (S), clear (reset) (C), and toggle (trigger) (T). DEC terminology is identical except for the "toggle" input which is termed "complement".

R-series module elements are shown in Table 3 with their MIL-STD symbol. For gating functions, two logically equivalent MIL-STD symbols are compared with the appropriate DEC symbol (shown without the polarity indicators). A table of combinations is included in instances where clarification may be necessary.

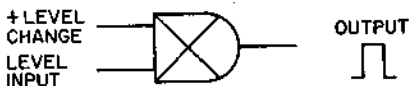
DEC R series flip flops, pulse amplifiers, and one shots use diode-capacitor-diode gates to generate and steer pulses to these elements. Operation of the DCD gate is explained in the R-Series section of the handbook. The DCD gate can be represented by symbols listed in MIL-STD-806B as shown below:



The 400 nanosecond level input represents the set up time of the gate and the + level change delay of 100 nanosecond represents the minimum duration of the positive level. The DEC symbol is:



In order that the unwieldy MIL representation need not be shown in the following representations, a new symbol is defined as being the equivalent of the DCD gate.



The inputs are defined in the positions shown above, regardless of the orientation of the gate.

In cases where a large number of connections may cause confusion, terminal points are letter referenced for both symbologies.

| AND | OR | AND | OR | A B X |
|--------------|----|--------------|----|----------------------------------|
| | | | | H H H H L L L H L L L L |
| | | | | H H L H L L L H H L L L |
| | | | | H H L H L H L H L L L L |
| | | | | H H L H L L L H L L L H |
| | | | | H H H H L H L H H L L L |
| | | | | H H H H L L L H H L L H |
| | | | | H H H H L H L H L L L H |
| | | | | H H L H L H L H H L L H |
| EXCLUSIVE OR | | EXCLUSIVE OR | | |
| | | | | L L L L L H L H L H H H |

TABLE 1. GATING SYMBOL EQUIVALENTS

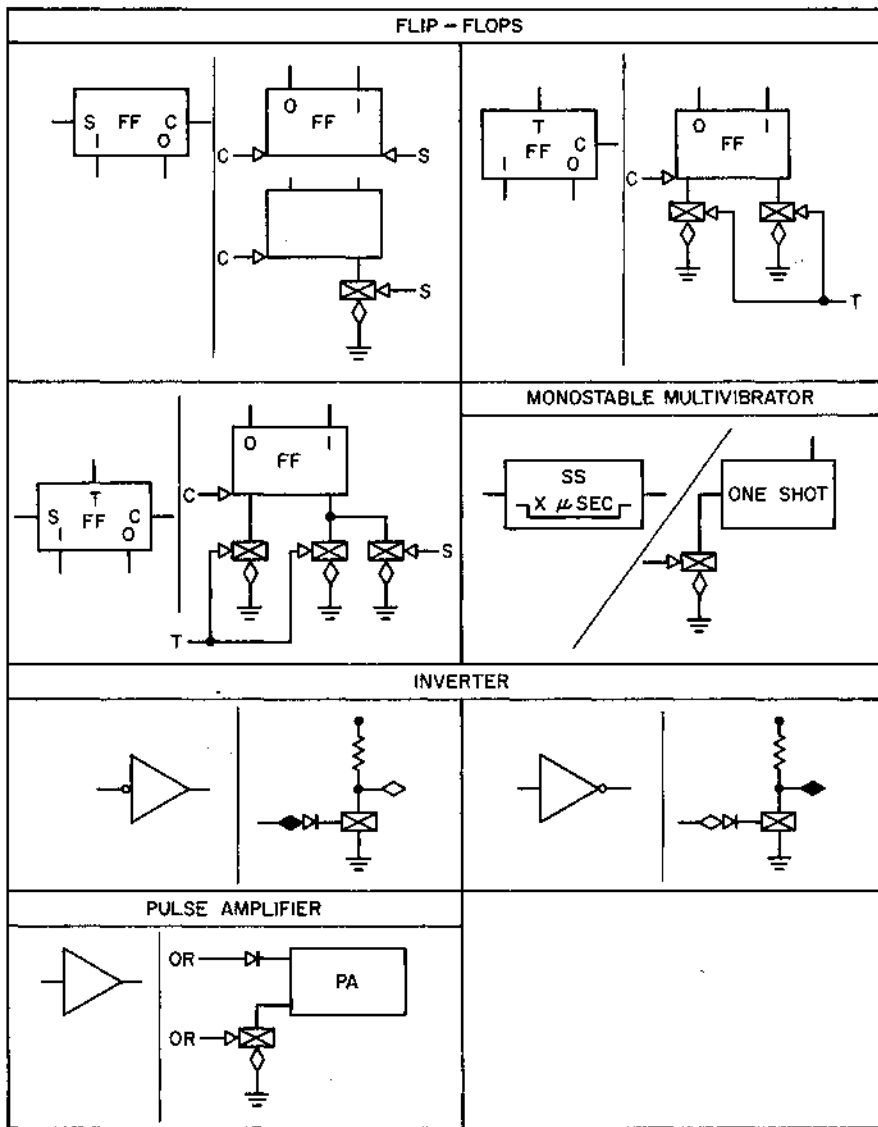


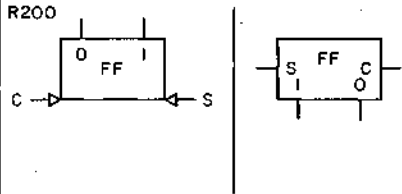
TABLE 2. LOGIC SYMBOL EQUIVALENTS

| TYPE | DEC | MIL-STD-806B | A B C D X |
|--------------------------------------------------|-----|--------------|----------------------------------------------------------------------------|
| R107 INVERTER | | | H L L H |
| R121 NEGATIVE NAND POSITIVE NOR | | | H H L H L H L H L L L H |
| R111 WITH R001 NEGATIVE NAND POSITIVE NOR | | | H H H H L L H H H L L L H H L L L L H L L L L L H E T C |
| R141 NEGATIVE AND / NOR POSITIVE OR / NAND | | | H H H H L L H L H L H L H L L H H L L H L L H H H L L L L H |
| R122 NEGATIVE NOR POSITIVE NAND | | | H H L H L H L H H L L H |

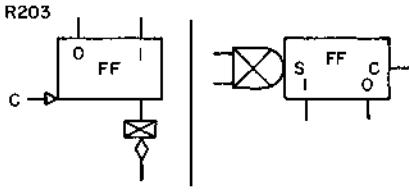
TABLE 3. R-SERIES MODULE SYMBOL EQUIVALENTS

