SUBCOURSE OD 0465

EDITION 6

DIGITAL CIRCUITS AND PRECISION SOLDERING

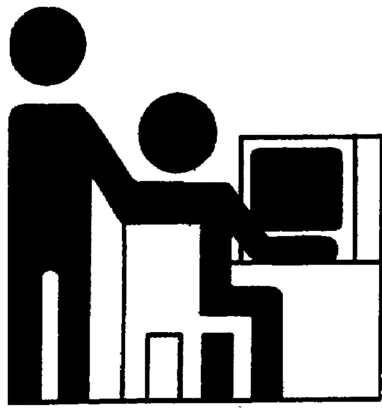
AIPD

READINESS/ PROFESSIONALISM

THRU GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



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DIGITAL CIRCUITS AND PRECISION SOLDERING

SUBCOURSE OD0465

US Army Combined Arms Support Command
Fort Lee, VA 23801-1809

8 Credit Hours

GENERAL

The purpose of this subcourse is to enhance your knowledge regarding digital circuits and precision soldering.

Eight credit hours are allowed for this subcourse. It consists of two lessons, with a total of seven tasks and an examination, outlined as follows:

Lesson 1: THEORY OF BINARY NUMBERS, BOOLEAN ALGEBRA, DIODE LOGIC GATES, DIGITAL CIRCUITS, AND THEIR INTERRELATIONSHIP WITH DIGITAL COMPUTERS

TASK 1: Describe the basic fundamentals and components which comprise a digital computer.

TASK 2: Explain the theory of binary numbers.

TASK 3: Explain the theory of Boolean algebra.

TASK 4: Explain the theory of diode logic gates.

TASK 5: Explain the theory of digital circuits.

Lesson 2: PROCEDURES FOR SOLDERING, DESOLDERING, AND REPAIR OF DEFECTIVE ELECTRICAL/ELECTRONIC CIRCUITS, INCLUDING INSPECTION STANDARDS

TASK 1: Identify the procedures used to solder, desolder and repair defective electrical/electronic circuits.

TASK 2: Identify inspection standards in accordance with MIL-STD 1460 (MU).

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LESSON 1

THEORY OF BINARY NUMBERS, BOOLEAN ALGEBRA, DIODE LOGIC GATES, DIGITAL CIRCUITS, AND THEIR INTERRELATIONSHIP WITH DIGITAL COMPUTERS

TASK 1. Describe the basic fundamentals and components which comprise a digital computer.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Computers are rapidly finding applications in military operations. In addition to the early uses in finance, stock and inventory management, and personnel control, the computer is now plotting and controlling artillery and missile fire, switching communications systems, and assisting in long range planning and doctrine development.

A significant recent development in computer applications is their use in training. Some are fed programs that actually interact with the students as they learn a subject. Others are programmed to control learning resources and simulate complicated technical systems which a soldier is learning to operate or maintain.

There are two general types of computers, analog and digital. They are different in construction, use, and operation. Many operations require parts of both to complete the job. When both types are combined, the result is known as a hybrid computer. This lesson deals with the theory used in constructing a digital computer.

2. Digital Computer

The digital computer uses numerical representations of information for its input and output. Input is defined as information transferred from its point of origin, or from secondary or external storage, into the internal storage or main memory of the computer. Output is defined as information transferred from the internal storage of a computer to secondary or external storage.

Within the machine, numbers or digits are used in the arithmetic operations of addition, subtraction, division, and multiplication. The digits or numbers can be fed into the computer by a keyboard much like that of a typewriter. Computer registers store the information and perform the required operations in separate steps. Digital counting can be done in several ways, such as counting holes in a paper card or tape, the teeth on a gear wheel, or electrical pulses in a circuit.

An example of a simple digital computer would be a mileage counter. The mileage counter on a vehicle is the odometer. It consists of six dials rotated by a flexible cable connected to the vehicle's drive shaft. The counter gives the driver a visual indication of distance traveled. Each dial completes a full rotation as it moves from 0 to 9 and back to 0. When the tenths-of-a-mile dial has completed one rotation, the 0-to-9 mile dial counter advances one digit. This same operation continues from the O-to-9 counter to the tens-of-miles counter and on up to a number limited only by the number of dials. Because each dial computes the distance traveled and indicates precisely a single discrete digit, the mileage counter is a form of digital computer.

a. *Fundamental Considerations*. The operation of the digital computer can best be learned by understanding how it differs from other electronic equipment, and why it is necessary to study number systems, arithmetic operations, Boolean algebra, diode logic gates, and digital circuits. Digital computers are related to other electronic equipment, such as radar and analog computers, because they are built of transistors, diodes, capacitors, resistors, and wires. That is where the similarity ends. In a digital computer, the terms of problems or equations to be solved are represented directly by numbers. The numbers exist within the computer in a two value, or binary form. For example, a number can represent a two-pole switch, either open or closed, or a biased transistor or diode, either on or off, depending on whether a particular condition is a 0 or 1. Because of this two-value system, precise threshold (turn on/off) values are met.

The main processes of a computer are its arithmetic operations. A single computer can solve many problems or equations, according to the directions (program) and data fed into it. A computer provides correct solutions consistently when correctly programmed. The input data are allowed to change only at discrete time intervals; therefore, the value of the solutions changes in the same way.

The digital computer's advantages lie in its high speed and accuracy. Small problems are solved in rapid succession, and large problems are broken down into a series of small problems.

To a competent electronic technician most of the basic circuits in a digital computer are simple, but the interconnection scheme is vast and involved. To learn the logic of this interconnection is a considerable task. The basis of this logic is a branch of mathematics, almost unheard of before the digital computer was developed, called Boolean algebra, in honor of the English logician and mathematician, George Boole, who first identified it.

b. *Basic Components*. The digital computer's basic components fall into two classes, those which store or retain information (memory elements), and those which make decisions based on the information supplied to them (decision elements).

Mathematical problems are solved by making decisions in a certain sequence, based on the stored numerical data and operation instructions. All decisions are of one of two values, either high or low, yes or no, true or false. Information stored in the memory elements is also in a two-value form. This is made possible by using only the numerals 0 and 1 to represent numerical quantities and expressing all instructions in a special code made up of the numerals 0 and 1.

Only two voltage states are allowed to exist on the input and output lines--one state representing the numeral 0 and the other state representing the numeral 1. It then becomes possible to think of input states, internal states, and output states. Within the computer, there is a master timing generator (called a clock) which produces timing or clock pulses, at a fixed frequency. The internal states and the states of the input and output lines can change only when a clock pulse appears. Between pulses, the states cannot change. The inputs can be coming from a punched card reader or from an analog-to-digital converter. The internal memory devices can be flip/flop circuits or magnetic cores. The output lines can go to the selector magnets of a typewriter or to a digital-to-analog converter.

The important points to note and remember are as follows:

- The inputs, internal state, and output can change only when triggered by a clock pulse.

- Only two conditions are possible on the input lines, internally, or on the output lines.

The two conditions are sufficiently separate to avoid confusion. One level is represented by the digit 1; the other level by the digit 0. These two digits are the symbols used in the binary number system which can be used to express any quantity, either exactly or as closely as needed. The two conditions are represented by different voltage values, the digit 0 by 0 volts and the digit 1 by +5 or -5 volts.:

- The specific problems which a computer may solve are not necessarily prescribed by its design.

A particular problem is solved by presetting the internal states for that problem before applying the numerical values of the terms to the input lines.

c. *Functional Block Diagram*. The five essential functions of a digital computer can be diagramed in block form. By looking at the block diagram, hardware items can be identified as belonging to one of the functional blocks. Most of these items would be in the input and output devices. Memory devices are generally recognizable, but you cannot be sure whether a memory device is functionally a part of memory, control, or the arithmetic functional group.

FIGURE 1. DIGITAL COMPUTER, FUNCTIONAL BLOCK DIAGRAM.

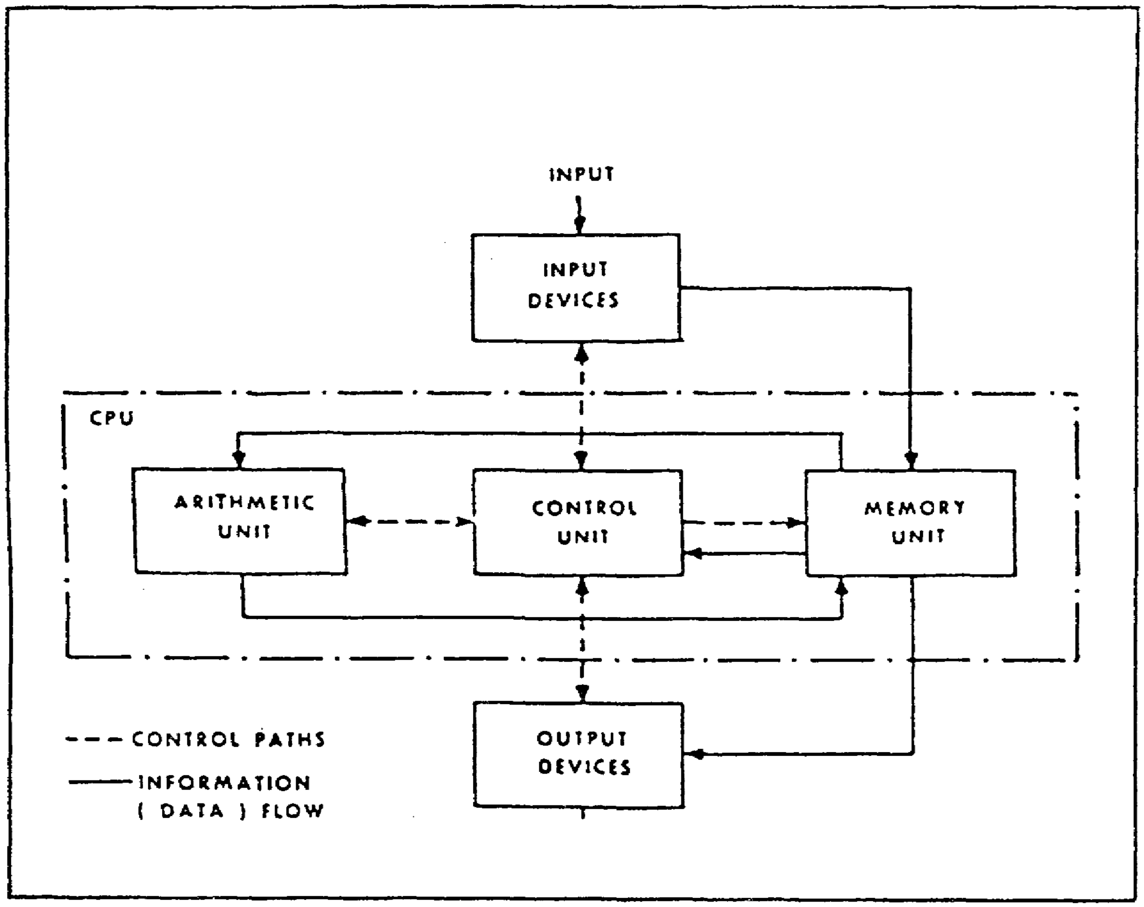


Figure 1 indicates that each block has a one-way or a two-way connection to other blocks. These interconnecting lines do not represent single wires, but a total number of conductors connecting any two blocks. While there is a general direction of movement from input to output, there are many possible paths a signal can take. Thus, troubleshooting a computer by signal tracing from input to output (as is done with radar, analog computer, or radio equipment) is impossible.

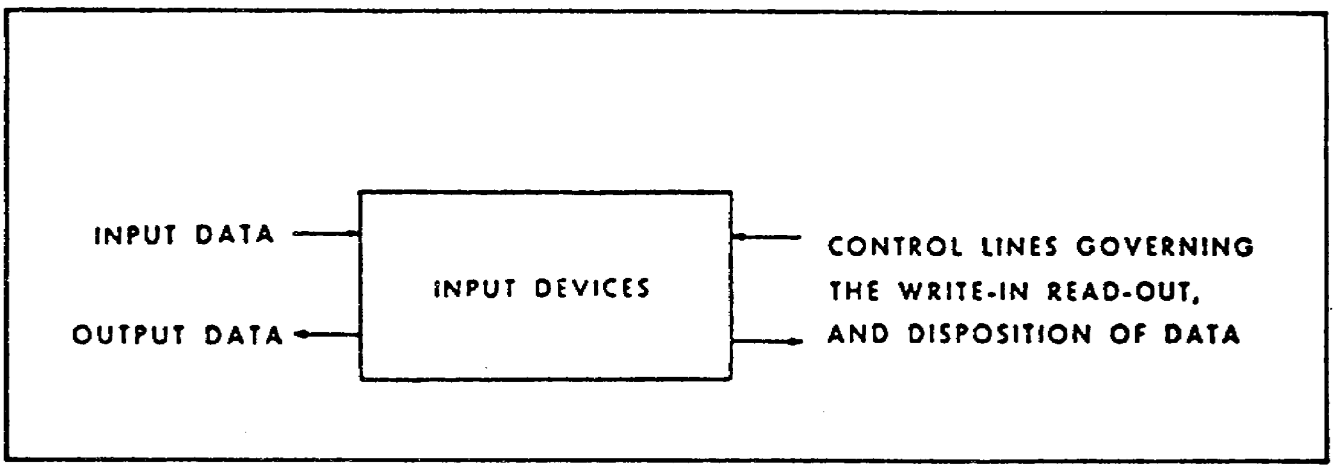
The computer designer establishes the interconnecting network inside and between the blocks. The design is based on what the computer analyst tells the designer the computer must do, the speed at which it must operate, the space and weight limitations, and the circuit components.

Effective troubleshooting techniques must be based on the ability to read and understand logic equations and diagrams, to understand the function and operation of each functional entity or section, and to devise and use programs that will help fault location.

d. *Individual Blocks and Circuits*. An explanation of the individual blocks included in the functional block diagram, leads to an overall understanding of the computer.

(1) *Input Devices*. Input devices are keyboards, punched card readers, punched tape readers, magnetic tape readers, print readers, and analog-to-digital converters. They read, or accept, data in original form and, if necessary, convert it to binary digital form (figure 2). One of the problems concerning the design of the input equipment is the great difference in speed between most input devices and the much faster electronic circuits in the control, arithmetic, and memory sections. One solution is the use of high speed tape reading and tape writing equipment.

FIGURE 2. INPUT DEVICES BLOCK.

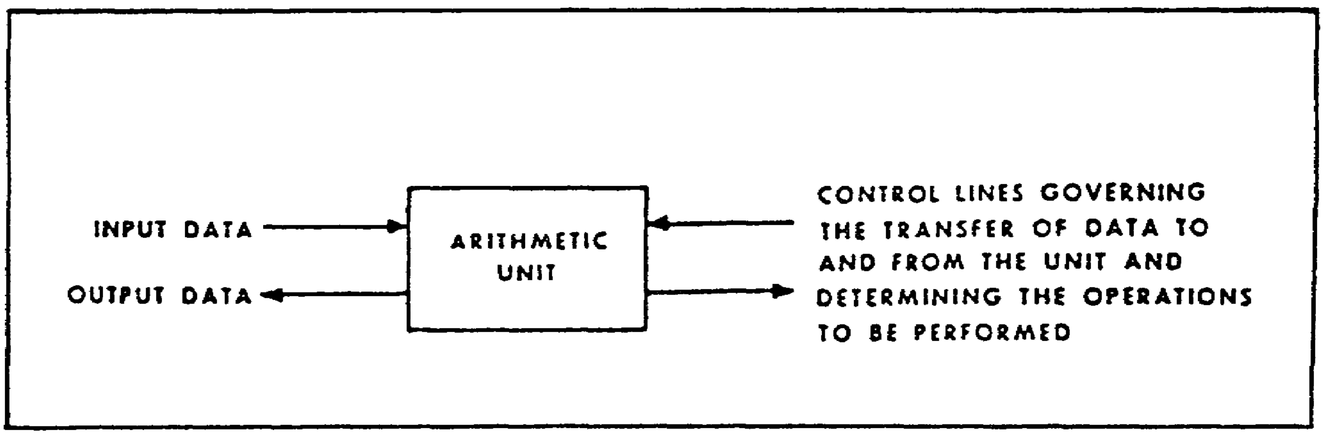


For example, in a computer where punched cards are the primary input medium, it is uneconomical to tie up the entire machine during the relatively slow process of reading cards. It is better to read the cards in a separate machine and transcribe the information on magnetic tape while the computer is otherwise employed. Then, the input information, now on magnetic tape, can be written into the computer much fester than from the cards.

(2) *Arithmetic Unit*. The arithmetic unit (figure 3) of the computer is limited in its mathematical ability. No problem can be solved unless it can be reduced to the simple arithmetic operations of addition, subtraction, multiplication, or division. The computer cannot be given an entire equation and commanded to produce a solution. Instead, the equation must be reduced to its simplest elements.

The process of reducing a problem to its simplest elements, in a sequence and form that will allow its solution by a particular computer is called computer programming. The arithmetic unit includes, as a minimum, the ability to count and add. Fortunately, the other arithmetic operations can be reduced to counting and adding.

FIGURE 3. ARITHMETIC UNIT BLOCK.

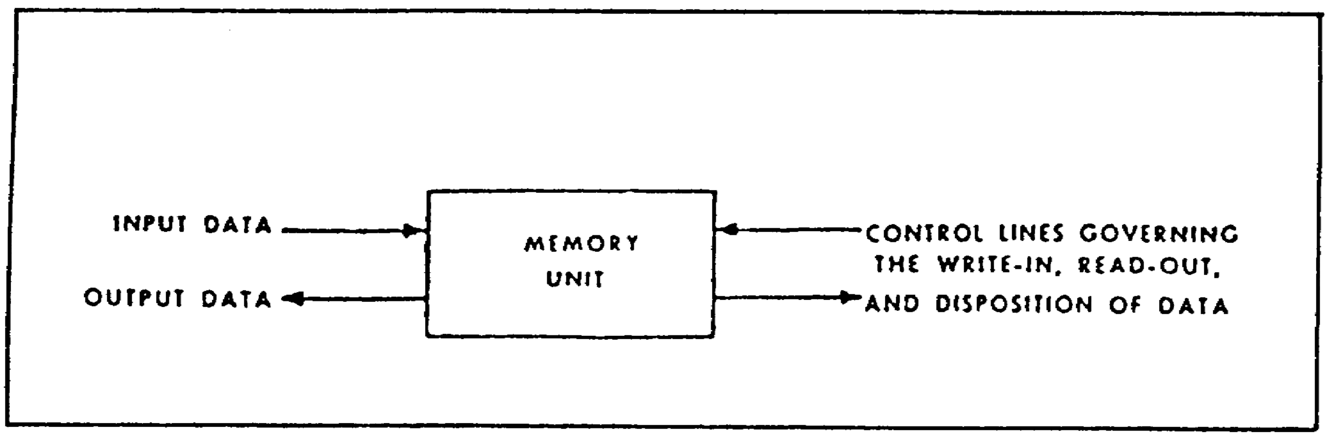


(3) *Memory Unit*. The memory unit (figure 4 on the following page) holds information until it is needed in the computing process. The results may be kept in memory until needed in further computation, or removed as part of the solution of the problem. Examples of memory devices are magnetic cores, drums, disks, tapes, wires, cathode ray tubes, flip/flop circuits, and delay lines.

The smallest element of information stored in a memory device is called a "bit". A single bit can represent only the binary digit 0 or 1, but bits can be combined to represent "words" of numerical quantities, algebraic signs, operation commands, or any other information. The state of a particular bit location in memory is either 0 or 1, depending on whether it is off or on, at a low or high voltage level, in one direction or the other of magnetic saturation, or any other valid two-valued scheme of representation. In most computers, words are of the same length--10 to 50 bits per word being typical. However, modern computers can handle words of different lengths.