FLIP — FLOPS

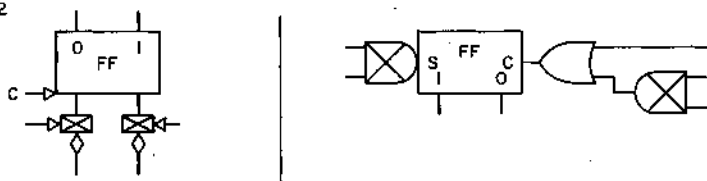
R200



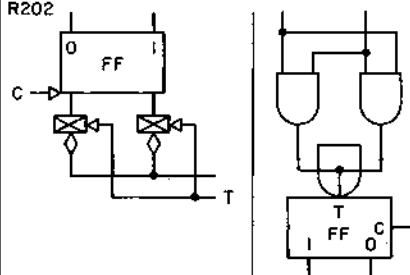
R203



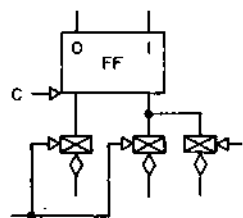
R202



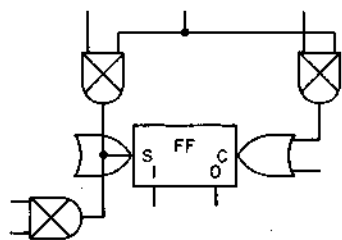
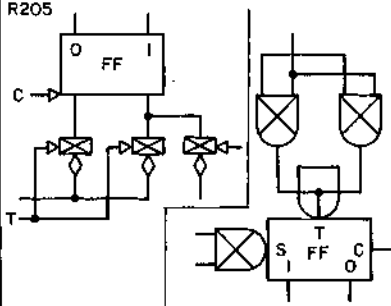
R202



R205

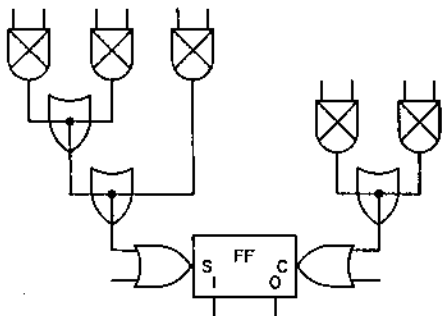
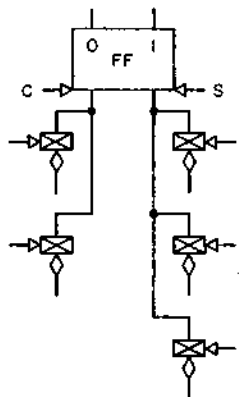


R205

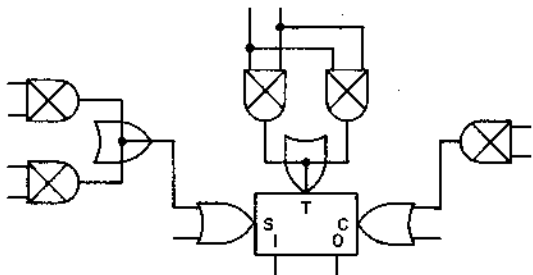
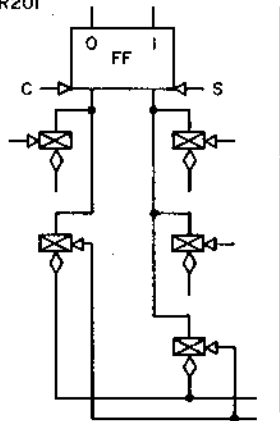


FLIP — FLOPS

R201

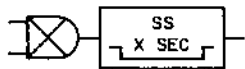
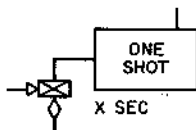


R201



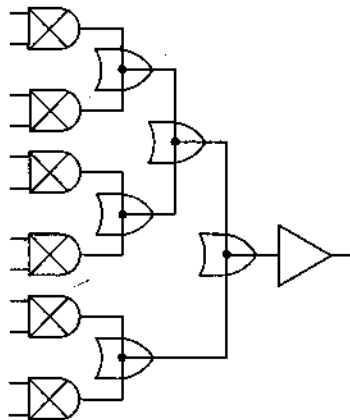
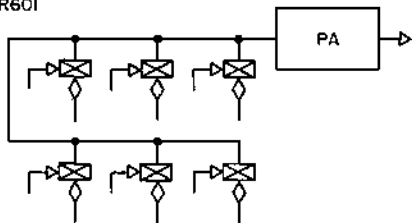
MONOSTABLE MULTIVIBRATOR

R302

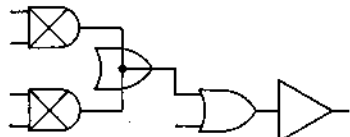
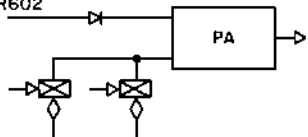


PULSE AMPLIFIERS

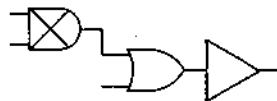
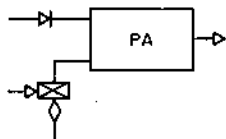
R601



R602

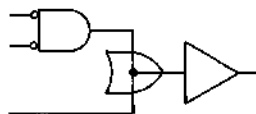
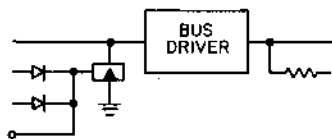


R603



BUS DRIVER

R650



APPENDIX 2 POWERS OF TWO

| 2^n | n | 2^{-n} |
|------------------------|-----|----------------------------------------------------------------------------|
| 1 | 0 | 1.0 |
| 2 | 1 | 0.5 |
| 4 | 2 | 0.25 |
| 8 | 3 | 0.125 |
| 16 | 4 | 0.0625 |
| 32 | 5 | 0.03125 |
| 64 | 6 | 0.015625 |
| 128 | 7 | 0.0078125 |
| 256 | 8 | 0.00390625 |
| 512 | 9 | 0.001953125 |
| 1024 | 10 | 0.0009765625 |
| 2048 | 11 | 0.00048828125 |
| 4096 | 12 | 0.000244140625 |
| 8192 | 13 | 0.0001220703125 |
| 16384 | 14 | 0.00006103515625 |
| 32768 | 15 | 0.000030517578125 |
| 65536 | 16 | 0.0000152587890625 |
| 131072 | 17 | 0.00000762939453125 |
| 262144 | 18 | 0.000003814697265625 |
| 524288 | 19 | 0.0000019073486328125 |
| 1048576 | 20 | 0.00000095367431640625 |
| 2097152 | 21 | 0.000000476837158203125 |
| 4194304 | 22 | 0.0000002384185791015625 |
| 8388608 | 23 | 0.00000011920928955078125 |
| 16777216 | 24 | 0.000000059604644775390625 |
| 33554432 | 25 | 0.0000000298023223876953125 |
| 67108864 | 26 | 0.00000001490116119384765625 |
| 134217728 | 27 | 0.00000000745058096923828125 |
| 268435456 | 28 | 0.0000000037252902984619140625 |
| 536870912 | 29 | 0.00000000186264514923095703125 |
| 1073741824 | 30 | 0.000000000931322574615478515625 |
| 2147483648 | 31 | 0.0000000004656612873072392578125 |
| 4294967296 | 32 | 0.00000000023283064385386962890625 |
| 8589934592 | 33 | 0.00000000011641532182693481453125 |
| 17179869184 | 34 | 0.0000000000582076609134674072265625 |
| 34359738368 | 35 | 0.00000000002910383045673370361328125 |
| 68719476736 | 36 | 0.000000000014551915228366851806640625 |
| 137438953472 | 37 | 0.000000000007275957618189425903203203125 |
| 274877906944 | 38 | 0.00000000000363797880709171295166015625 |
| 549755813888 | 39 | 0.00000000000181898940354585647830078125 |
| 1099511627776 | 40 | 0.0000000000009094947017729282379180390625 |
| 2199023255552 | 41 | 0.00000000000045474735088646411895751953125 |
| 4398046511104 | 42 | 0.000000000000227373675443232059478759765625 |
| 8796093022208 | 43 | 0.000000000000113686837216160297393798828125 |
| 17592186044416 | 44 | 0.0000000000000568434188608081486958894140625 |
| 35184372088832 | 45 | 0.000000000000028421709430404007434844970370125 |
| 70368744177664 | 46 | 0.000000000000014210854712020037174224853515625 |
| 140737488355328 | 47 | 0.00000000000000710542735760100185871124267578125 |
| 281474976710656 | 48 | 0.000000000000003552713678800500929355621337890625 |
| 562949952421312 | 49 | 0.000000000000001776356839400250464577810689453125 |
| 1125899904842524 | 50 | 0.000000000000000888784197001252323899533447265625 |
| 2251799816852448 | 51 | 0.000000000000000444389209859366261616945267236328125 |
| 4503599327370496 | 52 | 0.0000000000000002220446049250312080847263336181640625 |
| 9007199654740992 | 53 | 0.000000000000000111022302462615654042363166809088103125 |
| 18014399309481984 | 54 | 0.00000000000000005551115123125782021181883480541015625 |
| 36028797018363968 | 55 | 0.000000000000000027755575615628913510590791702470578125 |
| 72057594037327936 | 56 | 0.0000000000000000138777878078144567552959585113525930625 |
| 144115188075855872 | 57 | 0.00000000000000000693889390390722837764769792556762693125 |
| 288230376151711744 | 58 | 0.0000000000000000034694469519536141888238489627838134765625 |
| 576460752303423488 | 59 | 0.00000000000000000173472347597680709441132448139190673628125 |
| 1152921504606846976 | 60 | 0.00000000000000000086736173798840354720596224069595369140625 |
| 2305843009213693952 | 61 | 0.0000000000000000004336809689942017736029011203479766845703125 |
| 4611686018427387904 | 62 | 0.0000000000000000002168404344971008868014905601736882428515625 |
| 9223372036854737808 | 63 | 0.00000000000000000010842021724855044340074528088694171142578125 |
| 18446744073709551516 | 64 | 0.000000000000000000054101086242752217003762040434970655712890625 |
| 36893488147411303232 | 65 | 0.0000000000000000000271050543121376110851863202174854278564453125 |
| 73786976294838206464 | 66 | 0.00000000000000000001355525715606880542596316001078271392822265625 |
| 14757395258976412928 | 67 | 0.00000000000000000000677626357803402718456805054371366964111328125 |
| 295147905179352825856 | 68 | 0.00000000000000000000338813178901720135627329000271886784020556640625 |
| 590295810358705651712 | 69 | 0.0000000000000000000016940658945086007813664500135928924102783203125 |
| 1180591620717411303424 | 70 | 0.0000000000000000000008470328472543903390683225006794419620513916315625 |
| 2361183241434822606848 | 71 | 0.0000000000000000000004235164732715016953416125033982098102568580078125 |
| 4722366482869645213696 | 72 | 0.000000000000000000000211758236813575084767608625169910490512847900390625 |

APPENDIX 3

ABBREVIATIONS

Frequency

Hz = Hertz = cycles per second
KHz = 10^3 Hertz
MHz = 10^6 Hertz

Time

msec = millisecond = 10^{-3} second
 μ sec = microsecond = 10^{-6} second
nsec = nanosecond = 10^{-9} second

Current

amp = ampere
ma = milliampere = 10^{-3} ampere
 μ a = microampere = 10^{-6} ampere
na = nanoampere = 10^{-9} ampere

Voltage

v = volt
mv = millivolt = 10^{-3} volt
 μ v = microvolt = 10^{-6} volt

Resistance

K = kilohm = 10^3 ohms
meg = megohm = 10^6 ohm

Capacitance

μ f = microfarad = 10^{-6} farad
nf = nanofarad = 10^{-9} farad
pf = picofarad = 10^{-12} farad

Other

ac = alternating current
BD = bus driver
CD = capacitor-diode
D = delay
dc = direct current
DCD = diode-capacitor-diode
DEC = Digital Equipment Corporation
FF = flip-flop
LA = level amplifier
MP = mounting panel
PA = pulse amplifier
PG = pulse generator
P-P = peak to peak
PS = power supply

APPENDIX 4

DEFINITIONS

TIMING DEFINITIONS

Level Delay Time is the time delay between the point of 10% input change and the point of 10% output change in a given circuit. The input is assumed to be the output of a flip-flop of the same frequency series as the circuit under discussion, or a level change with similar characteristics. This is also referred to as delay for output fall or delay for output rise.

Pulse Delay Time is the time delay between the point of 10% input change and the point of 10% output change in a given circuit, when the input is a standard pulse of the same frequency line as the circuit under discussion.

Propagation Delay is the average signal delay per stage for many similar circuits connected in cascade.

Rise Time and Fall Time are the time delay between the 10% and 90% points of a voltage change.

Total Transition Time is the time delay between the point of 10% input change and the point of 90% output change in a given circuit. It is the sum of delay time and rise (or fall) time. Rise TTT is total transition time for rising output. Fall TTT is total transition time for falling output.

Set-up Time is the time required for a diode-capacitor-diode gate to open or close after a change of input level. This time is measured from the point of 10% input change.

APPENDIX 5

BIBLIOGRAPHY OF DIGITAL LOGIC

INTRODUCTORY BOOKS

A large number of books are currently becoming available on the principles of digital computers and digital logic. The following four are particularly well written and concise. They are on a level which would be suitable for an undergraduate course, an industrial training course, or for self-study. Only a knowledge of algebra, trigonometry and basic electronics is assumed.

Siegel, Paul, **Understanding Digital Computers**
New York: John Wiley & Sons, Inc., 1961.

Discusses logic and arithmetic, components and circuits used in logical building blocks, and the functional units of the digital computer.

Bartee, Thomas C., **Digital Computer Fundamentals**
New York: McGraw-Hill, 1960.

Includes a discussion of computer operations, programming, number systems, basic logical circuits and logical design, and the functional elements of a general purpose computer.

Irwin, Wayne C., **Digital Computer Principles**
Princeton, New Jersey: D. Van Nostrand Company, 1960.

Puts slightly more emphasis on logic and less on circuitry. It includes a discussion of number systems, a brief discussion of the circuitry, timing, and digital arithmetic, as well as Venn diagrams, Karnaugh maps, and Harvard minimizing chart.

Smith, Charles V. L., **Electronic Digital Computers**
New York: McGraw-Hill, 1959.

Discusses digital computer arithmetic, instruction codes, basic logic circuits, and functional elements of computers. It includes a variety of specific examples, principally from the parallel direct-coupled asynchronous machine developed at the Institute for Advanced Study at Aberdeen Proving Ground.

LOGICAL DESIGN

The following texts provide a more theoretical treatment of switching theory and machine design. They are suitable for a fourth year undergraduate course, a first year graduate course, or home study by a practicing design engineer or research scientist. The reader should be familiar with college mathematics and basic electronics.

Bartee, Thomas C., Lebow, Irwin L., and Reed, Irving S., **Theory and Design of Digital Machines** New York: McGraw-Hill, 1962

Combines switching theory and machine design. Including the design of general purpose, special purpose, and sequential machines.