The memory unit may be static or dynamic in operation. In a static unit, the binary bits of each word are assigned a set of locations with arbitrary numbering. In a dynamic unit, each word exists as a timed sequence of electrical or mechanical pulses that circulate about a closed loop. In such a loop, the memory location becomes essentially the time, with respect to a given reference time, at which the first bit of the word passes a specified point in the circulation loop. If a number of loops are used, a location must be specified, both in position and time. In the memory loops, acoustical delay lines may be used as memory elements. In both static and dynamic memory units, the location of each word in a unit is given by a number, known as the "address" of that word.

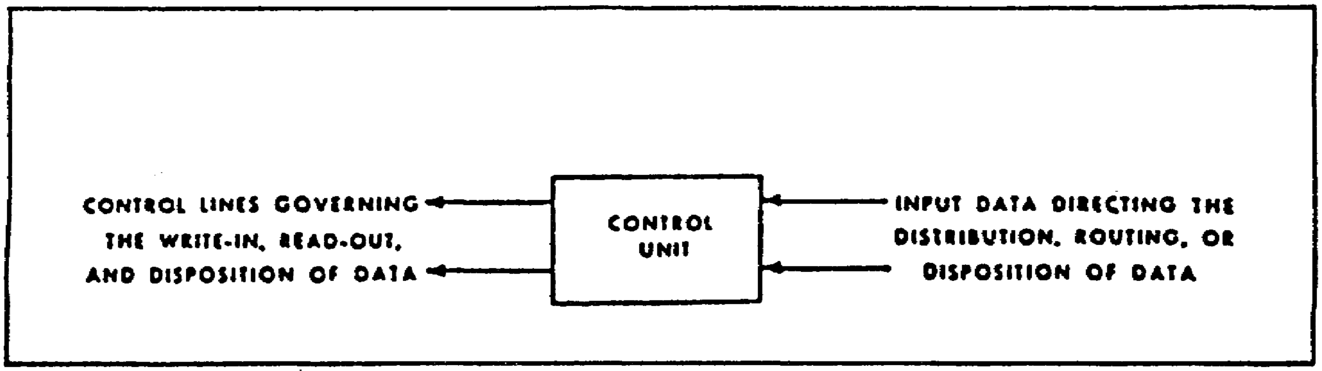
FIGURE 4. MEMORY UNIT BLOCK.



Memory addresses are frequently expressed as a two-part number, containing a channel number and a sector number, or their equivalents.

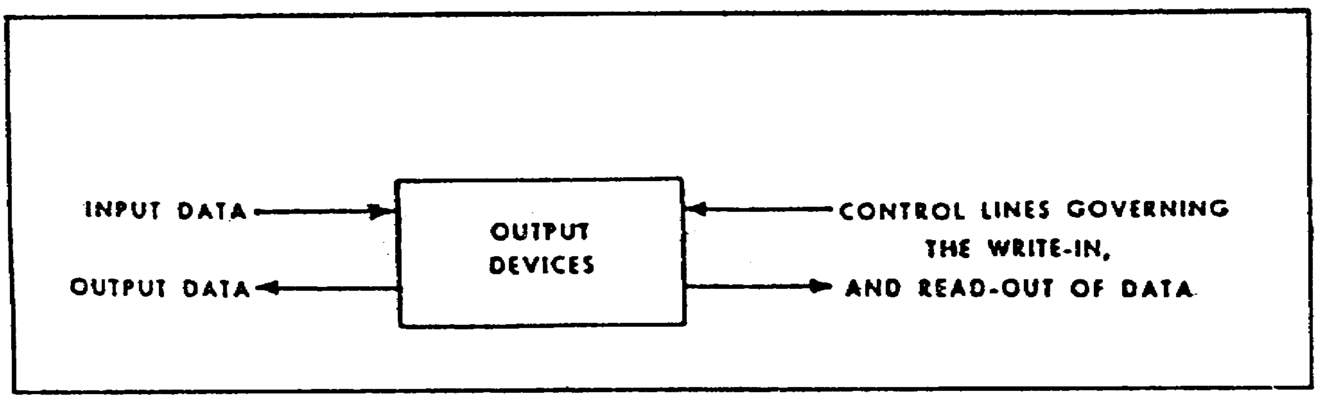
(4) *Control Unit*. The control unit (figure 5 on the following page), as its name implies, controls the routing and disposition of data, operational instructions, and the sequence of operations. In the same way that a great degree of variation occurs in the design of radar synchronizing or indicating systems, a similar wide variation exists in the design of the control unit. The control unit is composed of the same kind of logical devices and circuits that are used in the arithmetic unit. It is hard to tell by looking whether such a device or circuit is in the control unit or the arithmetic unit, because the basic operations of computing and control are so closely related.

FIGURE 5. CONTROL UNIT BLOCK.



(5) *Output Device*. The primary purpose of an output device is to furnish or record solutions in a usable form. Examples of output devices (figure 6) are electric typewriters, lighted numerals, paper tape, card punches, printers, and digital-to-analog converters.

FIGURE 6. OUTPUT DEVICES BLOCK.



(6) *Buffer*. Though not always identified as a part of the input or output equipment, the buffer is a necessary part of the data route between input, memory, control, arithmetic, and output. The buffer compensates for differences in the speed of information flow of operations between two sections of a computer. For example, magnetic tape may be used to compensate for the slower speed of a punched card reader machine and the faster operation of the main memory unit.

A buffer must accept information at one speed and discharge it at another. No harmonic relationship need exist between these two speeds. Either the input or the output speed can be the faster-, but input buffers generally have a slower input speed than output speed. This is true because input devices generally operate more slowly than the computer's internal sections. Output buffers generally have a higher input speed than output speed.

Basically, a buffer is a memory device that accepts, stores, and transmits data, and may be built from the same elements as the main memory. Additionally, a buffer may rearrange, insert, or delete information in the words that pass through it. Fundamentally, all buffers prevent interference between the sections of the computer, thus enabling all sections to operate at maximum speeds.

(7) *Registers*. Registers are commonly found in both the control and arithmetic units. A register provides temporary storage for a word, or perhaps for a small number of words. In this respect, a register is a temporary memory device because it stores data for fixed or predictable periods. The register in a computer is somewhat like a cash register in a department store, where the receipts are stored each day but removed at the close of business.

The register has many applications. The name given to a certain register refers to its use. For example, a shift register is one that shifts a word a certain number of positions, left or right, when so instructed; other examples are circulating registers, and accumulator registers.

e. *Summary*. In summary, the collection of processes in a digital computer system is referred to as the "configuration". The memory provides a storage for data while they are not involved in processing; the arithmetic, memory, and control units are the main computational and symbol manipulating processes of the digital computer system. It is these three units that do the actual interpretation of program instructions. The input/output devices maintain contact with peripheral devices, which are the producers and consumers of data, including programs. The registers and buffers of the input/output devices are all local storages of their respective processes. These storage elements normally differ in size and in their access time.

LESSON 1

THEORY OF BINARY NUMBERS, BOOLEAN ALGEBRA, DIODE LOGIC GATES, DIGITAL CIRCUITS, AND THEIR INTERRELATIONSHIP WITH DIGITAL COMPUTERS

TASK 2. Explain the theory of binary numbers.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Modern digital computers are designed to work with "binary" data entry; thus, a basic appreciation of binary numbers is essential if you are to gain a real understanding of how a computer works. It is NOT essential that you become extremely proficient in handling binary numbers. You do NOT have to begin thinking in binary, and personal difficulties in converting from decimal to binary and back again will NOT doom you to certain failure in any computer-related course. Even the professional programmer finds proficiency in handling pure binary numbers to be, at best, of marginal importance.

At this point, what is really important is that you realize that it's not only possible to store and manipulate binary data, but that this approach makes a great deal of sense in a computer.

The purpose of this section is to give you an appreciation for the value of using binary numbers, and to create in your mind a willingness to accept the use of binary data in a computer as being reasonable, possible, and very sensible.

2. Decimal Numbers

Since the decimal numbering system is more familiar to most people, let's start the discussion of binary numbers by taking a close look at a few decimal numbers. Consider the two numbers 3 and 30. Both contain a common digit, a three, but we all know that we are looking at two different numbers. What's the difference between the three in the number 3 and the three in the number 30? The answer is its position. Closer analysis reveals that the number thirty (30) is really another way of saying "three tens and no ones."

To put it another way, any decimal number consists of a series of digits - 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 - written in precise relative positions. The number twenty-three is written as 23, while a different combination of the same two digits, 32, represents a completely different number.

Take a look at the number 3580; what is really represented by this combination of digits is:

units	0	times	1	=	0
tens	+8	times	10	=	80
hundreds	+5	times	100	=	500
thousands	+3	times	1000	=	3000

In other words, to find the value of any number, multiply each digit by its positional (or place) value, and add these products. This is known as the "digits-times-place-value rule."

Take a closer look at the sequence of place values. In the example just described, we started with 3 then went to 30. What would you expect the next higher place value to be? It would, of course, be 300. Just add one more zero.

What does this really mean? We started with 3. To move up to the tens position, we multiplied this starting value by 10 (our BASE - this is a base-ten numbering system). The hundreds position, stated another way, is 10 x 10. The thousands position is 10 x 10 x 10. It is easy to perceive the pattern.

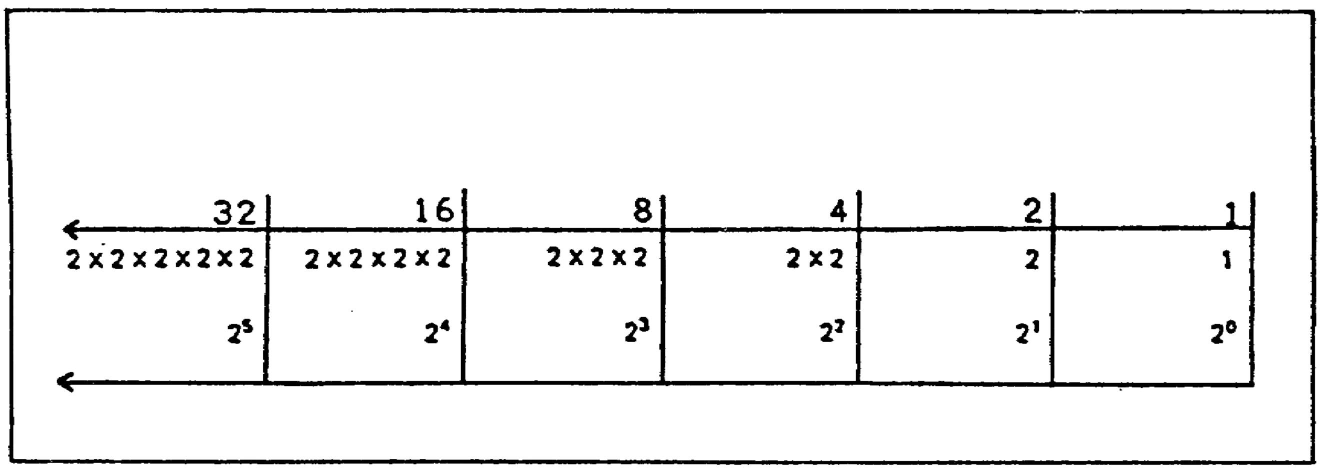
Each time we move up one position, we multiply by one more ten.

Eventually, we reach a point where it becomes a bit tedious to write down all those tens. You probably know that 10 x 10 can be written as "ten squared". The exponent or "power" of ten indicates the number of times that the number is to be multiplied by itself. This saves writing a lot of zeros when a number becomes very large. Numbers expressed in this way are written in scientific notation.

3. Binary Numbers

There is nothing to restrict the application of these rules to a base-ten numbering system. If the positional values are represented as powers of two instead of ten, we have the framework of the base-two or BINARY numbering system (figure 7).

FIGURE 7. BINARY PLACE VALUES.



As in the decimal numbering system, the digit zero (0) is needed to represent "no value" in a given position. In addition to zero, the binary numbering system needs only one other digit, a one (1), in order to form numbers. Why only these two digits? Only values less than the base can be represented in a single position. Since the base of the binary system is two (2), only numbers less than two can be so represented--O and 1.

Once again, as in the decimal numbering system, the digit-times-place-value rule still works; it's just that the place values are different, representing powers of two rather than powers of ten.

Consider, for example, the binary number 1101. Using the digit-times-place-value rule and remembering that we have a binary number, we can perform the following analysis:

2^0	or units	1 times 1 =	1
2^1	or twos	+0 times 2 =	0
2^2	or fours	+1 times 4 =	4
2^3	or eights	+1 times 8 =	8
			13

The example above gives us the decimal equivalent of the binary number 1101.

Any whole number can be written in binary. How do we tell the difference between a binary 11 (which is equal to three in decimal) and a decimal eleven? Normally, the binary number is enclosed within a set of parentheses, and a subscript is used to indicate the base. This is merely a convenient way of differentiating between numbers with different bases.

For a computer, an electronic device, binary numbers are much more convenient to use than are base-ten numbers. Since data representation requires only the two digits, 0 and 1, the computer, using binary numbers, can work with the simple on/off logic of electrical circuits. Binary is truly an electronic numbering system, which can easily be adapted to represent the presence or the absence of a voltage.

The 0 might represent 5 volts and the 1 might represent 0 volts, or vice versa. The assignment of bit value to a voltage condition is completely arbitrary and is normally determined by the circuit designer.

a. *Binary, Octal, Hexadecimal, and Decimal Conversions*. Table 1 (on the following page) shows the sequence of count to the first break point in several commonly encountered number systems. The first break point occurs at 10 in all of the number systems shown. Unless the radix shown is known, the value 10 is entirely meaningless. Designation of the number system is accomplished by using the radix as a subscript numeral.

TABLE 1. NUMBER SYSTEMS SEQUENCE OF COUNT.

SYSTEM	RADIX	COUNT
Binary	2	- 0,1,10
Ternary	3	- 0,1,2,10
Quaternary	4	- 0,1,2,3,10
Quinary	5	- 0,1,2,3,4,10
Sexternary	6	- 0,1,2,3,4,5,10
Septernary	7	- 0,1,2,3,4,5,6,10
Octal	8	- 0,1,2,3,4,5,6,7,10
Nodal	9	- 0,1,2,3,4,5,6,7,8,10
Decimal	10	- 0,1,2,3,4,5,6,7,8,9,10
Unidecimal	11	- 0,1,2,3,4,5,6,7,8,9,A,10
Duodecimal	12	- 0,1,2,3,4,5,6,7,8,9,A,B,10

The conventional practice is to read and write all subscript numerals in the decimal system. Binary and decimal numbering systems can be converted from one to the other. Binary, octal, and hexadecimal numbering systems are frequently used in computers because special methods have been found which fit the requirements. Therefore, the need to convert number systems occurs frequently.

The group-of-three method is a binary to octal conversion process. It requires memorizing the binary to octal conversion from 0 to 7 to cover the octal radix of 8, as shown below.

THREE BINARY DIGITS	OCTAL DIGIT
000	0
001	1
010	2
011	3
100	4
101	5
110	6
111	7

The first step is to separate the binary expressions into groups with three digits. Begin at the radix point and move to the left. Next, write the octal equivalent for each group directly below each group of three. When this has been accomplished, the binary to octal conversion is complete (table 2 on the following page).

TABLE 2. BINARY TO OCTAL NUMBER CONVERSION.

BINARY NUMBER	**111010101000_2**			
Step #1	**111**	**010**	**101**	**000**
Step #2	**7**	**2**	**5**	**0**
Therefore	**$111010101000_2 = 7250_8$**			

Octal to binary conversion can be accomplished by writing the three bit binary group for each decimal digit as shown below in table 3.

TABLE 3. OCTAL TO BINARY NUMBER CONVERSION.

Octal Number	**7250_8**			
Step #1	**7**	**2**	**5**	**0**
Step #2	**111**	**010**	**101**	**000**
Therefore	**$7250_8 = 111010101000_2$**			

Another shortcut method used in computer work is the binary to hexadecimal conversion and its reverse form of hexadecimal to binary. The hexadecimal number system utilizes 16 characters. Table 4 (on the following page) lists the binary-to-hexadecimal-to-decimal conversion.

TABLE 4. BINARY-TO-HEXADECIMAL-TO-DECIMAL CONVERSION.

Binary		Hexadecimal		Decimal
0000	=	0	=	0
0001	=	1	=	1
0010	=	2	=	2
0011	=	3	=	3
0100	=	4	=	4
0101	=	5	=	5
0110	=	6	=	6
0111	=	7	=	7
1000	=	8	=	8
1001	=	9	=	9
1010	=	A	=	10
1011	=	B	=	11
1100	=	C	=	12
1101	=	D	=	13
1110	=	E	=	14
1111	=	F	=	15

This method is based on the equivalency of any four bit binary group to a particular hexadecimal digit. The procedure is very similar to the procedure for converting binary to octal.

Begin by separating the binary expression into groups with four digits. Begin at the radix point and move to the left. Write the hexadecimal equivalent for each group directly below each group of four. When this step is finished, the binary to hexadecimal conversion is completed, as shown in table 5.

TABLE 5. BINARY TO HEXADECIMAL CONVERSION.

Binary Number	1010101010110001_2			
Step #1	1010	1010	1011	0001
Step #2	A	A	B	1

Therefore $1010101010110001_2 = AAB1_{16}$

Let's clear up a possible point of confusion right now. There are no computers that actually work in octal or in hexadecimal; they all work in binary. The value of the base-8 and base-16 number systems lies in the ease of conversion to or from binary, a circumstance which allows numbers written in these systems to be used as a shorthand for displaying the actual binary contents of a computer's memory.

b. *Coding*. "Coding" is the word used to describe the conversion of a decimal number to its binary equivalent. The binary numbers we have been using are the pure binary code. This code is a weighted code, as the positional value of the bits, when added together, equals the decimal equivalent. What follows is a description of other binary-based numbering systems.

(1) *Binary-Coded-Decimal (BCD) Number Representation*. Since most of the circuitry in digital computers is inherently binary in operation, the binary number system is the most natural number system for a computer. Also, computers built to use binary numbers require less circuitry and are more efficient than machines using other number systems.

On the other hand, use of the decimal system is deeply ingrained in people, causing a natural reluctance to calculate in binary numbers. Also, since pay checks, bills, tax rates, and prices are all figured in the decimal system, the values of most things must be converted from decimal to binary before computations can begin.

For these and other reasons, most of the early machines operated in binary-coded-decimal (BCD) number systems.. Some of these BCD systems are still in use but have been supplemented by additional coding systems. These newer systems, such as excess-3, octal, and hexadecimal, provide greater flexibility in the application of the computer to various jobs.

(2) *8-4-2-1 Code*. The BCD code is shown in table 6. Note that the binary numbers are a true binary translation of decimal digits. This occurs because the binary code progresses as a true binary count.

TABLE 6. BINARY EQUIVALENTS OF FIRST TEN DECIMAL NUMBERS.

DECIMAL	BINARY
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Table 7 shows how two decimal numbers would be expressed in 8-4-2-1 code, and how additions would be performed. In the example, the numbers have been selected so that the process of addition does not generate a carry.

TABLE 7. NUMERIC EXPRESSIONS.

Decimal		Binary	Coded	Decimal	(8-4-2-1)
1325	=	0001	0011	0010	0101
+5274	=	0101	0010	0111	0100
6599	=	0110	0101	1001	1001

In a computing machine, the generation of a carry cannot be avoided. Using the BCD, the four bit base of 16 must be reached or exceeded to generate a carry. To correct for the carry requirement, 0110 is added to the sum of each BCD number requiring a carry, (shown in table 8 on the following page).

TABLE 8. EXAMPLE OF THE CARRY WITH BCD CODE.

Decimal		Binary	Coded	Decimal	(8-4-2-1)
0325	=	0000	0011	0010	0101
+0279	=	0000	0010	0111	0100
0604	=	0000	0101	1001	1110
					0110
				1	0100
				1010	
				0110	
			1	0000	
			0110		
		0000	0110	0000	0100

The example shown in table 8 illustrates the action which must take place in the machine to obtain the final correct answer when the addition of 0325 and 0279 is accomplished. The least significant BCD number requires a carry, so 0110 is added. This addition causes a 1 to be transferred to the next higher order. When the 1 is added, that BCD number requires correction and 0110 is added. This addition generates another 1, which has to be transferred to the next higher order. When this 1 is added, the final correct answer has been found.