Chu, Yaohan, **Digital Computer Design Fundamentals** New York: McGraw-Hill, 1962

Discusses arithmetic operations in binary, BCD, floating point, and residue numbers. Also describes circuitry, using different types of modern circuit elements. The text leads to the design of a simple computer.

Ledley, Robert S., **Digital Computer and Control Engineering** New York: McGraw-Hill, 1960

A thick book that includes programming, systems design, logic design, and circuit design. A simple computer, Pedagog, is designed from start to finish.

Phister, Montgomery, Jr., **Logical Design of Digital Computers** New York: John Wiley & Sons, Inc., 1958

Develops the design of a computer from boolean equations. It covers all subjects, including circuits, memory, and input output, from a strictly mathematical approach.

Scott, Norman R., **Analog and Digital Computer Technology** New York: McGraw-Hill, 1960

Excellent basic book on principles and applications of analog and digital computers. Analog topics include general approach to problem solving, representation of non-linear functions, and amplifier design. Digital topics covered are problem solving approach (very little on programming), number systems, switching and logic circuits and their design, arithmetic and control circuits, and memory elements. Written for graduate and advanced undergraduate electrical engineers.

REFERENCE WORKS

These books are intended primarily as an aid to the practicing designer. Each section is prepared by a specialist in the field, and contains detailed, concise information.

Grabbe, Ramo and Wooldridge (editors)

Handbook of Automation, Computation and Control

New York: John Wiley & Sons, 1959.

Volume 1 — **Control Fundamentals**. Emphasizes mathematics including sets and relations, Boolean algebra, probability, and statistics, as well as numerical analysis, operations research, and information theory.

Volume 2 — **Computers and Data Processing**. Discusses computer terminology, digital computer programming, the design and use of digital computers, data processors, analog computers, and unusual computer systems. Included in this is a discussion of digital computer circuits, logical design, and techniques for reliability.

Volume 3 — **Systems and Components**. Includes systems engineering, manufacturing process control, chemical process control, and industrial control. The component section treats selection, mathematical description, and integration of components into systems.

Huskey, Harry D., & Korn, Granino A., **Computer Handbook** New York: McGraw-Hill, 1962

Section 1 discusses analog computers including terminology, basic building blocks, design of computer systems, and computer applications. Section 2 deals with digital computers, including definitions, components, circuits, logic design, programming, system design, and applications.

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PRICE LIST

EFFECTIVE APRIL 1, 1967

R SERIES

| | | | |
|-------|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| *R001 | DIODE NETWORK | Seven diodes for adding inputs to gates and flip-flops. | \$ 4.00 |
| *R002 | DIODE NETWORK | Five 2-input diode networks; OR for ground AND for negative signals, when connected to diode-gate node points. | \$ 5.00 |
| *R107 | INVERTER | Seven one-input diode gates. One inverter also has node input. | \$ 24.00 |
| *R111 | EXPANDABLE NAND/NOR GATE | Three 2-input diode-transistor gates. NOR's for ground and NAND's for negative inputs. Node terminal provided for additional inputs. | \$ 14.00 |
| R113 | NAND/NOR GATE | Five 2-input diode transistor gates. NOR's for ground and NAND's for negative inputs. | \$ 20.00 |
| *R121 | NAND/NOR GATE | Four R111-type gates with loads internally connected and without nodes. | \$ 17.00 |
| *R122 | NOR/NAND GATE | Logical complement of R121, but somewhat slower. One ma input and 18 ma outputs like R121. | \$ 26.00 |
| R123 | INPUT BUS GATE | Six two-input R111-type gates without loads or nodes. Each gate shares one input with another. | \$ 19.00 |
| R131 | EXCLUSIVE OR | Four gates which perform exclusive OR function. | \$ 35.00 |
| *R141 | AND/NOR GATE | Seven 2-input gates. OR's NAND'ed together for ground inputs; AND's NOR'ed together for negative inputs. | \$ 13.00 |
| *R151 | OCTAL DECODER | One of eight outputs is grounded for each combination of states in three pairs of complementary inputs. | \$ 33.00 |
| R181 | DC CARRY CHAIN | Six cascaded AND gates for counting without carry delay. | \$ 35.00 |
| *R200 | FLIP-FLOP | Two-transistor flip-flop is set or cleared from its own outputs or direct set and clear inputs. Operates at up to 2 megacycles. | \$ 9.50 |
| *R201 | FLIP-FLOP | Flip-Flop with direct set and clear inputs and five diode capacitor-diode gates. Can be set or cleared from its outputs. | \$ 22.00 |
| *R202 | DUAL FLIP-FLOP | Two flip-flops, each with clear input and two diode-capacitor-diode input gates. Can be set or cleared from its outputs. | \$ 25.00 |
| *R203 | TRIPLE FLIP-FLOP | Three flip-flops, each with direct clear input and diode-capacitor-diode gate. Can be set or cleared from its outputs. | \$ 28.00 |
| *R204 | QUADRUPLE FLIP-FLOP | Four flip-flops, each with direct clear and set inputs. Two flip-flops share each direct-clear input. Can be set or cleared from its outputs. | \$ 28.00 |
| *R205 | DUAL FLIP-FLOP | Two flip-flops with common clear and each having three diode-capacitor-diode gates. Can be set or cleared from its outputs. | \$ 29.00 |
| *R302 | DELAY | Two one-shot multivibrators triggered by capacitor-diode gates. Independent delays controlled internally or externally. | \$ 44.00 |
| R303 | INTEGRATING ONE SHOT | Zero recovery time multivibrator with complementary output buffers. Delays controlled externally or internally. | \$ 45.00 |
| *R401 | VARIABLE CLOCK | | \$ 45.00 |
| *R405 | CRYSTAL CLOCK | | \$100.00 |
| R601 | PULSE AMPLIFIER | Pulse amplifier and six capacitor-diode input gates. Driven by 40 to 100-nanosecond, positive-going pulses at up to 2 megacycles or 400-nanosecond pulses at up to 1 megacycle. | \$ 25.00 |
| *R602 | PULSE AMPLIFIER | Two pulse amplifiers, each with two diode-capacitor-diode gates and one ungated input. Input frequency up to 2 megacycles. | \$ 22.00 |

*Normal Delivery off-the-shelf.