(3) *Excess-three Code (XS3)*. The "excess 3" code is formed by adding 3 to the decimal number and then forming the binary-coded number in the normal weighted binary code.

For example, to form the excess 3 representation for 4, first add 3, which yields 7, then the normal BCD is used, which is 0111. Therefore, 0111 is the excess 3 code for the decimal 4. Table 9 (on the following page) shows all 10 decimal digits and the excess 3 code for each.

TABLE 9. EXCESS 3 CODE.

Decimal	Excess 3 Binary Code
1	0100
2	0101
3	0110
4	0111
5	1000
6	1001
7	1010
8	1011
9	1100

The excess 3 code is not a weighted code, because the sum of the weights of the bits does not equal the number represented. The excess 3 code was primarily developed to simplify arithmetic operations within the computer.

(4) *ASCII Code*. ASCII, or the American Standard Code for Information Interchange, is a 7-bit code that is used in data transmission and intercommunication between a computer and its peripheral devices, such as printers, monitors, tape readers, and keyboards.

Table 10 (on the following page) is a chart representing the ASCII code. To find the ASCII code for a number, letter, character, or control function, first find it on the chart and look to the top of its column for the 3-bit binary number. This number is the first 3 bits of the ASCII code for that character. Then, look to the left of the row in which the character is located for the last 4 bits of the ASCII character. For example, the letter A has 100 at the top of its column and 0001 to the left of its row, so the ASCII code for A is 1000001.

There is room to add an eighth bit to the left of the ASCII code, since most computers use memories organized into 8-bit sections. The eighth bit is known as a parity bit. A parity bit is used in many computer systems for error checking. The computer designer may decide that all characters received and transmitted will have either an odd or an even number of ones. If we were using an even parity system for example, and the letter A were sent, the eight bit would have a value of 0, making the ASCII code 01000001. If we were using the odd parity system, the eighth bit would be a 1, making the character 11000001. In each case, the parity bit would be used to make sure that there were no lost or added bits. If an odd number of ones were received on an even parity system, the character would be rejected and would have to be sent over again. "Parity error" is the term for this process. Parity checking can be done for odd or even parity, depending on the designer's choice.

TABLE 10. AMERICAN STANDARD CODE FOR INFORMATION INTERCHANGE.

Column Bits (765) (4321)	000	001	010	011	100	101	110	111
0000	NUL	DLE	SP	0	@	P		p
0001	SOH	DC1	!	1	A	Q	a	q
0010	STX	DC2	"	2	B	R	b	r
0011	ETX	DC3	#	3	C	S	c	s
0100	EOT	DC4	$	4	D	T	d	t
0101	ENQ	NAK	%	5	E	U	e	u
0110	ACK	SYN	&	6	F	V	f	v
0111	BEL	ETB	'	7	G	W	g	w
1000	BS	CAN	(	8	H	X	h	x
1001	HT	EM	)	9	I	Y	i	y
1010	LF	SUB	*	:	J	Z	j	z
1011	VT	ESC	+	;	K	[	k	{
1100	FF	FS	,	<	L	\	l	¦
1101	CR	GS	-	=	M	]	m	}
1110	SO	RS	.	>	N	'	n	~
1111	SI	US	/	?	O	_	o	DEL

Explanation of Control Functions.

NUL - Null
SOH - Start of Heading
STX - Start of Text
ETX - End of Text
EOT - End of Transmission
ENQ - Enquiry
ACK - Acknowledge
BED - Bell (Aud Signal)

DC1 - Device Control 1
DC2 - Device Control 2
DC3 - Device Control 3
DC4 - Device Control 4
NAK - Neg Acknowledge
SYN - Synch Idle
ETE - End Trans Block
CAN -- Cancel

Explanation of Control Functions. (Continued)

BS - Backspace	EM - End of Medium
HT - Horizontal Tab	SUB - Substitute
LF - Line Feed	ESC - Escape
VT - Vertical Tab	FS - File Separator
FF - Form Feed	GS - Group Separator
CR - Carriage Return	RS - Record Separator
SO - Shift Out	US - Unit Separator
SI - Shift In	DEL - Delete
DLB - Data Link Escape	BP - Blank Space

(5) *The Gray Code*. The Gray Code is a popular binary code because its structure is such that it minimizes certain kinds of errors. Study the chart below (table 11), and see how the Gray Code compares with the pure binary code.

TABLE 11. PURE BINARY AND GRAY CODE COMPARISON.

Decimal	Pure Binary	Gray Code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111
11	1011	1110
12	1100	1010
13	1101	1011
14	1110	1001
15	1111	1000

At the point where the pure binary code breaks from 0111 to 1000 (decimal 7 to decimal 8) all 4 bits change to their complements. Electronic circuits called flip-flops are generally used as 1-bit memory storage elements. The sequence of a certain voltage on one of the flip-flops will represent a 1 and another voltage will be a 0. It takes four such circuits to count to, or store, a 4-bit number.

The time it takes for a flip-flop to change states is very short, but it can still cause problems if all the flip-flops involved in a 4-bit counter or memory do not change states at the same time. In high-speed logic circuits, the Gray Code may be used because, as you may have noticed, only one bit at a time changes as the count increases. Because of this, timing errors are minimized.

The Gray Code is not very useful in arithmetic operations because it is not a weighted code. The sum of the occupied bit positions does not equal the count. Because of this, when arithmetic operations are required, the Gray-coded number must be converted back to a weighted code, such as 8421, BCD, or pure binary.

LESSON 1

THEORY OF BINARY NUMBERS, BOOLEAN ALGEBRA, DIODE LOGIC GATES, DIGITAL CIRCUITS, AND THEIR INTERRELATIONSHIP WITH DIGITAL COMPUTERS

TASK 3. Explain the theory of Boolean algebra.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

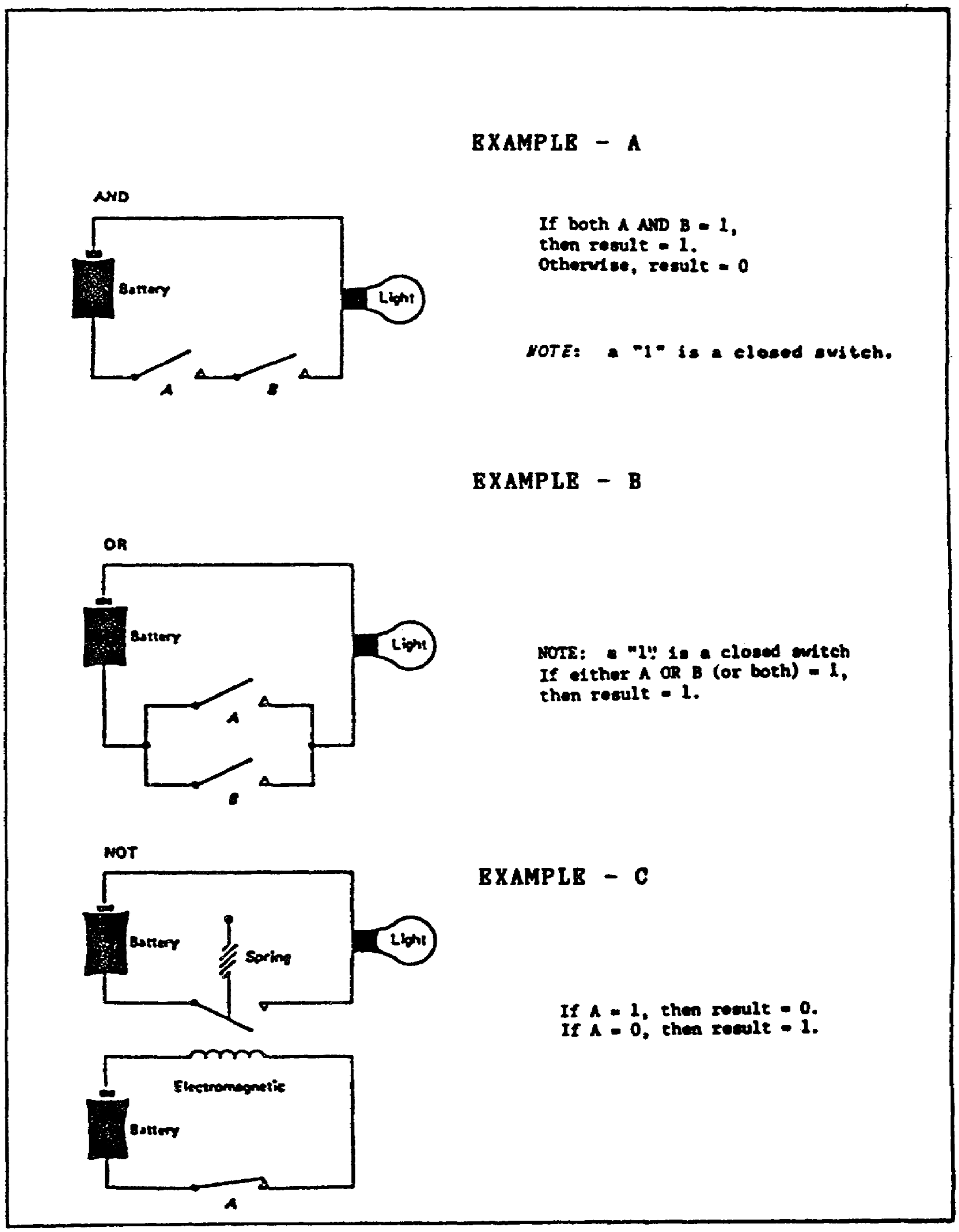
1. Introduction

In this section of the subcourse, the basic concepts, operations, and applications of Boolean algebra to the logical operation of the digital computer will be discussed. Boolean algebra is the mathematical foundation for the logical circuit design and interconnecting wiring networks, and the logical operations performed by the digital computer. Boolean algebra is a convenient way of representing complex switching networks without drawing the actual circuits. It is useful in translating switching problems into actual machine construction.

2. Boolean Algebra

In the mid-1800s, George Boole developed a new type of logic which today bears his name: Boolean algebra. Boolean algebra is based on the proposition that any expression can be made meaningful with two values (true and false). Since binary numbers and basic components of digital computers are two-valued (0 and 1), Boolean algebra is extensively used in computers. It is a shorthand method towards understanding machine operations based on formal logic.

FIGURE 8. THREE BOOLEAN LOGIC BLOCK EXAMPLES.



At its core, Boolean logic requires only three basic logic blocks: AND, OR, and NOT. The function of each of these logic blocks is shown in figure 8 on the previous page.

These simple gates can be combined to perform a number of more complex functions. All of the functions performed by a computer are implemented through a combination of these three basic building blocks.

Logical argument, or analysis, can be expressed with words, diagrams, and symbols. In the following discussion, symbols are used to explain Boolean algebra. Boolean algebra laws are written as equations and will be applied to logical circuits.

3. Boolean Algebra Laws

(1) *Law of Identity*. $A = A$. The expression is spoken as "A equals A." This is logically the same as saying, "Whatever is, is."

(2) *Law of Complementarity*. $AX\bar{A} = 0$; $A + \bar{A} = 1$. $\bar{A}$ is spoken as "not A" or "A bar" or "A not"; "not A" is the most common expression used. A means the negation or complement of A. $AX\bar{A} = 0$ is a symbolic way of saying that A and $\bar{A}$ do not intersect or that no region is common to A and $\bar{A}$. The expression also shows that A and $\bar{A}$ are mutually exclusive. This is logically the same as saying, "Nothing can both be and not be." In $A + A = 1$, this + is spoken as OR and the expression is known as a logical sum. $A + \bar{A}$ specifies and indicates the region that results from the union, addition, or disjunction of A and $\bar{A}$. This is a symbolic way of saying, "Anything must either be or not be."

(3) *Idempotent Law*. $AXA = A$; $A + A = A$. The equations show that the intersection of region A with region A is region A, and that the union of region A with region A is equal to region A. As with some other mathematical laws, this law appears obvious at first glance. While the expressions are not difficult to understand, this law is important and finds application in the solution of Boolean equations. The idempotent law indicates that Boolean algebra has no exponents or coefficients.

(4) *Law of Double Negative*. A = A. If, as an elementary school student you said, "I don't have no money," .you would probably have been corrected by your teacher to say, "I don't have any money." You made a grammatical error or double negative, unless you meant that you actually did have some money. double negation has the same meaning in Boolean algebra that it has in grammar. When A is primed by writing A, you might think of it as going from inside region A to outside region A. When A is primed by writing A, you can think of it as going from outside region A to inside region A.

Basically, the Boolean expressions discussed this far have consisted of terms and connectors; the terms are letters and the connectives are the signs X(and) and +(or). These terms and connectives are written in the same way in both Boolean and numerical algebra, but this is almost the total extent of the similarity between the two algebras.

The basic operations of Boolean algebra are AND, OR, and complement (negate); these have no correspondence to any of the operations of numerical algebra.

The law of identity holds in both algebras, but the laws of complementarity, idempotency, and double negation are not defined in numerical algebra. The law of idempotency states that there are no coefficients in Boolean algebra. The number 1 and 0 are used, but these symbolize a universe and a null class respectively, rather than representing numerical quantities.

(5) *Commutative Law*. AB = BA; A + B = B + A. This law holds true for both Boolean and numerical algebra and is equivalent to writing XY = YX OR X + Y = Y + X. This law simply states that the order of the terms does not affect the result.

(6) *Law of Absorption*. A(A = B) = A; A + AB = A. Boolean algebra allows the use of the signs of grouping (parentheses, brackets, and braces) in accordance with their normal mathematical usage. The law of absorption states that the intersection of class A with class union involving A is equal to A.

(7) *Law of Dualization* (DeMorgan's theorem). (AB) = A + B; (A + B) = A + B. This law states that a prime (complement) and entire expression is

equivalent to priming the individual terms and changing X to + or + to X.

(8) *Associative Law*. (AB) C = A(BC) = ABC; (A + B) + C = A + (B + C) = A + B + C. This law is a formal statement of an earlier assertion that the signs of grouping are admitted in accordance with their normal mathematical usage. This law holds equally in both numerical and Boolean algebras.

(9) *Distributive Law*. A(B + C) = AB + AC; A + BC = (A + B)(A + C). This law finds frequent application in the simplification of Boolean expressions and must be thoroughly understood. It is apparent that the first expression is valid in numerical algebra; it is equally apparent that the second is not. This situation requires caution in the application of the law to avoid error.

A summary of the foregoing laws is given below in table 12. It is not necessary to memorize them; they will have more meaning when applied to logical circuits.

TABLE 12. LAWS OF BOOLEAN ALGEBRA.

	RULE		**HOW TO READ EXPRESSION**
1.	**A + A = A**	**.......**	**A OR A equals A.**
2.	**A . A = A**	**.......**	**A AND A equals A.**
3.	**A + B = B + A**	**.......**	**A OR B equals B OR A.**
4.	**A . B = B . A**	**.......**	**A AND B equals B AND A.**
5.	**A + B + C =**	**.......**	**A OR B OR C equals parenthesis.**
	(A + B)+ C =	**.......**	**A OR B parenthesis OR C equals.**
	A +(B + C)	**.......**	**A OR parenthesis B OR C parenthesis.**
6.	**A . B . C =**	**.......**	**A OR B OR C equals parenthesis.**
	(A . B). C =	**.......**	**A AND B parenthesis AND C equals**
	A .(B . C)	**.......**	**A AND parenthesis B AND C parenthesis.**
7.	**A + 0 = A**	**.......**	**A OR ZERO equals A.**
8.	**A . 0 = 0**	**.......**	**A AND ZERO equals ZERO.**
9.	**A + 1 = 1**	**.......**	**A OR ONE equals ONE.**
10.	**A . 1 = A**	**.......**	**A AND ONE equals A.**
11.	**A + A = 1**	**.......**	**A OR NOT A equals ONE.**

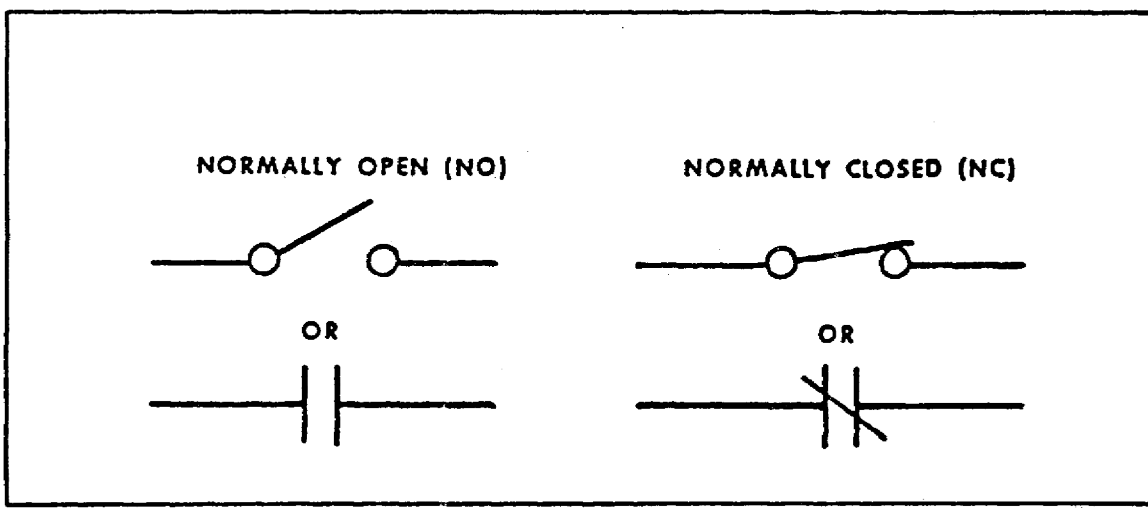
TABLE 12 (CONTINUED)

12.	$A \cdot \bar{A} = 0$	.... **A AND NOT A equals ZERO.**
13.	$A = A$	.... **NOT A notted equals A.**
14.	$(A + B)$	.... **Parenthesis A OR B parenthesis AND**
	$(A + C) =$	.... **parenthesis A OR C parenthesis.**
	$A + B \cdot C$	.... **equals A OR B AND C.**
15.	$A \cdot B + A \cdot C =$	.... **A AND B OR A AND C equals**
	$A \cdot (B + C)$	.... **A AND parenthesis B OR C parenthesis.**
16.	$A + A \cdot B = A$	.... **A OR A AND B equals A.**
17.	$A \cdot (A + B) = A$	.... **A AND parenthesis A OR B parenthesis equals A.**

a. *Logical Switching Networks*. A switch is a binary element with only two states, open or closed. The open and closed states refer to the switch contacts, which are open when the switch is in the off, nonactuated, de-energized, or quiescent state. (A quiescent state is the operating condition that exists in a circuit when no input signal is being applied).

In figure 9, the switch is known as a single-pole with normally open (NO) or normally closed (NC) contacts. The two lower single-pole switches may look like capacitors, but these symbols simplify the drawings and are approved by the Department of Defense, as set forth in USA Standard Y 32.16.

FIGURE 9. SINGLE-POLE SWITCH.

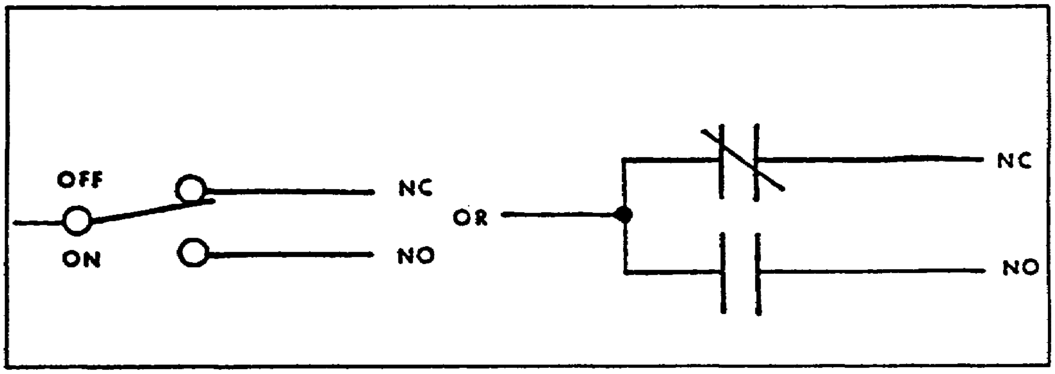


The presence of both NO and NC contacts indicates a double-pole switch (figure 10 on the next page).

This switch acts as a single-pole switch when one of the pole connectors is not used.

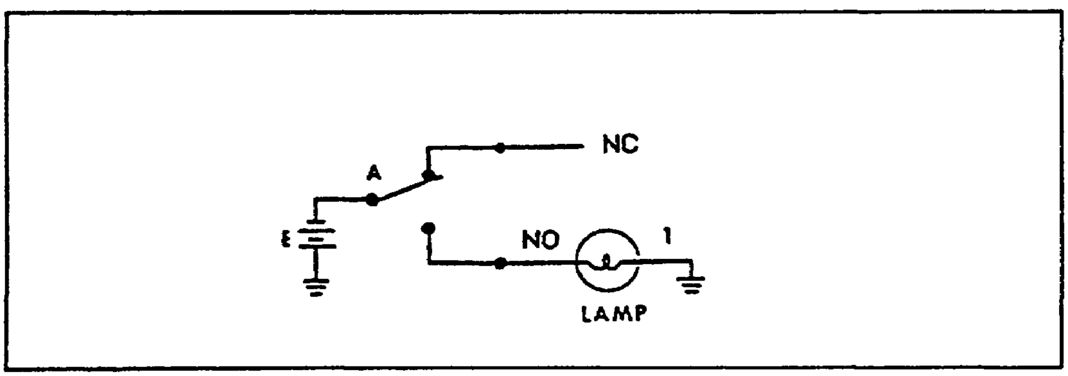
The type of switch construction and the method of operation are immaterial. The switch may be a set of relay contacts or a toggle pushbutton, pressure sensitive, cam operated, rotary, or electronic type of switch.

FIGURE 10. DOUBLE-POLE SWITCH.



When switch A (figure 11) is connected into a circuit, it is not apparent whether the circuit is open or closed until it is known whether either the NO or NC contact, or both, has been connected in the circuit. Consider the connection of switch A below in figure 11.

FIGURE 11. SWITCH "A" CONNECTION.

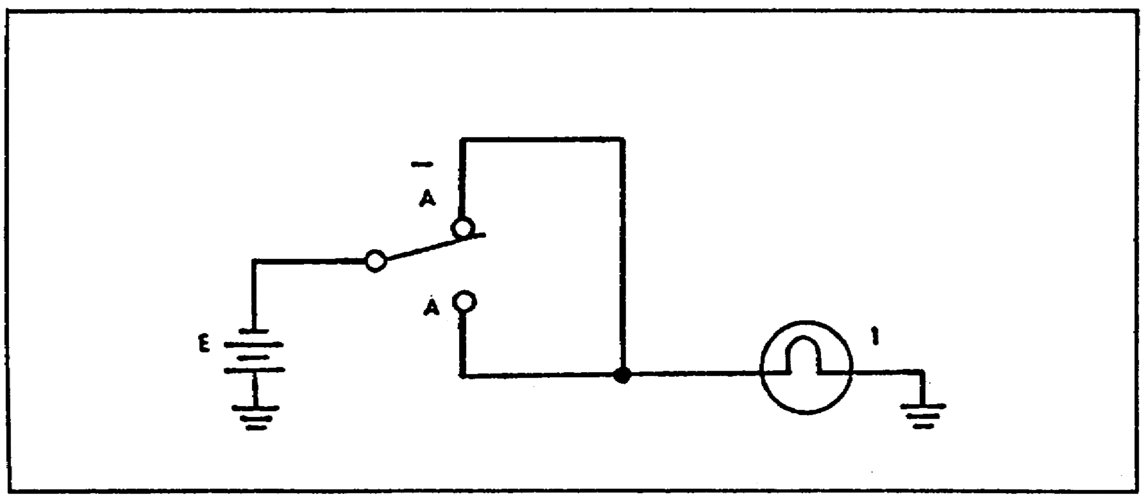


The function of this circuit is realized when the lamp is turned on. This elementary switching network can be expressed by the Boolean equation: A = f, where A = the NO contact (as previously stipulated) and f = a Boolean function (a complete circuit). You say also write A = 0. This equation states that A (the NC contact) is not connected and is equal to, 0 or is false.

- A switch is a binary device; its connection in a particular circuit will cause certain conditions to be true (high voltage) and others, false (low voltage).
- Conditions which are existent or possible are considered true (high voltage).
- Conditions which are nonexistent or impossible are considered false (low voltage). This applies to positive logic. The NC contact in figure 11 is nonexistent to the lamp and, therefore, is false.

(1) *Simplifying a Boolean Equation*. An important point to notice here is the logical equivalence of a parallel connection; the connective $A + \bar{A}$ = is normally spoken as "A or not A," but could be expressed with equal accuracy as "A in parallel with not A", or "A in union with not A". The equation f = 1 is interpreted as meaning that the lamp is always on, or that the switching network is equivalent to a short circuit. Reducing $A + \bar{A} = f$ to $f = 1$ (figure 12) by applying one of the laws of Boolean algebra is known as the simplification of a Boolean function. The corresponding Boolean equation is: $A + \bar{A} = f$, but $A + \bar{A} = 1$ (law of complementarity): therefore, $f = 1$.

FIGURE 12. PARALLEL SWITCH A.



Boolean equations are not evaluated in the manner of equations in numerical algebra because quantities are not involved. Boolean equations are solved by simplification.

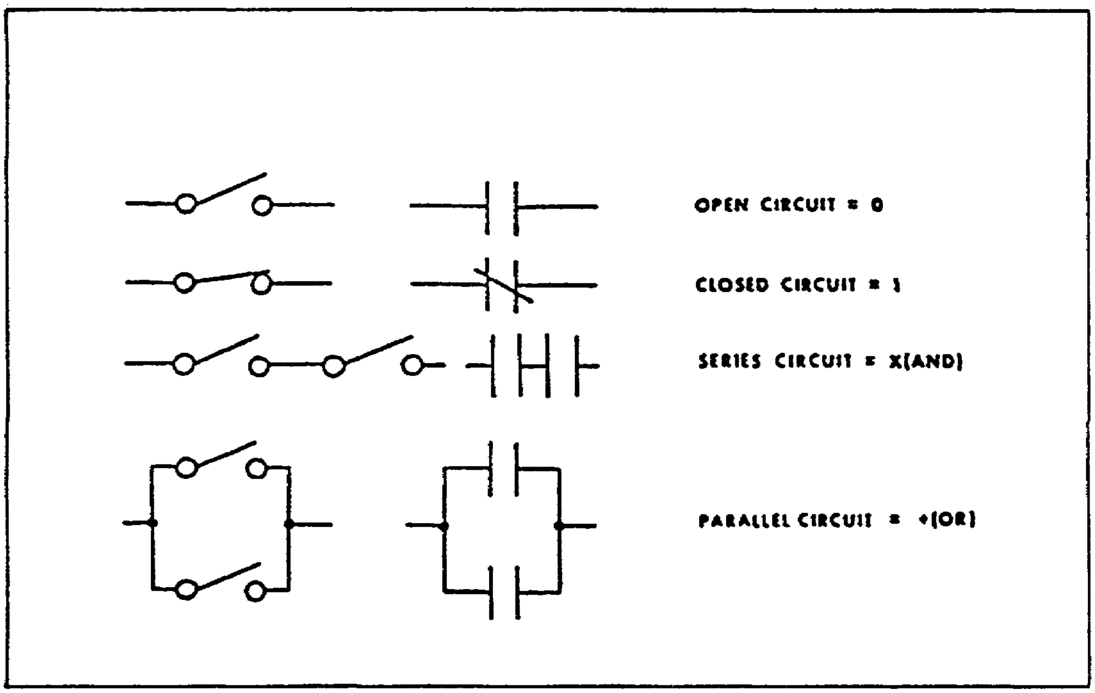
To simplify a Boolean equation means to reduce it to its simplest form--that expression which represents or describes the simplest work or fewest components. This is what makes Boolean algebra such a valuable tool. It allows the development of circuitry with the least number of components to perform a given function.

(2) *Representation of Circuit Connections*. A parallel circuit connection is represented in Boolean algebra by the connective +. The series circuit is represented by the connective X. Circuit switches with corresponding Boolean values and connectives are shown in figure 13.

There is no way to wire the contacts A and $\bar{A}$ of the switches in figure 12 into a series circuit between the battery and lamp. The Boolean equation for such a circuit is $A\bar{A} = f$, but $A\bar{A} = 0$ (law of complementarity); therefore, $f = 0$.

This result states that a series connection of a Boolean variable and its negate is equal to 0, which describes an open circuit or impractical condition.

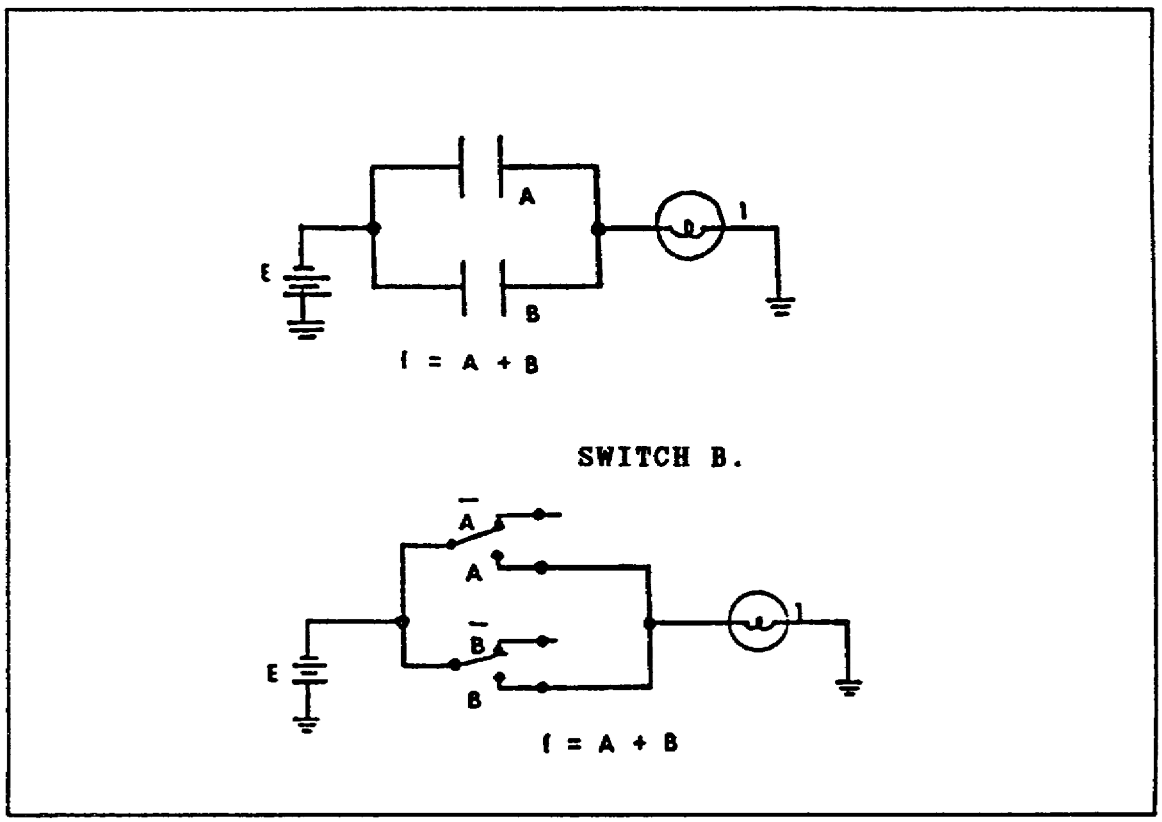
FIGURE 13. VALUES AND CONNECTIVES IF SWITCHING CIRCUITS.



The logical nature of a simple switching network shows that the wiring connections of the circuit can be described by Boolean equations. These equations form the shorthand for the wiring diagram.

b. *Logical Analysis of Multiswitch Network*. The practice of representing the normally closed contacts as the primed (negated) contacts will be continued. This is an arbitrary choice and should not be interpreted as being a military or industry standard. The following circuit is a parallel connection of two switches (figure 14). It can easily be seen that closing either switch will turn on the lamp. The Boolean equations that describe this circuit are A = 0; B = 0; A + B = f. The last equation is the simplest form because it cannot be reduced any further. The lower version of figure 14 uses the single-pole switch symbols.

FIGURE 14. SWITCH A.



By letting 0 represent an open switch, 1 a closed switch, and 0 and 1 the off and on states of the lamp, respectively, the circuit can be represented in table form, called a "truth table", as shown in table 13 on the following page.

(1) *Truth Table Analysis.* An analysis of table 13 is as follows:

- The top row of table 13 shows that when switches A and B are open, the circuit is open.
- The second row shows that when switch A is open and switch B is closed, the circuit is closed (complete).
- The third row shows that the circuit is closed when A is closed and B is open.
- The bottom row shows that closing both switches closes the circuit.

TABLE 13. TRUTH TABLE FOR VARIABLES A B.

A	B	f
0	0	0
0	1	1
1	0	1
1	1	1

The table is constructed by writing the switch designations (A and B in this case) at the head of the columns on the left side of the table and the function (f) at the head of the column on the right side; 0's and l's are then written on the left side to produce a binary count from 0 to the highest value obtainable within the order of columns. This simply means to start with all O's and keep advancing this count by unity to obtain all l's.

Inspect the circuit under the conditions indicated by the first row (both switches open) to determine whether the circuit is open or closed. In this case, the circuit is open, so a 0 is written in the f column on the same row. Proceeding to the second row, with switch A open and B closed, the circuit is closed so a I is written in the f column. This procedure is repeated until a value for f is found for each row.

(2) *Equivalent Boolean Equation*. A Boolean equation can now be written for each row in which f has the value of 1:

$\bar{A}\,B = f$ (second row)
$A\,\bar{B} = f$ (third row)
$A\,B = f$ (fourth row)

These three equations can be written as one single equation:

$\bar{A}B + A\bar{B} + AB = f$

This equation can be expressed in words as: the circuit is closed when A is open and B is closed, when A is closed and B is open, or when both A and B are closed. It can be seen that the circuit behavior is correctly described.

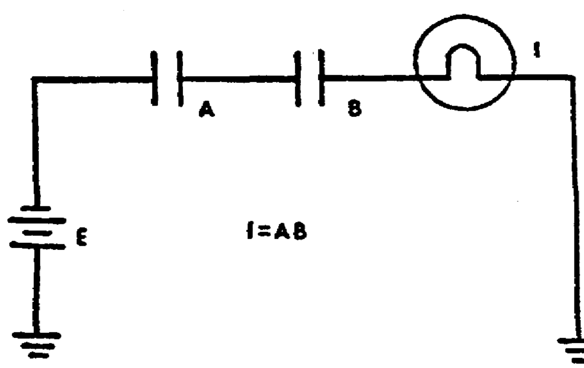
(3) *Application of Propositional Algebra*. Propositional algebra deals with specific propositions such as, if switch A is open and switch B is closed, the lamp is lit. If this statement is false, it is identical to a null class. The truth table permits the class membership to be counted.

(a) Connecting switches A and B in series produces the circuit shown in figure 15. The Boolean equations are as follows:

$\bar{A} = 0,\ \bar{B} = 0,\ \bar{A}\bar{B} = 0,\ AB = F$

The truth table shows that the function is true only when A and B are true.

FIGURE 15. SWITCHING CIRCUIT WITH TRUTH TABLE.



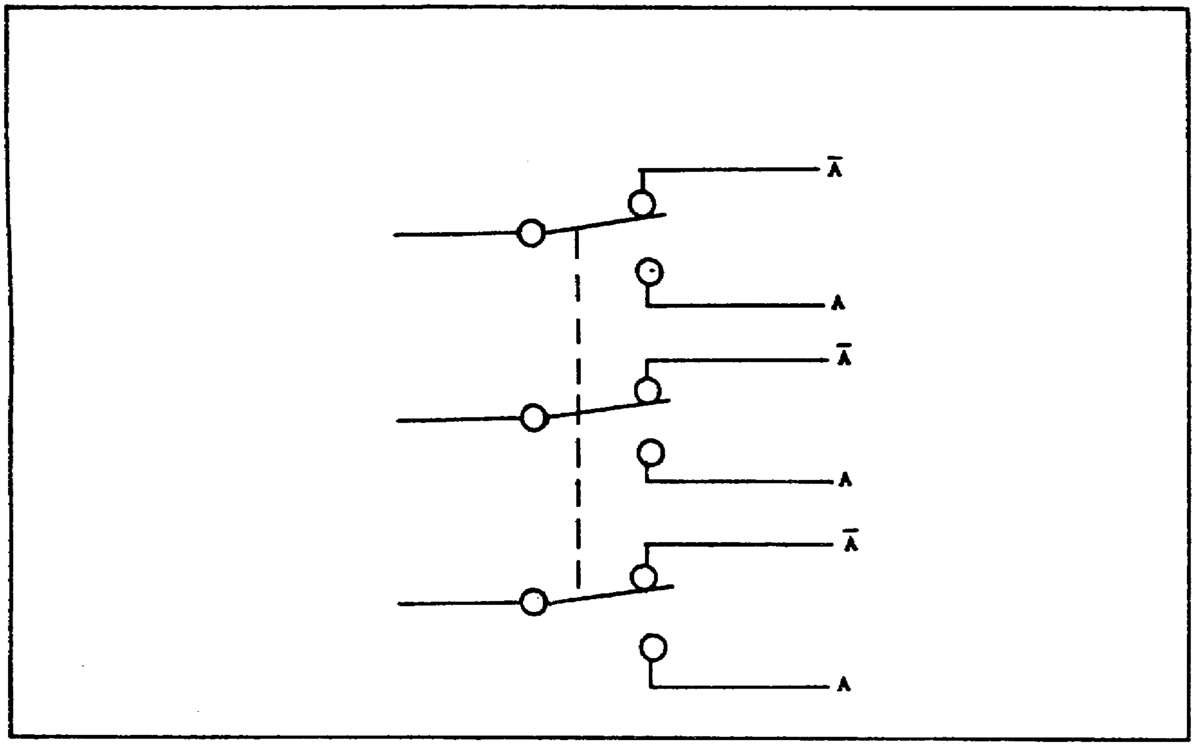
A	B	f
0	0	0
0	1	0
1	0	0
1	1	1

(b) A multiple switch or a relay with more than one set of contacts can be diagramed as shown in figure 16.

The dashed line represents a nonconductive mechanical linkage. The several sets of contacts may be connected independently, in series, in parallel, or any other combination.

(c) Figure 17 (on the following page) shows some network possibilities with one double-pole switch. In all the networks, the Boolean functions are $f = A$, $f = \bar{A}$, or $f = 0$. The functions $f = A$ and $f = \bar{A}$ indicate that the two switch sections can be replaced with one.

FIGURE 16. MULTIPLE SWITCH OR RELAY.



(d) When two or more multiple switches are considered, the network possibilities are greatly increased. Figures 18 through 21 (on the following pages) show some possible networks and simplified equivalents.

The examples shown in figures 18 through 20 give some idea of the use of Boolean algebra in reducing the number of switches (components) to do a certain job. The larger the job, the greater the value of Boolean algebra and the less chance of simplification by inspection.

FIGURE 17. NETWORK EXAMPLES.