**2mc only off-the-shelf delivery.

R SERIES (Cont.)

| | | | |
|-------|-----------------|-------------------------------------------------------------------------------------------------------------------------------|----------|
| *R603 | PULSE AMPLIFIER | Three pulse amplifiers, each with one diode-capacitor-diode gate and one ungated input. Input frequency up to 2 megacycles. | \$ 28.00 |
| *R650 | BUS DRIVER | Two inverting bus drivers, each with 2-input NOR or NAND diode-transistor gate. Node terminal provided for additional inputs. | \$ 23.00 |

W SERIES (Cont.)

| | | | |
|---------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| *W002 | CLAMPED LOAD | Fifteen 2-milliampere clamped loads. | \$ 13.00 |
| *W005 | CLAMPED LOAD | Fifteen 5-milliampere clamped loads. | \$ 15.00 |
| W018 | CONNECTOR MODULE | For 18-line, ribbon-cable connections. For each foot of cable or fraction. | \$ 18.00 \$.60 |
| W018U | CONNECTOR MODULE | Without cable. | \$ 9.00 |
| W021-R | CONNECTOR MODULE | For 9 direct ribbon-cable connections: For each foot of cable, or fraction: | \$ 13.00 \$.60 |
| W021-RU | CONNECTOR MODULE | Without cable. | \$ 4.00 |
| W021-C | CONNECTOR MODULE | For 9 direct co-axial connections: For each foot of cable, or fraction: | \$ 31.00 \$ 1.50 |
| W021-CU | CONNECTOR MODULE | Without cable. | \$ 4.50 |
| W022-R | CONNECTOR MODULE | For 9 terminated ribbon connections: For each foot of cable, or fraction: | \$ 13.50 \$.60 |
| W022-RU | CONNECTOR MODULE | Without cable. | \$ 4.50 |
| W022-C | CONNECTOR MODULE | For 9 terminated co-ax connections: For each foot of cable, or fraction: | \$ 33.00 \$ 1.50 |
| W022-CU | CONNECTOR MODULE | Without cable. | \$ 6.50 |
| W023 | CONNECTOR MODULE | For 18-line, ribbon-cable connections. For each foot of cable or fraction. | \$ 13.00 \$.60 |
| W023U | CONNECTOR MODULE | Without cable. | \$ 4.00 |
| W028-R | CONNECTOR MODULE | For 9 jumperable ribbon connections: For each foot of cable, or fraction: | \$ 13.00 \$.60 |
| W028-RU | CONNECTOR MODULE | Without cable. | \$ 4.00 |
| W028-C | CONNECTOR MODULE | For 9 jumperable co-ax connections: For each foot of cable, or fraction: | \$ 31.00 \$ 1.50 |
| W028-CU | CONNECTOR MODULE | Without cable. | \$ 4.50 |
| *W040 | SOLENOID DRIVER | Two high-current-drive amplifiers, each with a diode NOR or NAND gate. Node terminal provided for additional inputs. | \$ 36.00 |
| W042 | 10 AMP DRIVER | Four germanium transistor drivers which can provide up to 10 amps of DC drive. | \$ 80.00 |
| W043 | SOLENOID DRIVER | Two high-current-drive amplifiers, each with a diode NOR or NAND gate. Node terminal provided for additional inputs. | \$ 35.00 |
| *W050 | INDICATOR DRIVER | Seven amplifiers for miniature, incandescent indicators. | \$ 13.00 |
| W051 | 100ma DRIVER | Seven higher-current circuits. | \$ 22.00 |
| W061 | RELAY DRIVER | Four quarter-amp, 55 volt, all-silicon drivers for loads returned to positive voltage. | \$ 35.00 |
| W080 | ISOLATED AC-DC SWITCH | Two floating switches controlled by light beams. Allows isolated control of line-operated devices. One-quarter amp at 125v AC or DC. | \$ 60.00 |

*Normal Delivery off-the-shelf.

W SERIES (Cont.)

| | | | |
|-------|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| W103 | DEVICE SELECTOR | For PDP-8. | \$ 52.00 |
| W108 | DECODING DRIVER | 300-ma, bipolar drive with 8 drivers. | \$ 75.00 |
| W500 | HIGH IMPEDANCE FOLLOWER | Seven fault-protected circuits, each comprising two cascaded emitter-follower amplifiers. Up to $\pm 30v$ in. | \$ 25.00 |
| *W501 | LEVEL CONVERTER AND SCHMITT TRIGGER | Produces standard pulses from contact closures or non-standard negative logic levels. Switching thresholds can be 0 to 2.5 volts. Contact-bounce integrator included. | \$ 13.00 |
| W502 | PHOTON COUPLED TRIGGER | Two isolated trigger circuits; each responds to light from tungsten filament falling on a photocell. Inputs 14v or 48v. | \$ 38.00 |
| *W510 | POSITIVE LEVEL CONVERTER | Three inverters with input thresholds which can be set at 0, +1v, or +2v. | \$ 17.00 |
| *W511 | NEGATIVE LEVEL CONVERTER | Two circuits for converting inputs between -50 volts and +25 volts to 3 volt levels. Switching point can be set to 0, 1, -2, or -3 volts. | \$ 17.00 |
| W512 | POSITIVE LEVEL CONVERTER | W and A Series Interface for Positive Logic Systems. | \$ 25.00 |
| W520 | COMPARATOR | An inexpensive comparator for A/D work, or a general purpose input level converter. Three circuits, each is a 4-transistor difference amplifier, DEC Standard levels at the output. | \$ 43.00 |
| W532 | DUAL AMPLIFIERS | Two AC-coupled differential amplifiers. | \$ 30.00 |
| W533 | DUAL RECTIFYING SLICER | Two slicers that amplifies signals from a W532 and converts them to DEC signal. | \$ 30.00 |
| W590 | IBM N LINE TO DEC CONVERTER | Each of five inverting amplifiers provides inputs compatible with three types of IBM N lines. | \$ 26.00 |
| *W600 | NEGATIVE LEVEL AMPLIFIER | Three diode-transistor inverting amplifiers convert standard levels to outputs of ground and 1 to -15 volts. Node terminals provide for additional inputs. | \$ 12.00 |
| *W601 | POSITIVE LEVEL AMPLIFIER | Three diode-transistor inverting amplifiers convert standard levels to ground and 1 to 20-volt outputs. Additional gates added through node terminals. | \$ 13.00 |
| W602 | BIPOLAR LEVEL AMPLIFIER | Three inverting amplifiers for output levels at +6, +3, 0, -3, or -6 volts. | \$ 40.00 |
| W603 | POSITIVE LEVEL AMPLIFIER | Amplifier drives positive logic systems from FLIP CHIP systems. | \$ 23.00 |
| W607 | PULSE AMPLIFIER | Three pulse amplifiers. Input: 40-nanosecond (or wider) pulses at up to 2.5 megacycles. | \$ 42.00 |
| W640 | PULSE AMPLIFIER | Three standardizing amplifiers with transformer-coupled outputs of 400 nsec at up to 500 kc, or 1 μ sec at up to 200 kc. | \$ 42.00 |
| W690 | DEC TO IBM N LINE CONVERTER | Each of four inverting drivers provides outputs compatible with three types of IBM N lines. | \$ 36.00 |
| W700 | SWITCH FILTER | Six switch filters reduce the effects of contact bounce. | \$ 20.00 |
| W705 | POWER SUPPLY (+3.6v) | Supplies up to 1 amp at +3.6 volts. | \$ 15.00 |
| W706 | TELETYPE RECEIVER | Integrated-circuit, serial-to-parallel Teletype code converter. | \$150.00 |
| W707 | TELETYPE TRANSMITTER | Integrated-circuit, parallel-to-serial Teletype code converter. | \$150.00 |
| W708 | TELETYPE INTERFACER | Provides special gating controls and clock synchronization for Teletype and data communications systems, when used with the W706 and W707. | \$ 55.00 |

*Normal Delivery off-the-shelf.