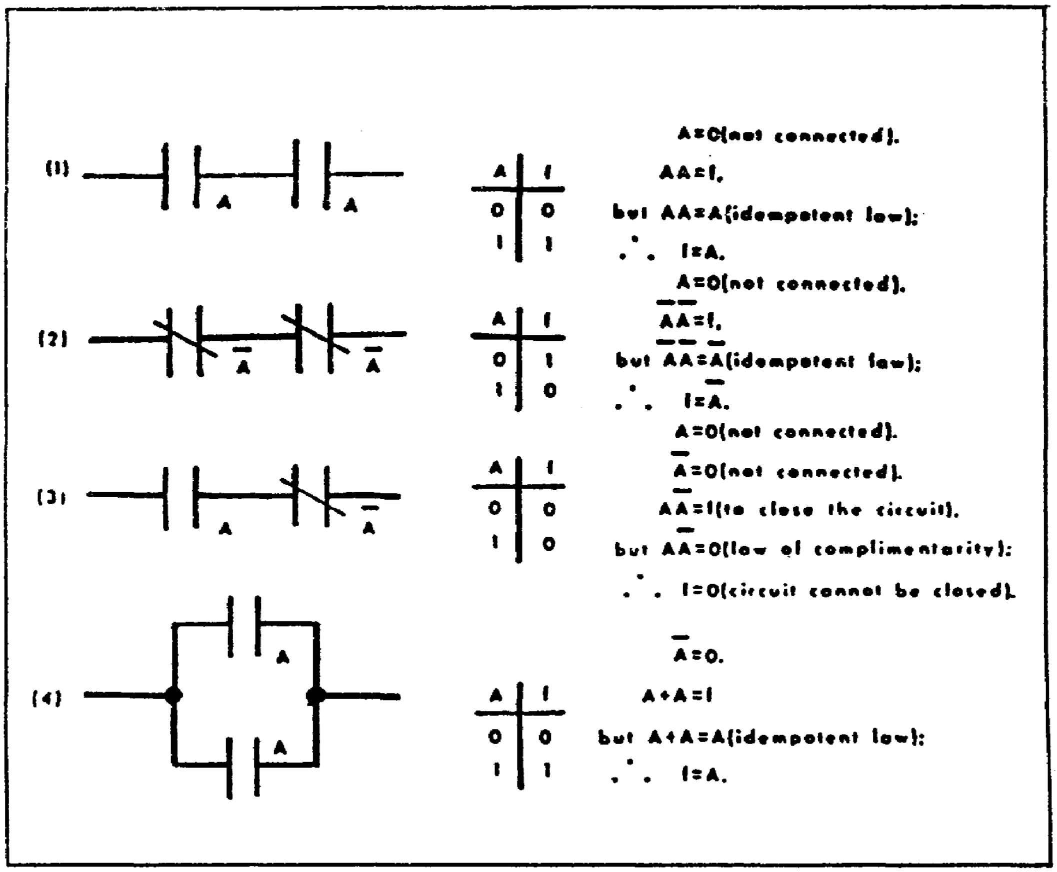


FIGURE 18. EXAMPLE 1.

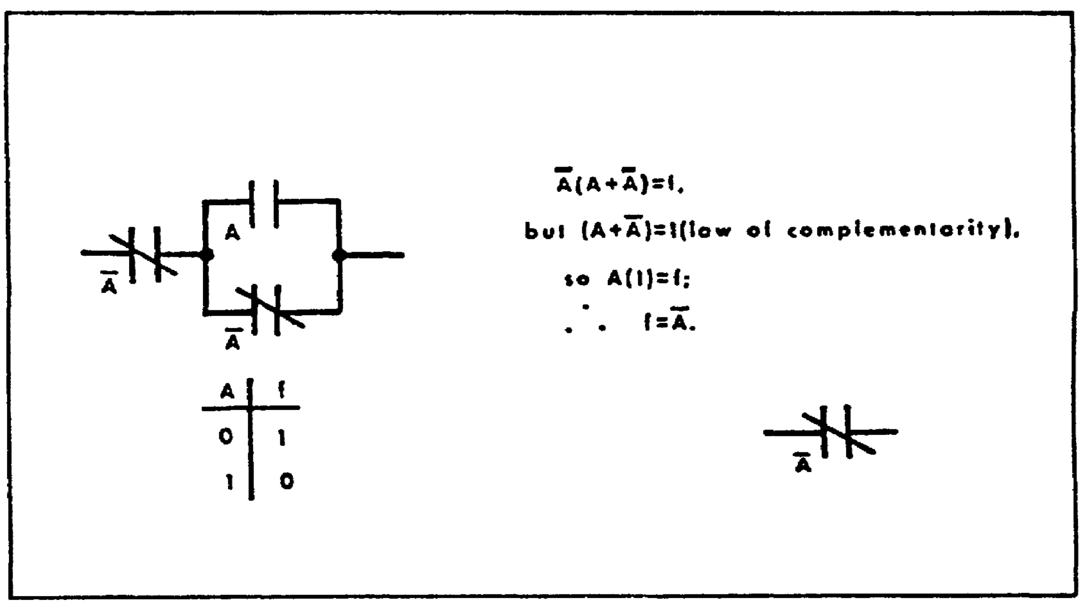
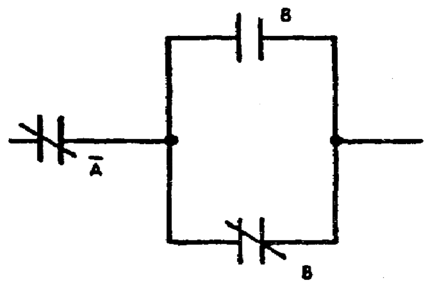


FIGURE 19. EXAMPLE 2.



$\bar{A}\bar{B}+\bar{A}B=f.$

$\bar{A}(\bar{B}+B)=f$ (distributive law).

$(\bar{B}+B)=1$ (law of complementarity).

$\bar{A}(1)=f;$

$f=\bar{A}.$

A	B	f
0	0	1
0	1	1
1	0	0
1	1	0

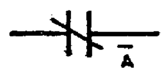
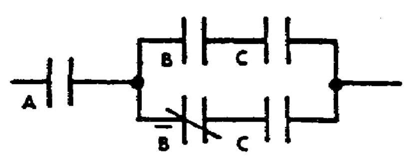
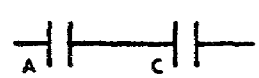


FIGURE 20. EXAMPLE 3.

A	B	C	f
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	1





$A\bar{B}C+ABC=f$ (from the truth table).

$AC(\bar{B}+B)=f$ (distributive law).

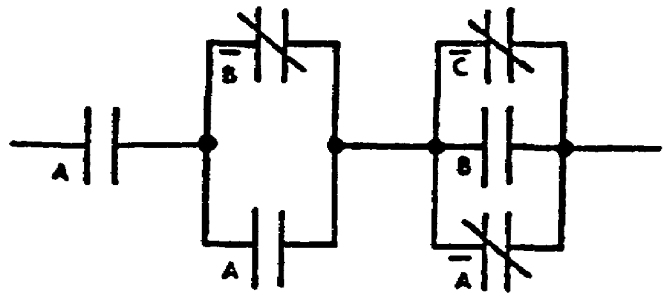
$\bar{B}+B=1$ (law of complementarity).

$AC(1)=f$

$\therefore$ $f=AC$ (the intersection of AC with 1 is AC).

FIGURE 21. EXAMPLE 4.

A	B	C	f
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1



$A\bar{B}\bar{C}+AB\bar{C}+ABC=f.$

$A(\bar{B}\bar{C}+B\bar{C}+BC)=f$ (distributive law).

$A\left[\bar{C}(\bar{B}+B)+BC\right]=f$ (distributive law).

$(\bar{B}+B)=1.$

$A\left[\bar{C}(1)+BC\right]=f.$

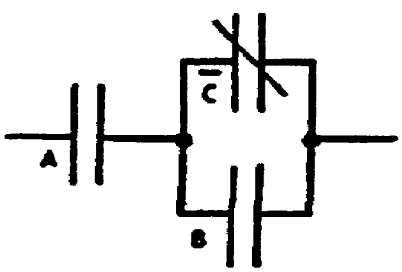
$A(\bar{C}+BC)=f.$

$(\bar{C}+BC)=(\bar{C}+B)(\bar{C}+C).$

$(\bar{C}+C)=1.$

$(\bar{C}+B)(1)=(\bar{C}+B);$

$A(\bar{C}+B)=f$



LESSON 1

THEORY OF BINARY NUMBERS, BOOLEAN ALGEBRA, DIODE LOGIC GATES, DIGITAL CIRCUITS, AND THEIR INTERRELATIONSHIP WITH DIGITAL COMPUTERS

TASK 4. Explain the theory of diode logic gates.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

It is possible to describe a switching network with a Boolean equation and, conversely, to mechanize a Boolean function with a switching network. The fundamental nature of a diode, electron tube, or semiconductor device is that of a switch in that it is a two-valued element that is either conducting (closed) or nonconducting (open). Although the idea of using a diode as a switch is not new, the large-scale use of diodes to produce an extensive switching network is of recent origin. The advantages of semiconductor diodes in switching networks are small size, fast response, low power requirement, reliability, and low cost. The main objective of this task is to show how extensive switching networks with diodes are constructed.

2. Diode Logic

A diode can be thought of as a voltage-operated switch. When the proper voltage conditions are present across the diode, the switch is closed; when the proper voltage conditions are not present, the switch is open. The diode circuit equivalent of switch contacts in series (AND circuit) and switch contacts in parallel (OR circuit) will be developed. Such circuits are commonly referred to as diode AND or OR gates, or gate circuits. Both AND gates and OR gates are classified as diode logic circuits.

a. *Diode AND Gate Circuit*. Consider the circuit in figure 22. The voltage between point C and ground is equal to E while the switch is open. Closing the switch applies ground to point C. An output taken from point C will be E volts or 0 volts, depending on whether the switch is open or closed.

FIGURE 22. SIMPLE SWITCH DECISION CIRCUIT.

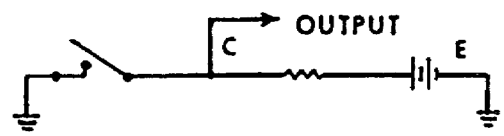
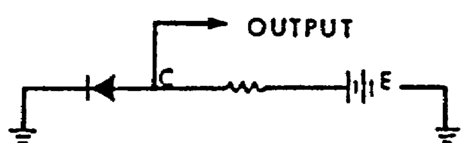


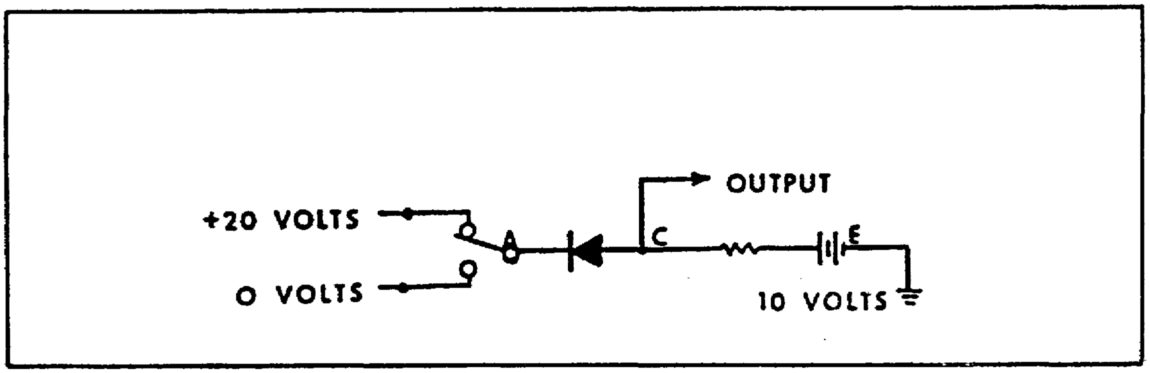
FIGURE 23. DEVELOPMENT OF DIODE DECISION CIRCUIT.



The switch has been replaced with a diode in figure 23. The output from point C will be E volts or 0 volts, depending on the polarity of E, which determines whether or not the diode conducts. As drawn, the output is 0.

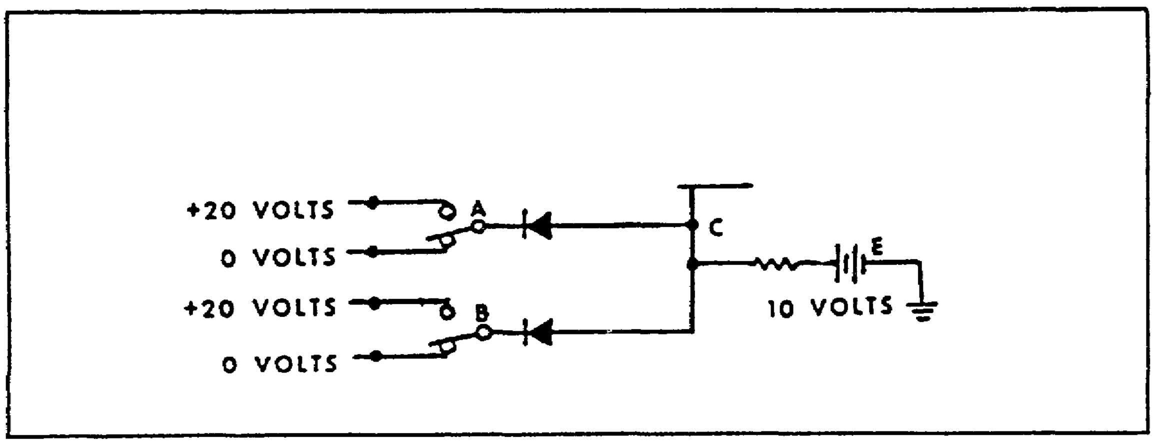
Connecting the diode's cathode (cathode is defined as a negatively charged electrode) to an input line on which the voltage can be changed is shown in figure 24. The output from point C will now be at 0 volts or + volts, depending on the position of switch A. As shown, the diode's cathode is positive with respect to its anode, it is not conducting, and +10 volts (E) is on the output lines. When the switch is the bottom position, the diode will conduct and 0 volts will be on the output line. The small forward resistance of the diode and the resultant small voltage drop can be ignored. An important point to note is that the diode performs as a decision element. By sensing the amplitude and polarity of the voltage on the input line, the output is either 0 or + 10 volts.

FIGURE 24. SIMPLE DIODE DECISION CIRCUIT.



Connecting two diodes side by side is shown in figure 25. With both switches as shown, both diodes will be conducting and the output will be 0 volts.

FIGURE 25. DIODE "AND" GATE, OUTPUT 0 VOLTS (NUMBER 1).



With switch A set to 0 volts and switch B set to + 20 volts (figure 26 on the following page), diode A is conducting and diode B is cut off. The output is 0 volts because diode A is conducting. Reversing the settings of switches A and B will reverse the status of conduction of the diodes but the output will remain at 0 volts because one diode is conducting. Setting both switches to + 20 volts (figure 27 on the following page) causes both diodes to be cut off (no current flows in the resistor) and the output is + 10 volts from the supply. Only this condition results in output of + 10 volts.

FIGURE 26. DIODE "AND" GATE, OUTPUT 0 VOLTS (NUMBER 2).

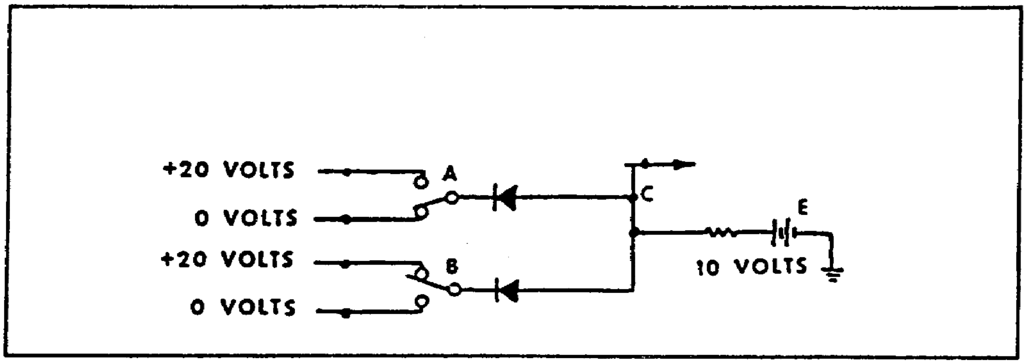
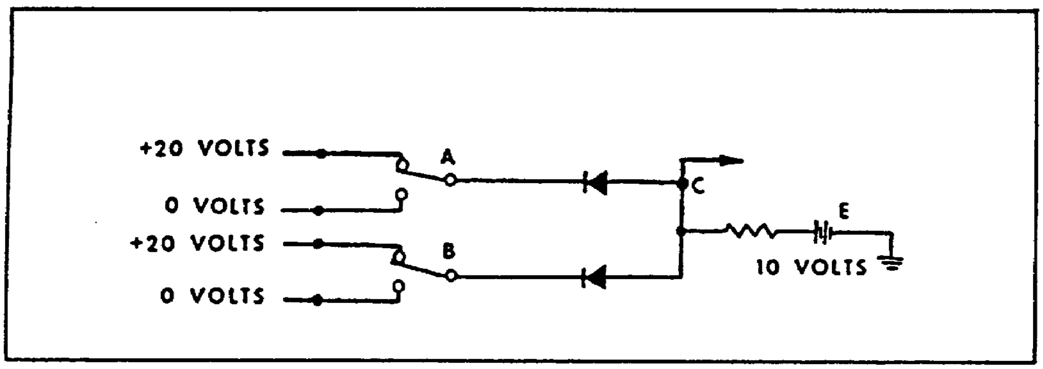


FIGURE 27. DIODE "AND" GATE, OUTPUT +10 VOLTS.



By letting 0 represent the low condition (O volts) and 1 represent the high condition (+10 volts), the circuit behavior can be described with a truth table (table 14). The function f = AB describes two series-connected switches. With the conditions established, this function also describes the

TABLE 14. TRUTH TABLE FOR f = AB.

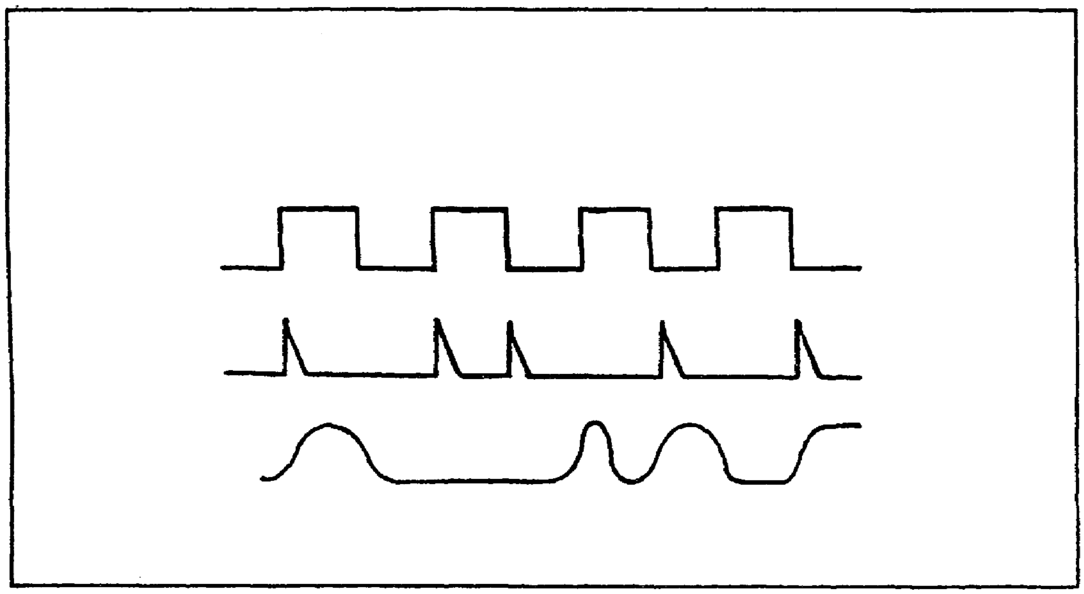
A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

C = AB pr f = AB

previously discussed diode circuit. You may then say with certainty that the diode circuit is the logical equivalent of two series connected switches. This is a diode AND gate. To add more diodes would be equivalent to adding more switch contacts to the series string.