W SERIES (Cont.)

| | | | |
|-------|---------------------|----------------------------------------------------------------------------------------------|----------|
| W800 | RELAY | Two normally open reed relays for up to 1/8 amp, 200 volts with contact protection provided. | \$ 45.00 |
| W802 | RELAY MULTIPLIER | Eight double-pole, normally open relays, their drivers and a gating circuit. | \$160.00 |
| *W970 | BLANK BOARD | 36-pins | \$ 4.00 |
| *W971 | BLANK BOARD | Double-height W970, 72 pins | \$ 8.00 |
| *W972 | CLAD BOARD | 36-pins | \$ 3.00 |
| *W973 | CLAD BOARD | Double-height W972, 72 pins | \$ 6.00 |
| *W980 | MODULE EXTENDER | Allows access to circuits without breaking connections. | \$ 14.00 |
| W985 | ADAPTER | Puts a System Module in four FLIP CHIP slots. | \$ 34.00 |
| *W990 | BLANK BOARD | 18-Pins | \$ 2.50 |
| *W991 | BLANK BOARD | Double-height W990, 36-pins | \$ 5.00 |
| *W992 | CLAD BOARD | 18-pins | \$ 2.00 |
| *W993 | CLAD BOARD | Double-height W992, 36-pins | \$ 4.00 |
| *W994 | PERFORATED BOARD | | \$ 4.40 |
| *W995 | PERFORATED BOARD | A double-height W994. | \$ 8.80 |

B SERIES (Cont.)

| | | | |
|-------|------------------------------------|-----------------------------------------------------------------------------------------------------------------|----------|
| *B104 | INVERTER | Four 10-megacycle inverters and three clamped load resistors. | \$ 17.00 |
| *B105 | INVERTER | Five 10-megacycle inverters and five clamped load resistors. | \$ 21.00 |
| *B113 | NAND/NOR GATE | Four 2-input diode-transistor NOR or NAND gates with three clamped load resistors. | \$ 23.00 |
| B115 | NAND/NOR GATE | Three 3-input diode-transistor NOR or NAND gates and three clamped load resistors. | \$ 21.00 |
| B117 | NAND/NOR GATE | Two 6-input diode-transistor NOR or NAND gates. | \$ 14.00 |
| B123 | INVERTER | Three 10-ma clamped loads, 4 pairs transistor inverters. | \$ 31.00 |
| B124 | INVERTER | Three groups of three inverters, and three clamped load resistors. Logically complementary to B115. | \$ 31.00 |
| B130 | 3-BIT PARITY CIRCUIT | Two levels of gating at high speed, with complementary outputs. | \$ 50.00 |
| B155 | HALF BINARY-TO- OCTAL DECODER | One output is grounded for each of four input combinations, if each of three auxiliary inputs is also enabled. | \$ 25.00 |
| B171 | NAND/NOR GATE | One 12-input diode gate with two transistors. NOR and OR for ground signals; AND and NAND for negative signals. | \$ 18.00 |
| B200 | FLIP-FLOP | For building simple 10 mc registers at low cost. Short delay from pulse input to flip-flop output. | \$ 25.00 |
| *B201 | FLIP-FLOP | General purpose flip-flop and nine input transistors. | \$ 56.00 |
| B204 | QUADRUPLE FLIP-FLOP | Four flip-flops with an inverter for common clear. Can be set or cleared from their outputs. | \$ 29.00 |
| *B301 | DELAY | One shot multivibrator with both pulse and level outputs. | \$ 73.00 |
| B310 | DELAY | Four delay lines, each with maximum delay of 50 nanoseconds in 12.5 nanosecond steps. | \$ 66.00 |
| B360 | DELAY (WITH PULSE AMPLIFIER) | Adjustable delay line (250 nanoseconds, maximum) and a pulse amplifier. | \$ 84.00 |
| *B401 | VARIABLE CLOCK | | \$ 57.00 |
| B405 | CRYSTAL CLOCK | | \$100.00 |
| B602 | PULSE AMPLIFIER | Two pulse amplifiers for negative or positive pulses. | \$ 36.00 |
| B620 | CARRY PULSE AMPLIFIER | Two stages for long B201 counters. | \$ 47.00 |

*Normal Delivery off-the-shelf.

B SERIES (Cont.)

| | | | |
|------|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| B681 | POWER INVERTER | Four inverters each equivalent to two paralleled 6105-type inverters. Includes a 20 ma clamped load internally connected to each collector, and four separate 10 ma loads. | \$ 25.00 |
| B684 | BUS DRIVER | Two 40 ma drivers for direct or terminated connection. | \$ 52.00 |

A SERIES

| | | | |
|----------------------|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
| A100 A103 A121 | MULTIPLIER SWITCHES | Solid-state analog switches. Transition time: less than one microsecond; offset: 100 to 300 microvolts. Controlled by standard levels and high frequency carrier. Transformer-coupled for isolation. | \$100.00 \$ 78.00 \$ 65.00 |
| A111 | MULTIPLEXER SWITCH | Low level relay multiplexer with guarded contact wiring. Two three-pole relays. | \$ 93.00 |
| †A200 | OPERATIONAL AMPLIFIER | 15 volt amplifier with a 2×10^4 open-loop voltage gain and a 15-megahertz unity gain. Differential inputs accept up to 10-volt common-mode signals. | \$130.00 |
| A201 | OPERATIONAL AMPLIFIER | High-speed, 10-volt amplifier with a 10,000 open-loop voltage gain and a 15-megacycle gain-bandwidth product. Differential inputs accept up to 10-volt common-mode signals. | \$180.00 |
| A400 | SAMPLE AND HOLD AMPLIFIER | ± 10 volt sample and hold able to track a full scale excursion in 12 microseconds to 0.25% accuracy. | \$330.00 |
| *A502 | COMPARATOR | Difference amplifier for signals as small as one millivolt. Standard output drives R- or B-series modules. | \$110.00 |
| *A601 | DIGITAL-TO-ANALOG CONVERTER | Three-bit star networks with drivers and terminating resistor. | \$ 60.00 |
| *A604 | DIGITAL-TO-ANALOG CONVERTER | Two-bit network with drivers for more accuracy. | \$ 62.00 |
| A605 | DIGITAL-TO-ANALOG CONVERTER | Two-bit wirewound network with drivers for maximum accuracy. | \$ 78.00 |
| A606 | DIGITAL-TO-ANALOG CONVERTER | Two-bit network used with A604 to form one decade of BCD D to A conversion. | \$ 62.00 |
| A702 *A704 | REFERENCE SUPPLIES | Both — 10-volt references. A702: 10-millivolt ripple, 30-millivolt load regulation. A704: 0.1-millivolt ripple, 0.1-millivolt load regulation. | \$ 58.00 \$184.00 |
| A990 | AMPLIFIER BOARD | Predrilled etched board on which can be mounted one of several dozen types of operational amplifiers manufactured by three different companies. | \$ 4.00 |
| A992 | AMPLIFIER BOARD | Similar to A990, and also receives booster amplifiers. Accepts even more different types, from many manufacturers. | \$ 4.00 |

HARDWARE ACCESSORIES

| | | | |
|--------|----------|----------------------------------|------------|
| CAB-1 | CABINET | Includes End Panels | \$ 700.00† |
| | | Additional Cabinets | \$ 500.00† |
| CAB-2 | CABINET | Includes End Panels | \$ 700.00† |
| | | Additional Cabinets | \$ 500.00† |
| CAB-3 | CABINETS | Expander cabinet for PDP-8 | \$ 650.00 |
| CAB-6 | CABINET | Includes End Panels | \$ 800.00† |
| | | Additional Cabinets | \$ 600.00† |
| CAB-8A | CABINETS | Free standing with winged table. | \$1,100.00 |

†Normal Delivery off-the-shelf.

†Non-discountable

HARDWARE ACCESSORIES (Cont.)

| | | | |
|----------------|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| CAB-8E | CABINETS | Free standing with rectangular table. | \$1,000.00 |
| *H001 | BRACKETS | One pair brackets to mount a 1907 cover plate on a 19" mounting panel. Provides 3/4 inch standoff, cover plate flush with cabinet. | \$ 8.00 |
| *H002 | BRACKETS | One pair brackets to mount a 1907 cover plate on a 19 inch mounting panel. Provides 2 inch setback to leave room for lights, controls. | \$ 8.00 |
| H201 | CORE MEMORY | 4096 x 13 bit core memory (90 day guarantee) | \$2,000.00 |
| *H701 | POWER SUPPLIES | Small, chassis mounted supplies electrically similar to 782A. | \$ 116.00 |
| *H701A | POWER SUPPLIES | Small, chassis mounted supplies electrically similar to 782A. | \$ 136.00 |
| H704 | POWER SUPPLY | Will drive six operational amplifier modules. All silicon, regulated, floating supply providing ± 15 volts at up to 400 ma on both outputs. | \$ 200.00† |
| *H800F | CONNECTOR BLOCKS | Unmounted 144 pin connectors for 8 FLIP CHIP modules. | \$ 8.00 |
| *H800W | CONNECTOR BLOCKS | Unmounted 144 pin connectors for 8 FLIP CHIP modules. | \$ 8.00 |
| *H801F | CONNECTOR PINS | Set of 18 spare pins to fit FLIP CHIP sockets. | \$ 4.00 |
| *H801W | CONNECTOR PINS | Set of 18 spare pins to fit FLIP CHIP sockets. | \$ 4.00 |
| H802 | CONNECTOR BLOCK | For single FLIP CHIP modules. | \$ 4.00 |
| H803 | MODULE SOCKETS | Unmounted 288 pin connectors for 8-36 pin modules. | \$ 13.00 |
| H804 | MODULE SOCKETS | Unmounted 144 pin connector for 8-18 pin modules. | \$ 9.00 |
| H805 | CONNECTOR PINS | Set of 18 spare pins to fit H803 and H804 connectors. | \$ 4.00 |
| H810 (24) | PISTOL GRIP HAND WIRE WRAPPING TOOL | For wrapping #24 solid wire on DEC Type H800-W Connector Pins. | \$ 99.00† |
| H810 (30) | PISTOL GRIP HAND WIRE WRAPPING TOOL | For wrapping #30 solid wire on DEC Type H800-W Connector Pins. | \$ 99.00 |
| H810 (24 & 30) | PISTOL GRIP HAND WIRE WRAPPING TOOL | For wrapping #24 and 30 wire on DEC type H800W and H803 Connector Pins. | \$ 150.00† |
| H811 (24) | HAND WRAPPING TOOL | For wrapping #24 wire on Connector Pins in service or repair applications. | \$ 21.50† |
| H811A (30) | HAND WRAPPING TOOL | For wrapping #30 wire on Connector Pins in service or repair applications. | \$ 21.50† |
| H812 (24) | HAND UNWRAPPING TOOL | For removing #24 wire wrapped connections. | \$ 10.50† |
| H812A (30) | HAND UNWRAPPING TOOL | For removing #30 wire wrapped connections. | \$ 10.50† |
| H820 | GRIP CLIPS | Identical to slip-on connectors used on Type 913 patch-cords. Fit sizes 24-20 AWG wire. Shipped in packages of 1000. | \$ 47.80† |
| H825 | HAND CRIMPING TOOL | For crimping Type H820 Grip Clips. Insures a good electrical connection. | \$ 146.70† |
| H830 | STACK-ON RIVETING TOOL | | \$ 10.00 |
| *H900 | MOUNTING PANELS WITH POWER | For up to 32 modules. Power supplies electrically similar to 782, 782A. | \$ 180.00 |
| H900A | MOUNTING PANELS WITH POWER | For up to 32 modules. Power supplies electrically similar to 782, 782A. | \$ 200.00 |
| *H901 | MOUNTING PANEL | For patching up to 10 modules. | \$ 82.50 |
| *H902 | SWITCH AND INDICATOR PANEL | 5-in. panel for experimental use. Eight switches, eight indicator lamps with ground-enabled drivers, four rheostats for controlling clocks and delays. Complements H901 and 700D. Complete with indicator driver module. | \$ 112.80 |
| *H903 | ANALOG-DIGITAL PANEL | D-A converter and comparator (including module). | \$ 143.00 |
| H910 | | 36-pin equivalent of H900. | \$ 200.00 |
| H910A | | 36-pin equivalent of H900A. | \$ 200.00 |

*Normal Delivery off-the-shelf.

†Non-discountable

HARDWARE ACCESSORIES (Cont.)

| | | | |
|-------------|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| H911B | MOUNTING PANEL | Similar to the 1943 but uses H803 and H804 connectors. | \$ 151.00 |
| H911BP | MOUNTING PANEL | Following options available as indicated by the suffix letters: Marginal Check Switches (M) or terminal block (B); prewired power (P) or not. | \$ 161.00 |
| H911M | MOUNTING PANEL | | \$ 172.00 |
| H911MP | MOUNTING PANEL | | \$ 182.00 |
| °700D | POWER SUPPLY WITH DIAL | 5-in. panel for powering and pulsing experimental logic systems patched together on H901 panels. Contains a variable clock, three pulsers, with a telephone dial and three push-buttons for driving the pulsers. Designed especially for educational use. | \$ 323.00 |
| 700DA | | 50-cycle version of 700D. | \$ 343.00 |
| °728 | POWER SUPPLIES | +10 v @ 0.7 amp, -15 v @ 1.8 amp, for 17" DEC cabinet plenum-door mounting. | \$ 240.00 |
| 728A | | | \$ 260.00 |
| °782 | POWER SUPPLIES | Rack-mounted power supplies with regulated ± 10 and -15 volt output at up to 0.4 and 3 amperes, respectively. | \$ 128.00 |
| 782A | | Input: 782: 115 volts, 60 cycles. 782A: 112.5 to 235 volts, 50 cycles. | \$ 148.00 |
| °783 | POWER SUPPLIES | Rack-mounted power supplies with electrical characteristics similar to 728 and 728A. | \$ 240.00 |
| 783A | | | \$ 260.00 |
| 786 | VARIABLE POWER SUPPLIES | Standard rack mounting 0-24 volt variable supplies, 0-2.5 amp. | \$ 215.00 |
| 786A | | | \$ 235.00 |
| 831 | POWER CONTROL | Specify 4, 10, 20, or 30 amp circuit-breaker. | \$ 51.00 |
| °900 | CONTROL PANEL | A front panel and chassis exactly duplicating 700D but without power. For multi-student installations on a Logic Laboratory. | \$ 214.25 |
| °911 | BANANA PATCHCORDS | Ten each 2, 4, 8, 16, 32, or 64 inches. One box. | \$ 9.00 |
| °913 | WIRE WRAP PATCHCORDS | Hundred each 2, 4, 8, 16, 32 or 64 inches. One pkg. | \$ 18.00 |
| °914-7 | POWER JUMPERS | Ten each 7 inches long. One pkg. | \$ 4.00 |
| °914-19 | POWER JUMPERS | Ten each 19 inches long. One pkg. | \$ 4.00 |
| °932 | BUSSING STRIP | | \$.60 |
| °1907 | MOUNTING PANEL COVER | 5 1/4 by 19 inch cover plate to protect power and logic wiring and permit installation of lights and control switches on a 19 inch mounting panel. Use with one pair of brackets. H001 or H002 (order separately). | \$ 9.00 |
| °1943-F-B | | | \$ 111.00 |
| °1943-W-B | | | \$ 111.00 |
| °1943-F-B-P | | | \$ 121.00 |
| °1943-W-B-P | MOUNTING PANEL | Houses 64 modules in a standard 19-inch rack. Following options available as indicated by the suffix letters: Forked-pin solder (F) or wire-wrap (W) connectors; marginal-check switches (M) or terminal block (B); prewired power (P) or not. | \$ 121.00 |
| °1943-F-M | | | \$ 132.00 |
| °1943-W-M | | | \$ 132.00 |
| °1943-F-M-P | | | \$ 142.00 |
| °1943-W-M-P | | | \$ 142.00 |
| 1945-19 | HOLD DOWN BAR | For 1943 mounting panel (19-inch). | \$ 15.00 |
| 4906 | SINGLE INDICATOR | With amplifier. | \$ 9.50 |
| °4908 | SINGLE INDICATOR | Lamp and mounting hardware. | \$ 3.00 |
| 4912 | ADAPTER | Puts a FLIP CHIP module in 2 system module slots. | \$ 28.00 |
| °4913 | MOUNTING RACK | For a power supply and four 5 1/2" panels. | \$ 47.00 |
| 4917 | INDICATORS | 9 bit indicators with amplifiers. | \$ 73.00 |
| 4918 | INDICATORS | 18 bit indicator with amplifiers. | \$ 96.00 |