Input lines A and B need not originate as manually operated switches, but can be connected to any circuit element that can switch between two voltage values. Figure 28 shows some permissible voltage waveforms on the input lines.

FIGURE 28. WAVEFORMS.



The essential requirement that a diode AND gate must meet is that the output is 1, if all the inputs are 1. The designer has complete freedom in choosing the voltage values to be represented by 0 and 1, the polarity and amplitude of the supply voltage, and the direction of connection of the diode. Of course, the choice of one affects the others. Figures 29 through 31 (on the following pages) show some circuit possibilities. The conventional schematic configurations for diode logic circuits are used in these examples. The f column of the truth table shows the value of the output for each possible combination of the input voltages.

FIGURE 29. TWO INPUT DIODE "AND" GATE.

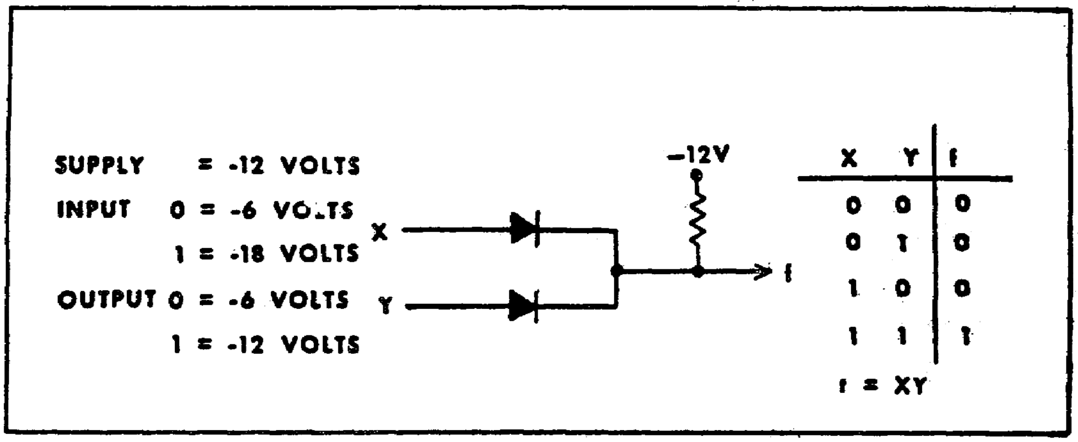
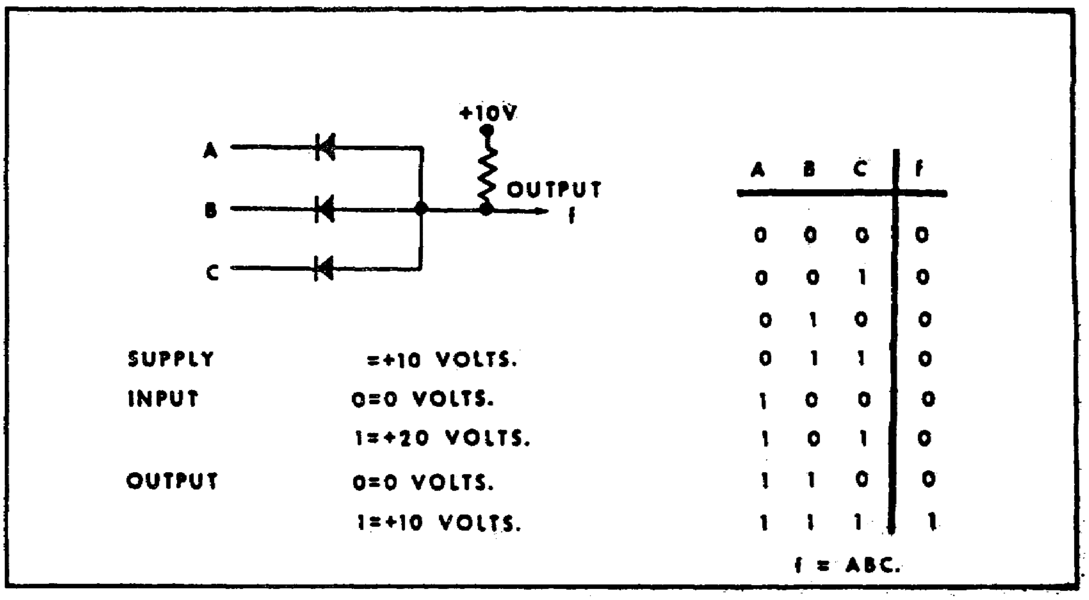
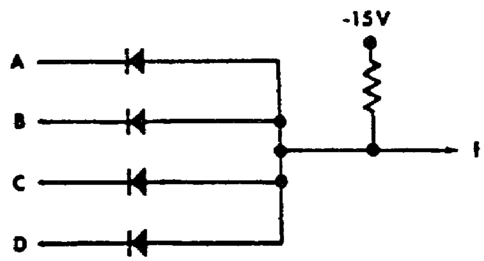


FIGURE 30. THREE INPUT DIODE "AND" GATE.



b. *Diode "OR" sate Circuit.* You cannot determine whether the OR or the AND operation is performed by a diode logic circuit if the input and supply voltages are not known. Only the relative polarities and values of the input and supply voltages, and their representation by 0 or 1, will determine whether a given diode circuit functions as an OR or an AND circuit, as shown in figure 32 on the following page.

FIGURE 31. FOUR INPUT DIODE "AND" GATE.



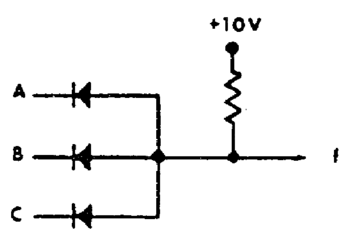
SUPPLY	=-15 VOLTS.	
INPUT	0=-25 VOLTS.	
	1= -5 VOLTS.	
OUTPUT	0=-25 VOLTS.	
	1=-15 VOLTS.	

A	B	C	D	f
0	0	0	0	0
0	0	0	1	0
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0
0	1	0	1	0
0	1	1	0	0
0	1	1	1	0
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	0
1	1	0	0	0
1	1	0	1	0
1	1	1	0	0
1	1	1	1	1

$f = ABCD$

FIGURE 32. THREE INPUT DIODE "OR" GATE.

SUPPLY	=+10 VOLTS.	
INPUT	0=+20 VOLTS.	
	1= 0 VOLTS.	
OUTPUT	0=+10 VOLTS.	
	1= 0 VOLTS.	



A	B	C	f
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

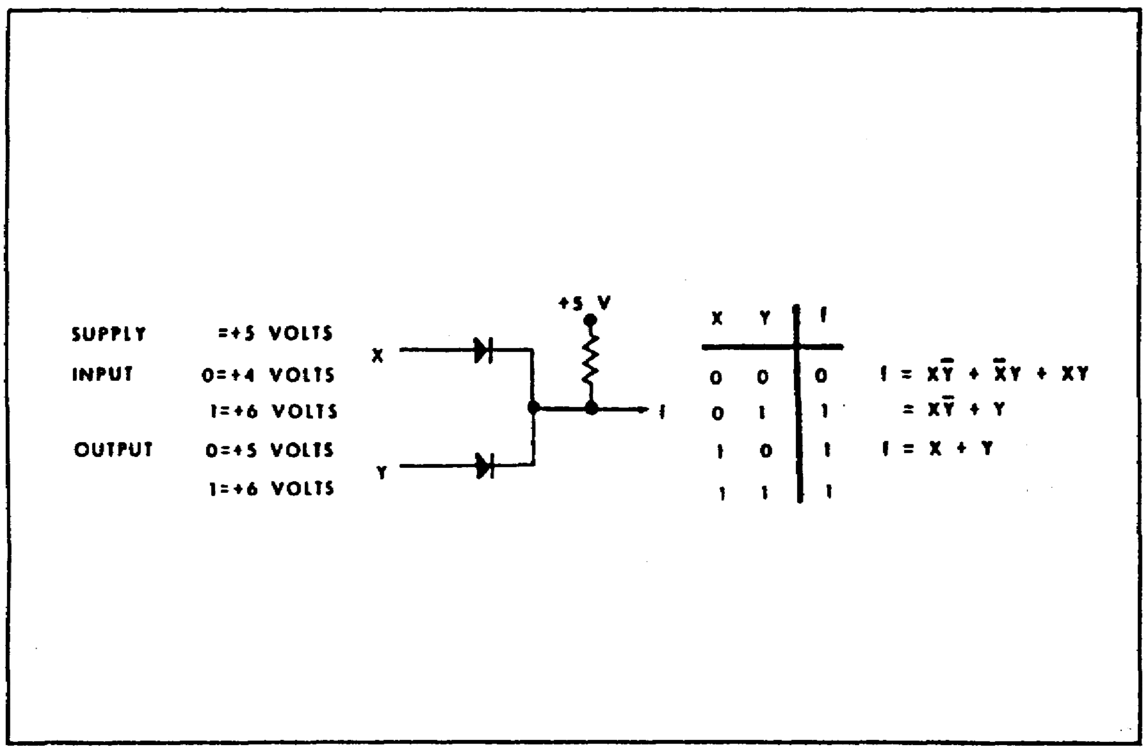
$$f = \bar{A}\bar{B}C + \bar{A}B\bar{C} + \bar{A}BC + A\bar{B}\bar{C} + A\bar{B}C + AB\bar{C} + ABC$$
$$= \bar{A}(\bar{B}C + B\bar{C} + BC) + A(\bar{B}\bar{C} + \bar{B}C + B\bar{C} + BC)$$
$$= \bar{A}(\bar{B}C + B) + A(\bar{B} + B)$$
$$= \bar{A}(C + B) + A.$$
$$f = A + B + C.$$

Figure 32 (on the previous page) shows how you can take the AND gate circuit of a previous example (figure 29 on page 46) and interchange the voltage values that represented conditions 0 and 1, on both input and output lines. The voltage polarities and values, both input and supply, remain unchanged. No change occurred within the circuit itself; the diodes still conduct only when the anode is positive with respect to the cathode. (Anode is defined as any positively charged electrode.)

The differences in the two circuits are that in the AND gate, the function is realized only when a certain voltage (+ 20 volts) is present simultaneously on all input lines. This condition results in a certain voltage (0 volts) being present on the output line.

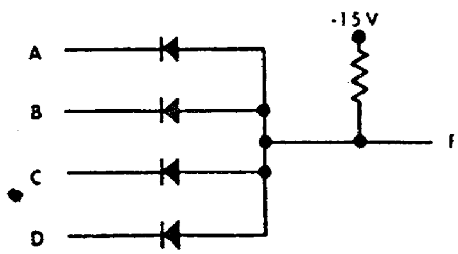
With respect to the truth tables, the 0 is generally regarded as representing a false promise or proposition. With respect to voltages, however, one voltage can be considered just as true or just as false as another. It is not the voltages themselves that are being labeled as true or false, but rather the propositions that are represented by the voltages. Figure 33 shows the exclusive use of

FIGURE 33. DIODE "OR" GATE, ALL VOLTAGES POSITIVE.



positive voltages, while figure 34 shows the exclusive use of negative voltages.

FIGURE 34. DIODE "OR" GATE, ALL VOLTAGES NEGATIVE.



A	B	C	D	f
0	0	0	0	0
0	0	0	1	1
0	0	1	0	1
0	0	1	1	1
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	1
1	0	0	1	1
1	0	1	0	1
1	0	1	1	1
1	1	0	0	1
1	1	0	1	1
1	1	1	0	1
1	1	1	1	1

SUPPLY = -15 VOLTS

INPUT 0 = -10 VOLTS

1 = -20 VOLTS

OUTPUT 0 = -15 VOLTS

1 = -20 VOLTS

$$f = \bar{A}\bar{B}\bar{C}D + \bar{A}\bar{B}C\bar{D} + \bar{A}\bar{B}CD + \bar{A}B\bar{C}\bar{D} + \bar{A}B\bar{C}D + \bar{A}BC\bar{D} + \bar{A}BCD + A\bar{B}\bar{C}\bar{D} + A\bar{B}\bar{C}D + A\bar{B}C\bar{D} +$$

$$A\bar{B}CD + AB\bar{C}\bar{D} + AB\bar{C}D + ABC\bar{D} + ABCD$$

$$= \bar{A}(\bar{B}\bar{C}D + \bar{B}C\bar{D} + \bar{B}CD + B\bar{C}\bar{D} + B\bar{C}D + BC\bar{D} + BCD) + A(\bar{B}\bar{C}\bar{D} + \bar{B}\bar{C}D + \bar{B}C\bar{D} + \bar{B}CD +$$

$$B\bar{C}\bar{D} + B\bar{C}D + BC\bar{D} + BCD)$$

$$= \bar{A}\left[\bar{B}(\bar{C}D + C\bar{D} + CD) + B(\bar{C}\bar{D} + \bar{C}D + C\bar{D} + CD)\right] + A\left[\bar{B}(\bar{C}\bar{D} + \bar{C}D + C\bar{D} + CD) +\right.$$

$$\left. B(\bar{C}\bar{D} + \bar{C}D + C\bar{D} + CD)\right]$$

$$= \bar{A}\left[\bar{B}(\bar{C}D + C) + B(\bar{C} + C)\right] + A(\bar{C}\bar{D} + \bar{C}D + C\bar{D} + CD)$$

$$= \bar{A}\left[\bar{B}(D + C) + B(1)\right] + A(\bar{C} + C)$$

$$= \bar{A}(\bar{B}D + \bar{B}C + B) + A(1)$$

$$= \bar{A}(\bar{B}D + C + B) + A$$

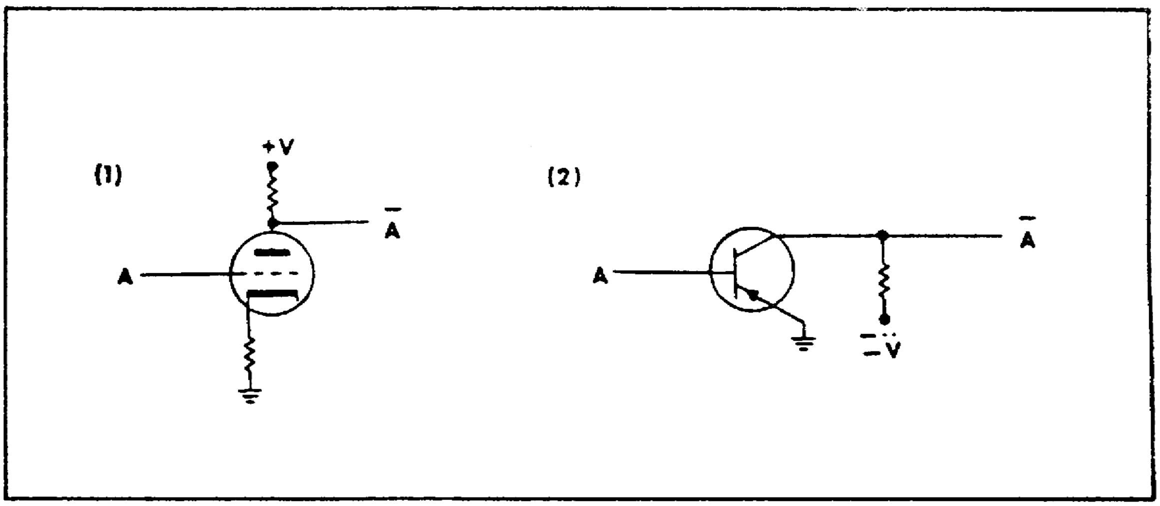
$$= \bar{A}(D + C + B) + A$$

$$= (D + C + B) + A$$

$$f = A + B + C + D$$

c. *AND and OR Gates Combined*. The diode gate circuits have been presented individually; they may be combined as necessary to mechanize such functions as $f = ABC + \overline{A}B\overline{C}$. At this time, we will consider the inversion or NOT (negation) circuits. With switches and relays, it is possible to use the NC contacts to express the inverted or NOT form of a given variable. Diodes do not have the equivalent of the NC contacts, thus an additional circuit is required. This reduces to a simple problem since negation of any giver voltage is its inverse. A simple inversion stage is all that is required. The triode vacuum tube and the transistor common emitter circuits, shown in figure 35, are commonly used as inverters.

FIGURE 35. INVERSION STAGES.



The schematic combination of diode gates and associated inverter stages is greatly simplified by the use of certain schematic symbols, called graphic symbols, to represent separate but entire stages. Figure 36 (on the following page) shows some of the graphic symbols in current use. Diagrams composed of these symbols are called logic diagrams. The logic symbols, to the left in figure 36 on the following page, are approved by the Department of Defense.

Figure 37 (on the following page) shows a Boolean function mechanized (constructed) with diode logic circuits. Both the schematic and logic diagrams are drawn so that their comparative merits can be determined. This example shows that the logic diagram (figure 37(2)) is simpler than the schematic diagram (figure 37(1)). Of even greater importance is that the logic diagram reveals immediately the operation being performed by a given stage. Combinations of AB and CD on figure 37(1) make it possible to distinguish the AND gate from the OR gate.

FIGURE 36. LOGIC SYMBOLS.

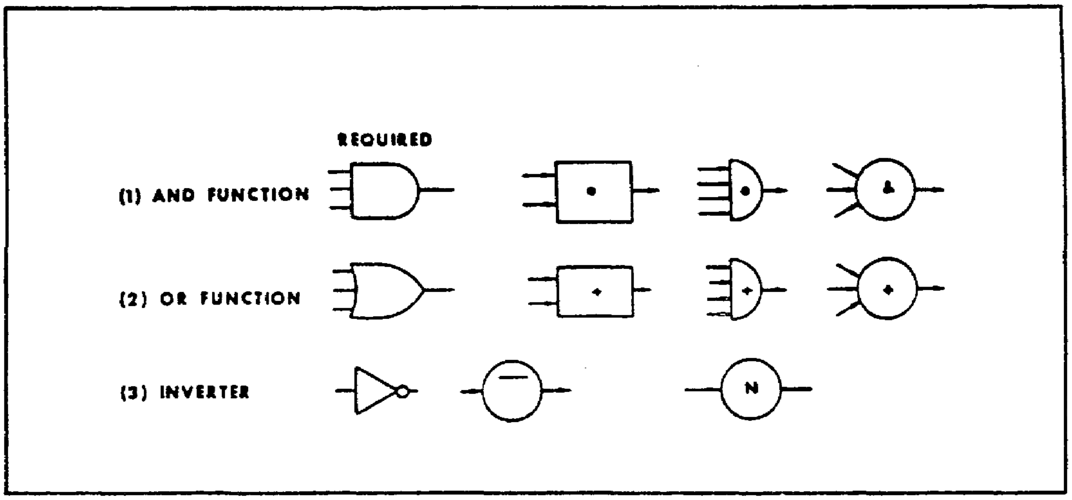
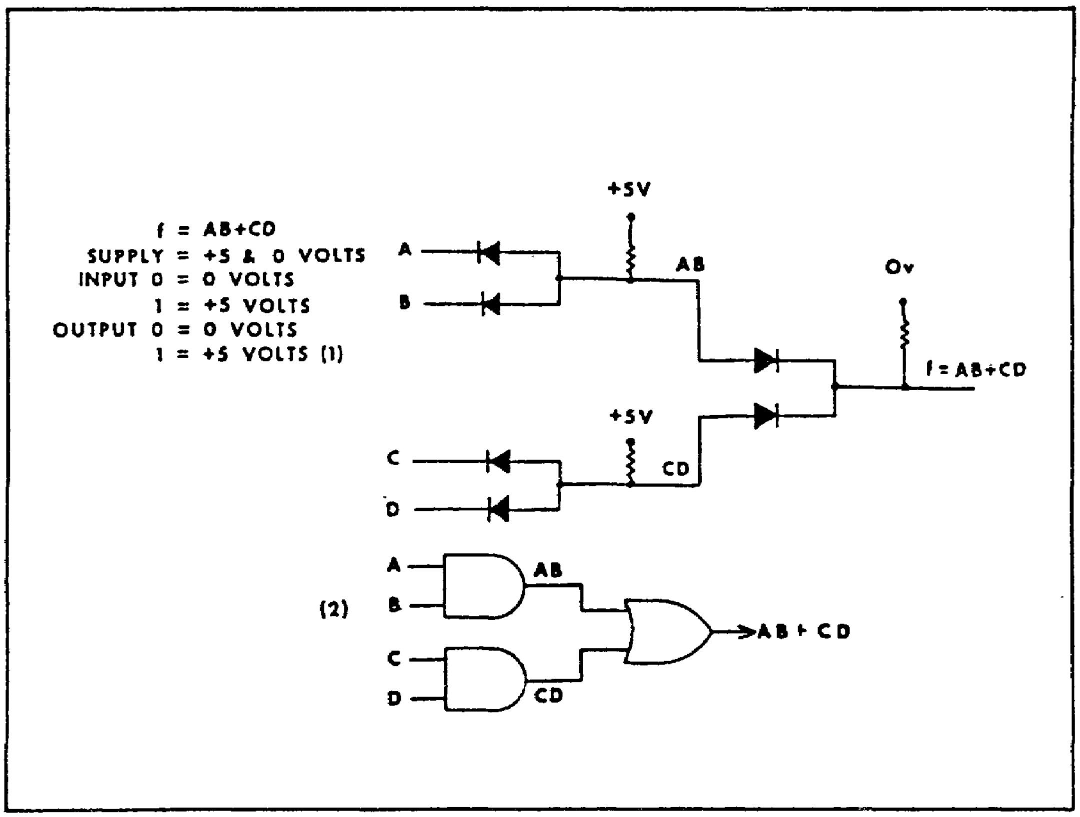


FIGURE 37. COMPARISON OF SCHEMATIC AND LOGIC SYMBOLS.