°Normal Delivery off-the-shelf.

OCTAIDS and PANELAIDS^Δ

| | | | |
|-------|----------------------------------|--------------------------------------|-----------------------------------|
| D001A | D-A CONVERTER | 8 Bits | \$ 377.25 |
| D001B | D-A CONVERTER | 9 Bits | \$ 439.25 |
| D001C | D-A CONVERTER | 10 Bits | \$ 439.25 |
| D001D | D-A CONVERTER | 11 Bits | \$ 501.25 |
| D001E | D-A CONVERTER | 12 Bits | \$ 519.25 |
| D001F | D-A CONVERTER | 13 Bits | \$ 597.25 |
| D002 | BCD UP-COUNTER | Single Decade Quad Decade | \$ 62.50 \$ 137.20 |
| D004 | BI-DIRECTIONAL DECADE COUNTER | Decoding Option Conversion Option | \$ 123.40 \$ 47.00 \$ 17.00 |
| D005 | INPUT BUFFER INTERFACE | For PDP-8/S | \$ 122.00 |
| D006 | OUTPUT BUFFER INTERFACE | For PDP-8/S | \$ 215.50 |
| D007 | DUAL SHIFT REGISTER | 8-Bits Single Register | \$ 249.00 \$ 133.00 |
| D008 | DUAL UP-COUNTER | 8 Bits Single Up-Counter | \$ 217.00 \$ 117.00 |
| C001 | A-D CONVERTER | 10 Bits, 60 Hertz | \$1,144.00 |
| C001A | A-D CONVERTER | 10 Bits, 50 Hertz | \$1,162.00 |
| C002 | A-D CONVERTER | 10 Bits, without AC power. | \$1,079.00 |
| C003 | BCD REAL TIME CLOCK | 50/60 Hertz | \$ 639.00 |
| C005 | I/O BUS INTERFACE | For PDP-8/S | \$ 12.00 |
| C006 | I/O BUFFER REGISTER | For PDP-8 or PDP-8/S | \$ 397.00 |

^ΔSee Printed Circuit Board Price List on Page 273.

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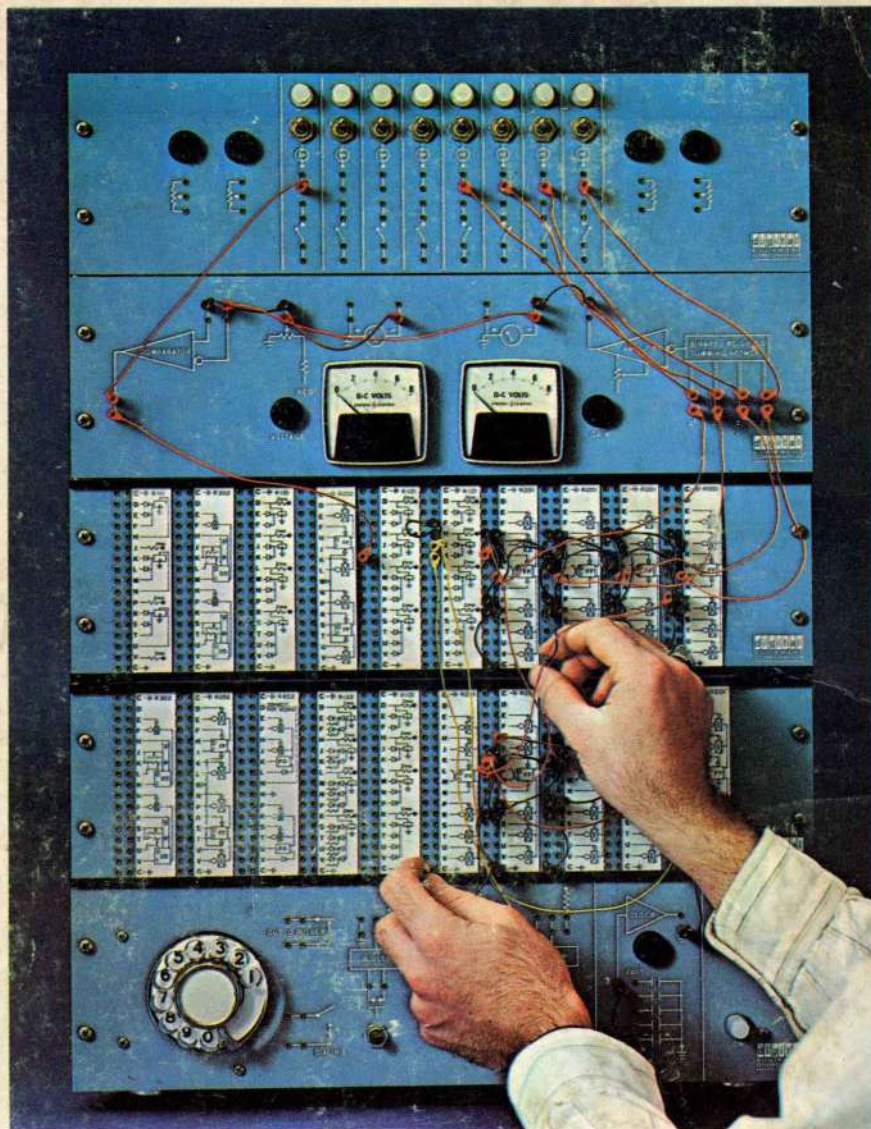
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