In the logic diagram portion of figure 37 (on the previous page), neither voltage values nor letters are needed to recognize the logical operations that are being performed.

It is possible to determine the number of diodes needed to mechanize a given function. There is a requirement of one diode for each input gate. The logic circuit shown in figure 38 requires 8 diodes for the AND gates and 3 diodes for the OR gate, a total of 11 diodes. Because cost is always a factor considered in the production of equipment, the designer must make every effort to use the smallest number of components. This means that he must simplify the Boolean expression to the form that requires the fewest number of diodes and related components for mechanization. Quick recognition of the expression that requires the fewest number of diodes requires an ability to count diodes in the algebraic expression without drawing the logic diagram. Of course, this ability is not required of the computer maintenance personnel as it is with the designer. In the equation in figure 38, there are 8 letters and 3 terms for a total of 11 diodes. Figure 39 (on the following page) shows how an expression may be broken down to simplify a circuit. A comparison is made between two circuits that will do the same job, but one (the lower) uses fewer components.

FIGURE 38. LOGIC DIAGRAM.

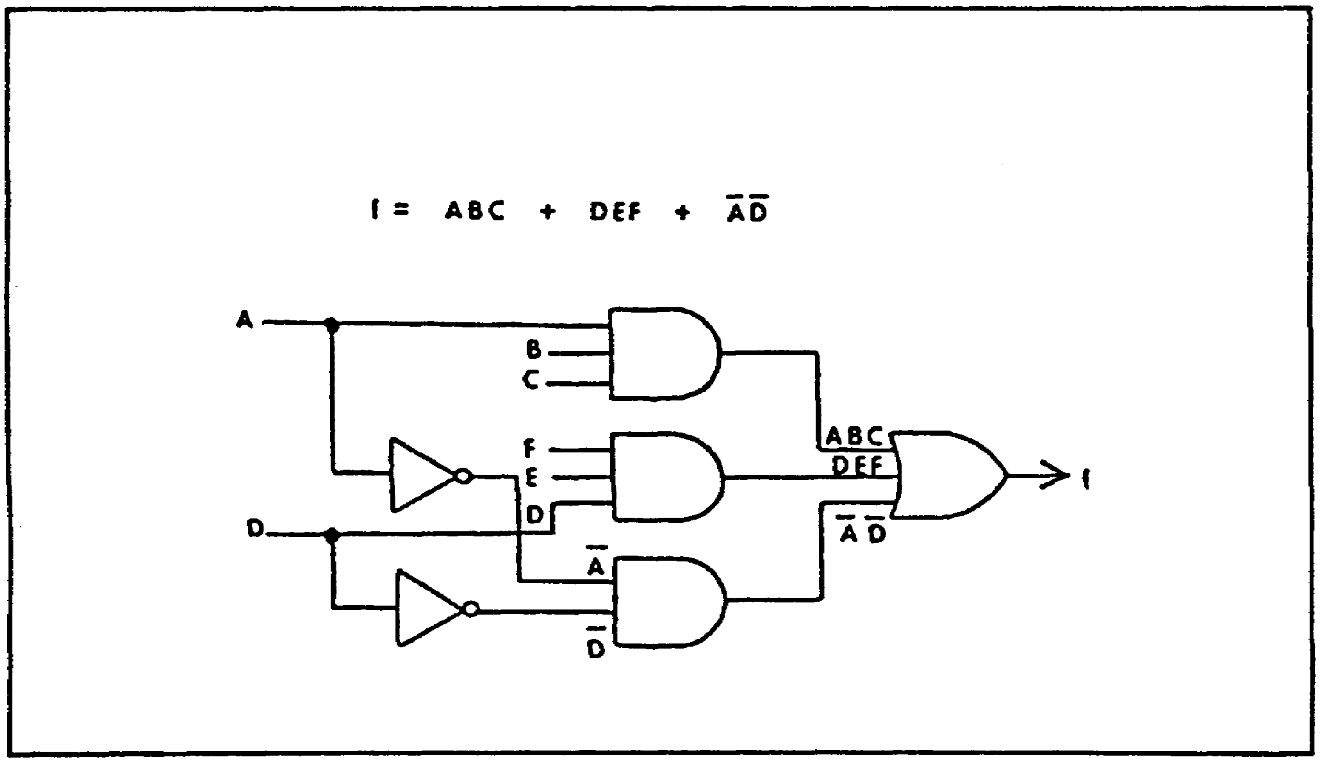
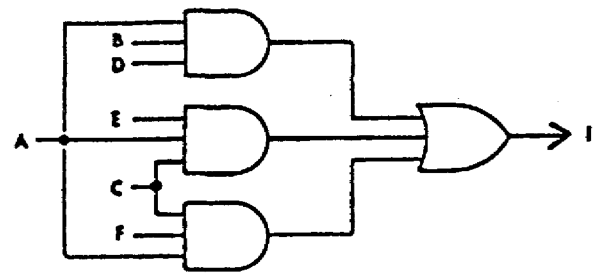


FIGURE 39. COUNTING DIODES TO DETERMINE RELATIVE SIMPLICITY.

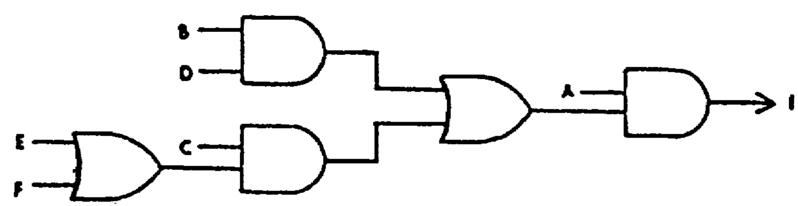


SIMPLIFYING:

f = ABD + ACE + ACF
= A(BD + CE + CF)
f = A(BD + C(E + F))

(E + F)	2 diode OR
C(E + F)	2 diode AND
BD	2 diode AND
BD + C(E + F)	2 diode OR
A (BD + C(E + F))	2 diode AND
	10 diode total

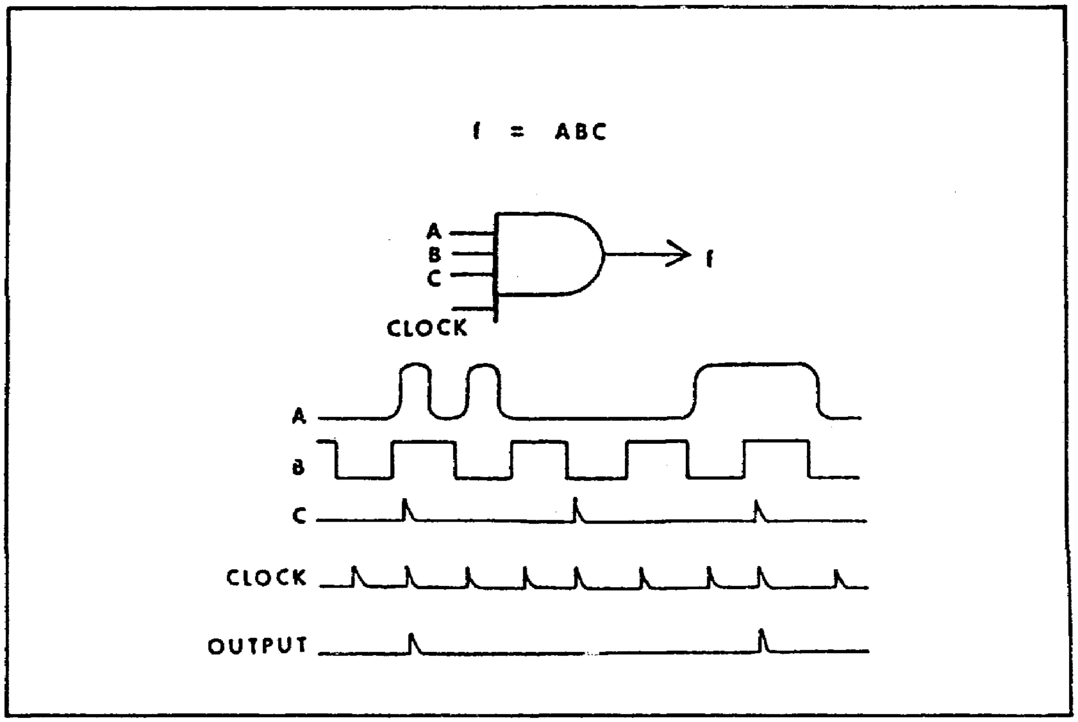
f = A(BD + C(E +F))



d. *Application of Clock Pulses*. It has previously been stated that the operations in a digital computer can occur at fixed time intervals. The response and operating time of the computing elements is so short that the duration of the operation is of the order of nanoseconds (one billionth part of a second) or, at the most, a few microseconds. This fact, coupled with the fast recovery time of the computing elements, allows the performance of logical and arithmetic operations at a frequency of one million or more per second. The master synchronizing signal or clock pulse can have a frequency of this order. The clock pulse is distributed throughout the computer to perform the timing function, and certain computing elements are designed so that they will not function in the absence of a clock pulse. The ways in which the operation of diode AND and OR gates may be made dependent upon the clock pulse will be explained.

A simple method of timing the operation of an AND gate is to apply the clock pulse as one of the required inputs. With this arrangement, an output is obtained only when all inputs and the clock pulse are present. Figure 40 shows such a circuit and a possible input-output waveform relationship.

FIGURE 40. CLOCK PULSE APPLICATION.



The timing of an OR gate cannot be done by applying the clock pulse as one of its logic inputs. An attempt to do so would result in an unbroken chain of clock pulses in the output, periodically combined with the other logic inputs. The basic problem is to enable the OR gate with the clock pulse. This use would allow the gate circuit to produce an output only while a clock pulse is present. To do this, the clock pulse would be used as the supply voltage. The circuit would now resemble an AND gate in that the clock pulse and at least one logic input are needed to produce an output. Any necessary timing below the clock frequency can be generated by gating the clock pulse.

LESSON 1

THEORY OF BINARY NUMBERS, BOOLEAN ALGEBRA, DIODE LOGIC GATES, DIGITAL CIRCUITS, AND THEIR INTERRELATIONSHIP WITH DIGITAL COMPUTERS

TASK 5. Explain the theory of digital circuits.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

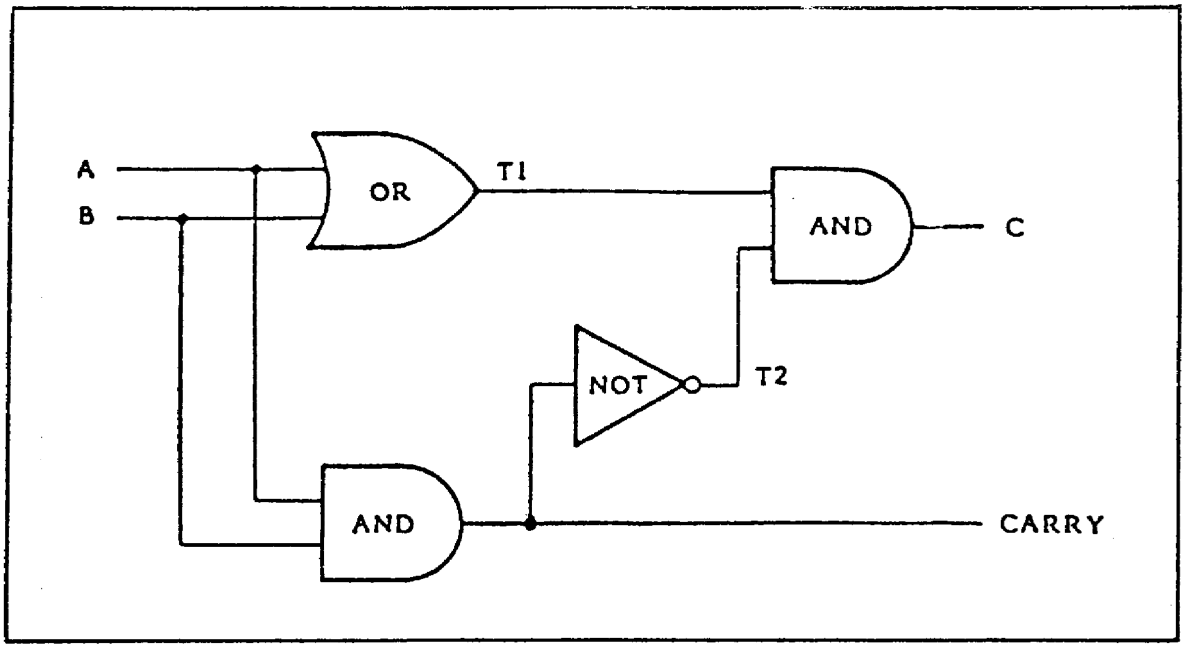
1. Introduction

A general definition of digital circuits is that they are a combination of gates designed by logic designers to process signals. Such circuits can include switches, diodes, transistors, or integrated circuits. The number of such elements employed and the way in which they are interconnected depend upon the Boolean function(s) being mechanized.

2. Digital Circuits.

Through the use of combinations of cooperating digital processes (gates), (gates are defined as the most basic form of digital processes which are the basis for logic design) we can construct digital circuits or, synonymously, gating networks. The digital circuits (networks) are designed to perform some processing logic. For example, the addition of two binary input digits (A and B) with the resulting output digit C and the CARRY. This circuit can be constructed as shown in figure 41 on the following page.

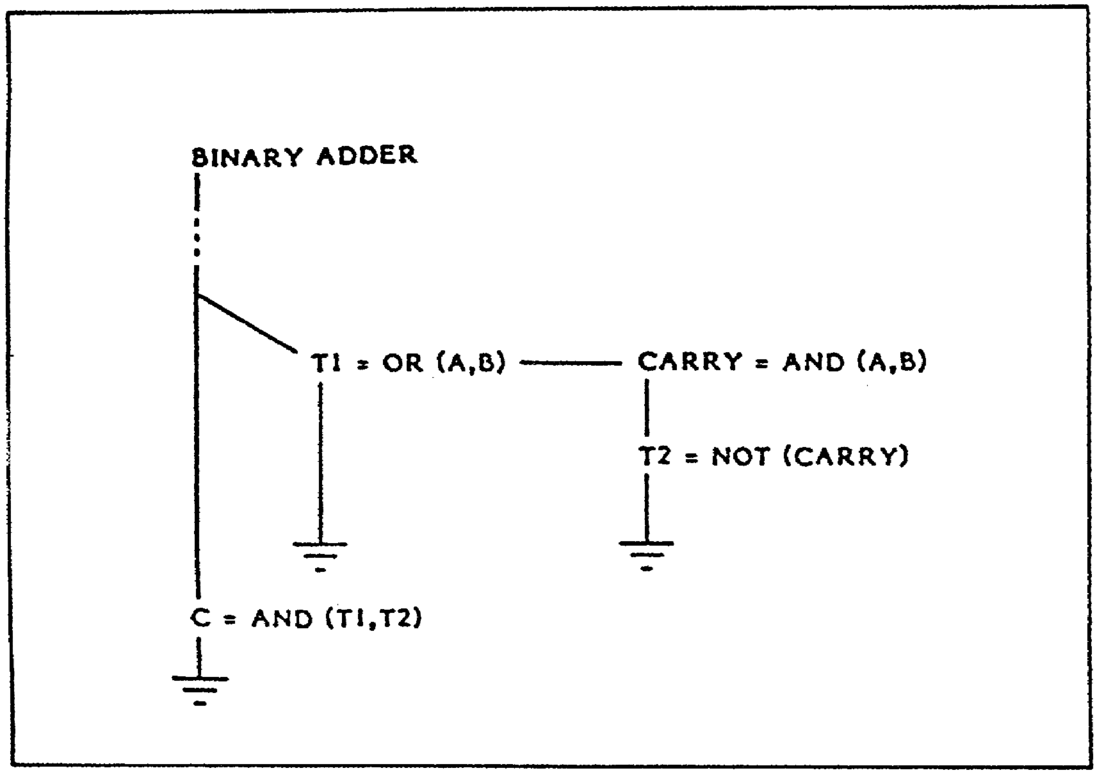
FIGURE 41. AN ADDER OF TWO BINARY DIGITS.



This type of digital circuit, which works on combinations of signals and gating processes is called a combinational circuit. Notice that the two input values A and B are sent to both the OR gate and the first AND gate at the same time; thus these two gating processes are executed as "parallel sequences." (Parallel sequences are defined as sequences of logic that are executed simultaneously, that is, at the same time). Next, the NOT gate is executed and finally the last AND gate is executed. Note that the CARRY was produced early in the circuit execution and the value of C at the latter part of the circuit execution. Thus, when signals are applied at the inputs A and B, further signals are generated as gate outputs. This generation of signals is called signal propagation. (Signal propagation is defined as the movement of signals through a digital circuit (gating network.)).

The total time that the circuit executes in producing its outputs is called the propagation time of the circuit. Propagation times for an adder circuit of this type are based upon the technology of the "transistor" used to realize the gates; however, in many modern technologies it can be as little as 2 to 3 nanoseconds (that is 2 to 3 billionths of a second). The reason for the great speed of computer systems should now be obvious. The logic of this adder circuit can also be represented in our dimensional flowchart process form shown in figure 42.

FIGURE 42. BINARY ADDER LOGIC.

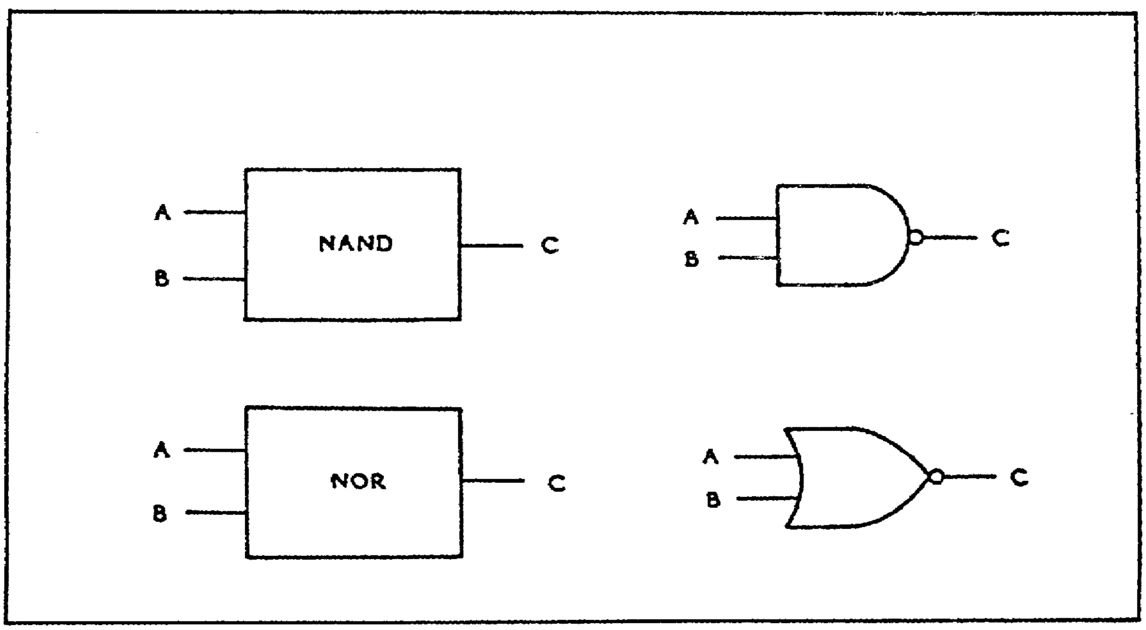


Here, we note the use of intermediate signals, labeled T1 and T2 as indicated in figure 41. The use of the equal sign (=) in this context means that the signal to the left of the equal sign receives the output value of the named gate processes, which have their inputs indicated in parenthesis. Note the use of "parallel sequence" execution of the logic sequences. Observe, however, that the NOT gate must be executed prior to the final AND gate.

It is important to recognize that in the building of this digital circuit, a new digital process (which is composed of gate processes) has been created. This is the beginning of the construction of many "higher level processes" that will go all the way up to the end "users" of the computer system. The illustration of the adder of two binary digits is called a half adder. (A half adder is defined as a combinational circuit designed to add two binary digits without logic for accommodating a carry in.) A half adder is a basic process that is used in a so-called full adder; that is, an adder process which, in addition to the logic of a half adder, includes the logic to take account of carries from other adder circuits. There are basically two strategies used for the adders in computer systems; namely, serial adders, which add one digit from each input value during a time frame, and including carry logic and parallel adders, which add all digits of the two values during the same time frame. Parallel adders are normally designed to deal with a fixed number of binary digits of precision (example 2, 4, 6, etc.). It is possible to build parallel adders from 2 to 64 bits of precision that have a "propagation time" of 6-8 nanoseconds.

Flip/flops (latches) are memory elements that retain their states while power is supplied to the computer system. A flip/flop is realized via the use of gate processes. Two additional gate processes which are basic building blocks of logic design; are the NAND gate and the NOR gate, which are represented in figure 43.

FIGURE 43. ADDITIONAL BASIC DIGITAL PROCESSES.



These gates are simply combinations of the use of an AND gate or an OR gate, followed by a NOT gate. Thus, they are single gate processes which are equivalent to the simple digital circuits shown in figures 44 and 45 on the following page.

FIGURE 44. CIRCUIT EQUIVALENT TO THE NAND GATE.

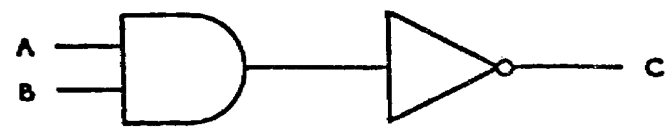
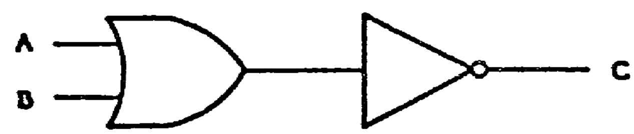


FIGURE 45. CIRCUIT EQUIVALENT TO THE NOR GATE.

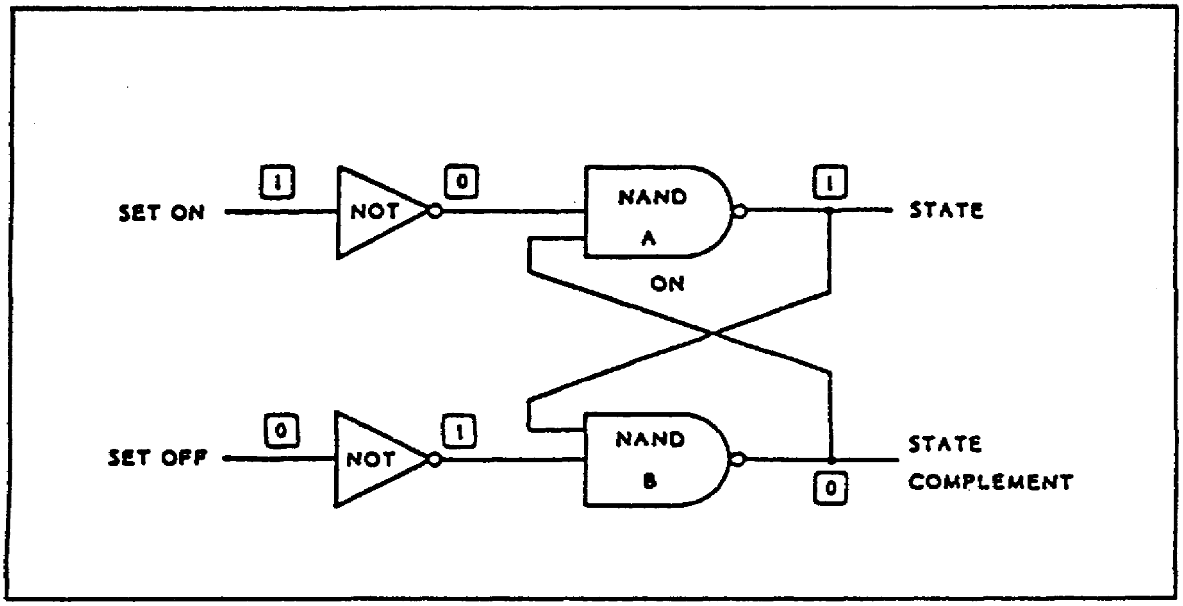


As with the AND, OR and NOT gates, a complete enumeration of all possible inputs and outputs of these two gates is shown below:

	SIGNAL VALUES		
GATE	A	B	C
NAND	0	0	1
	0	1	1
	1	0	1
	1	1	0
NOR	0	0	1
	0	1	0
	1	0	0
	1	1	0

In earlier enumeration of the AND and OR gates, it can be observed that in all cases, the output C is simply the complement (opposite value) of the AND and OR gate results for C. IMPORTANT: Our list of gate processes is now complete. This is the entire set used for logic design of all possible digital circuits. Returning to the flip/flop, a digital circuit will be used to show a flip/flop process. A possible circuit for this process appears in figure 46.

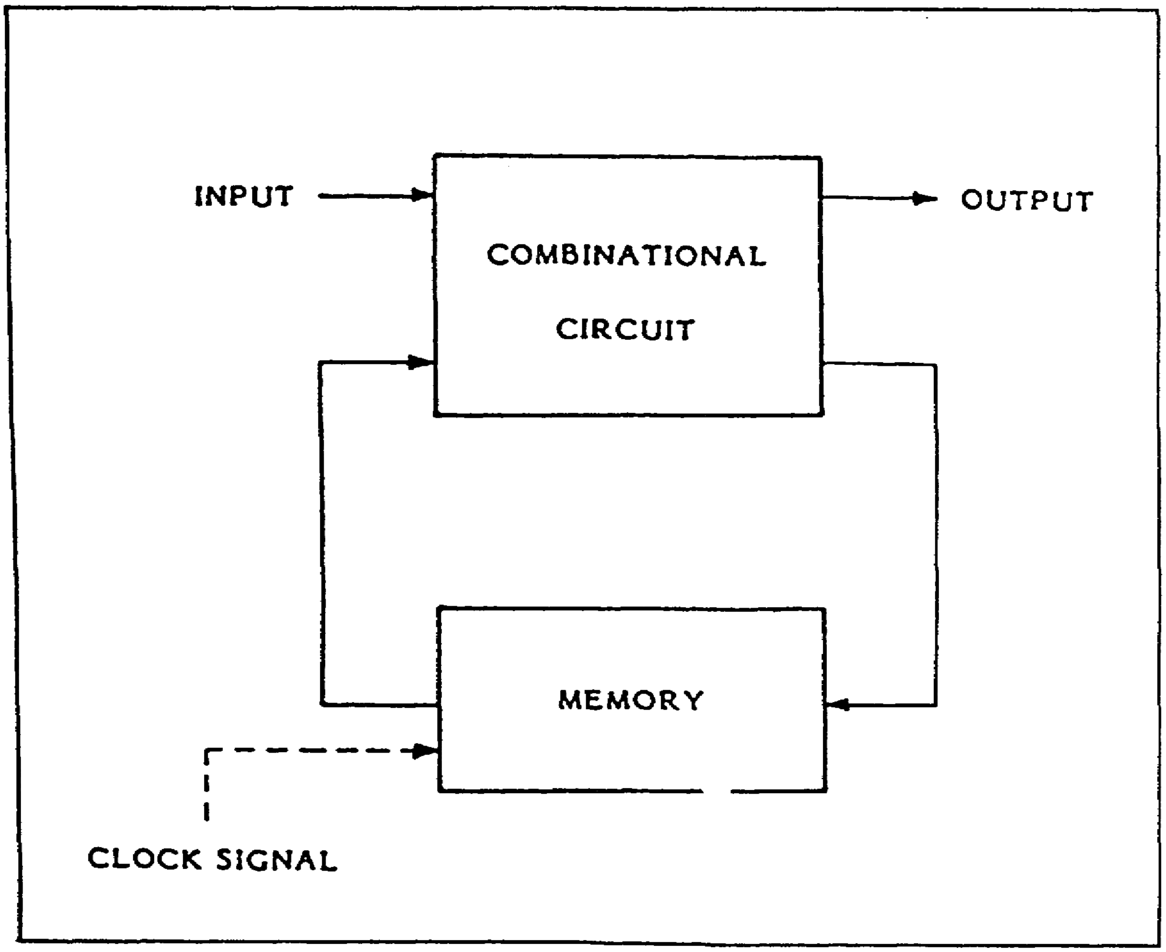
FIGURE 46. FLIP/FLOP CIRCUIT DIAGRAM.



The values in boxes represent the signal values where 1 is for high voltage (for example + 2 volts) and 0 is for low voltage (for example 0 volts). Observe that when the SET ON line is 1, its complement, given by the NOT gate, is 0 and is one input to NAND gate A; the other input must also be 0 if NAND gate A is to give a 1 as the STATE of the flip/flop. This is assured in this case by the SET OFF line being 0 resulting in a complement of 1 via the NOT gate and thus causing NAND gate B to have a 0 result as the STATE COMPLEMENT of the flip/flop. Note the coupling of the output of each NAND gate back into the other NAND gate as an input.

The clock signal used to specify "when" the flip/flop value is to be changed has not been illustrated. However, this is accomplished by using two AND gates prior to the two NOT gates in which the clock signal and the respective SET ON, SET OFF signals are inputs to the respective AND gates. The approach used to realizing the flip/flop process is only one approach. It is possible to use other gating network circuits which provide the equivalent flip/flop process function. As previously mentioned, flip/flops have the ability to retain the state ON or OFF as long as power is supplied. Flip/flop elements are an important part of the second major form of digital circuit, namely the "sequential circuit", which combines a memory element (one or more flip/flops, perhaps a register, or even a larger memory array), and a combinational circuit, as indicated in figure 47.

FIGURE 47. A SEQUENTIAL CIRCUIT.

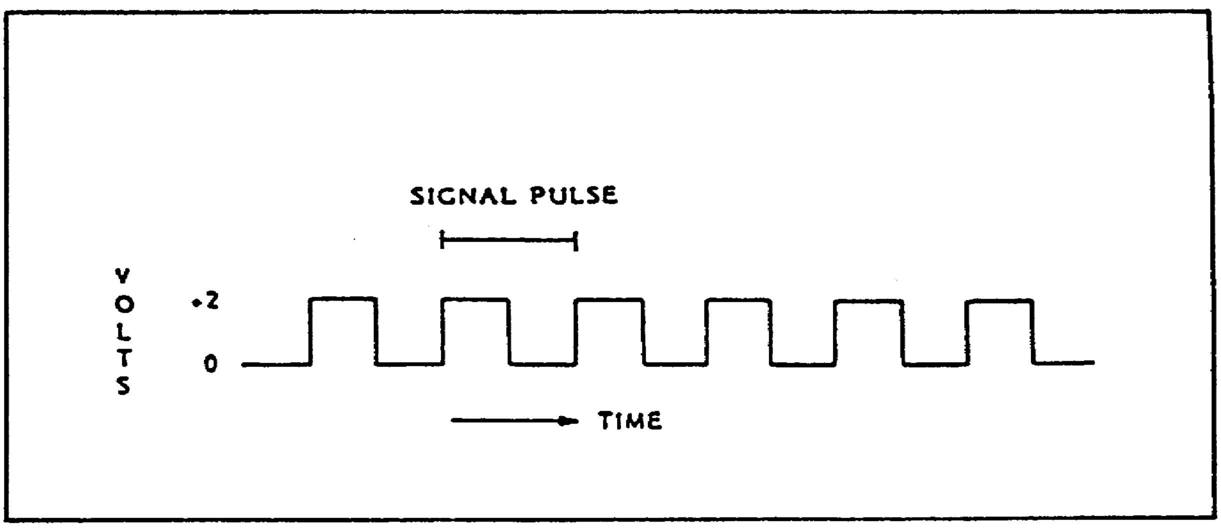


The word sequential should be taken to mean that things happen in sequence, one after another. The clock signal determines when things will happen. For example, at the time of the clock signal, the current state of all or part of the memory flip/flop may be "read out", along with a new input, and delivered to the gates of the combinational circuit for execution. After propagation through this gating network, at the next marking of the clock signal, the results are stored back into all or some of the flip/flops in the memory, and outputs may be produced.

A sequential circuit is the lowest level of "finite state machine" in computer systems. (Finite state machine is defined as the name given to a machine that has a limited number of unique states.) The state transitions occur at the time of a clock signal when the results are stored back into the memory. "Previous states", as well as new inputs, are taken into account in generating the "next states" and possible outputs.

The final subject of this discussion of digital circuits is the question of the "timing sequence", as provided by a clock signal. The clock signal is the true "driver" of digital processes, it controls the operation of a digital computer. In digital processes, clock signals are generated as an "oscillating" signal. That is, the value of the signal alternates between high and low voltage levels, as indicated in figure 48.

FIGURE 48. THE OSCILLATIONS OF A CLOCK SIGNAL.



Again, 0 volts and + 2 volts are used to illustrate low and high voltages. This form of signal, in general, is called a square edge signal and each individual oscillation is called a signal pulse. When the pulse rises to high voltage, it is called the leading edge of the pulse, when it is descending it is referred to as the trailing edge.

The clock signal is delivered to the sequential circuits of the cooperating hardware processes, where normal AND and NAND gates are used to determine the starting and ending points of logic execution within the circuit. In sequential circuits, for example, input values and memory values are delivered to the combinational circuit at the "leading edge" of a clock pulse, results must be propagated ("produced") for storing into the memory, and outputs produced, at the time of the next leading edge pulse.

The rate of oscillation of the clock pulse determines the performance of the hardware logic. However, the logic must be designed so that all necessary propagations within the circuits activated at the leading edge are completed before the next leading edge. The faster circuits are forced to wait upon the slowest of circuits (the worst case).

a. *Diode Gates*. The basic AND and OR gates were previously discussed in task 4 of this lesson on pages 41 thru 56. A variation of the diode AND and OR functions is shown in figures 49 and 50 (on the following page). The variation is the presence of small circle(s) at the input(s) or output(s). A small circle at the input(s) to any element indicates that a relatively low input signal activates the function. Conversely, the absence of a small circle indicates a relatively high input signal activates the function. Presence or absence of the circle at the output terminal indicates the electrical condition of an activated function.

The function shown in figure 49 is an AND gate. When both inputs are low, the output is high. The truth table shows the other combinations. The state indicators mean that the signal must be low to activate the function. A small circle at the symbol output indicates that the output of an activated function is low. This state indicator for a low is used on AND and OR function outputs.

In figure 50, the symbol shown represents an inclusive or (NOR) function with a low output state indicator.

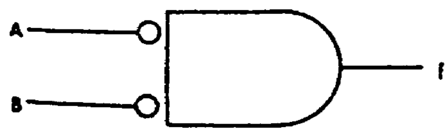
- The output is low if any one or more of the inputs is high.

- The only time there is a high output is when both inputs are low.

- Use of the state indicator for low input and output functions is always a small circle.

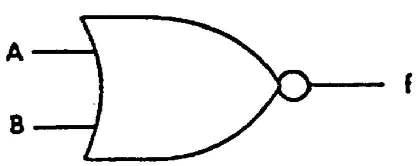
o The exclusive OR function differs from the previously discussed inclusive OR function in that the output is high only if any one input is high and all other inputs are low. The exclusive OR function allows more than one high output.

FIGURE 49. INPUT STATE INDICATORS ON AN "AND" GATE.



INPUT		OUTPUT
A	B	f
0	0	1
1	0	0
0	1	0
1	1	0

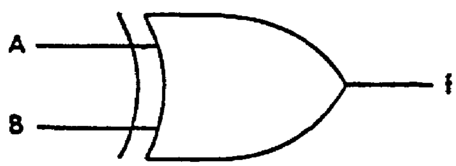
FIGURE 50. OUTPUT STATE INDICATORS ON AN "OR" GATE (NOR).



INPUT		OUTPUT
A	B	f
0	0	1
0	1	0
1	0	0
1	1	0

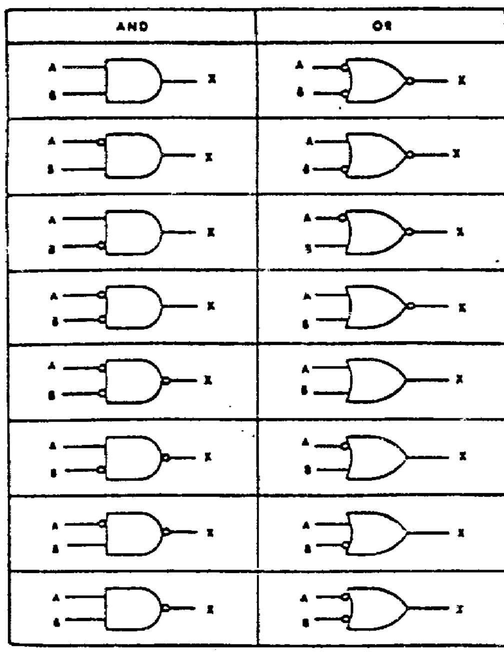
In figure 51 (on the following page), an exclusive OR function and truth table for the gate is shown. Application of function combinations is referred to as equivalents. This means that a particular function can be derived in different ways and yet do the same job. In figure 52, equivalents are shown between AND and OR functions, with the corresponding truth tables.

FIGURE 51. EXCLUSIVE "OR" FUNCTION.



INPUT		OUTPUT
A	B	f
L	L	L
L	H	H
H	L	H
H	H	L

FIGURE 52. TWO VARIABLE, "AND" AND "OR" FUNCTION EQUIVALENTS.

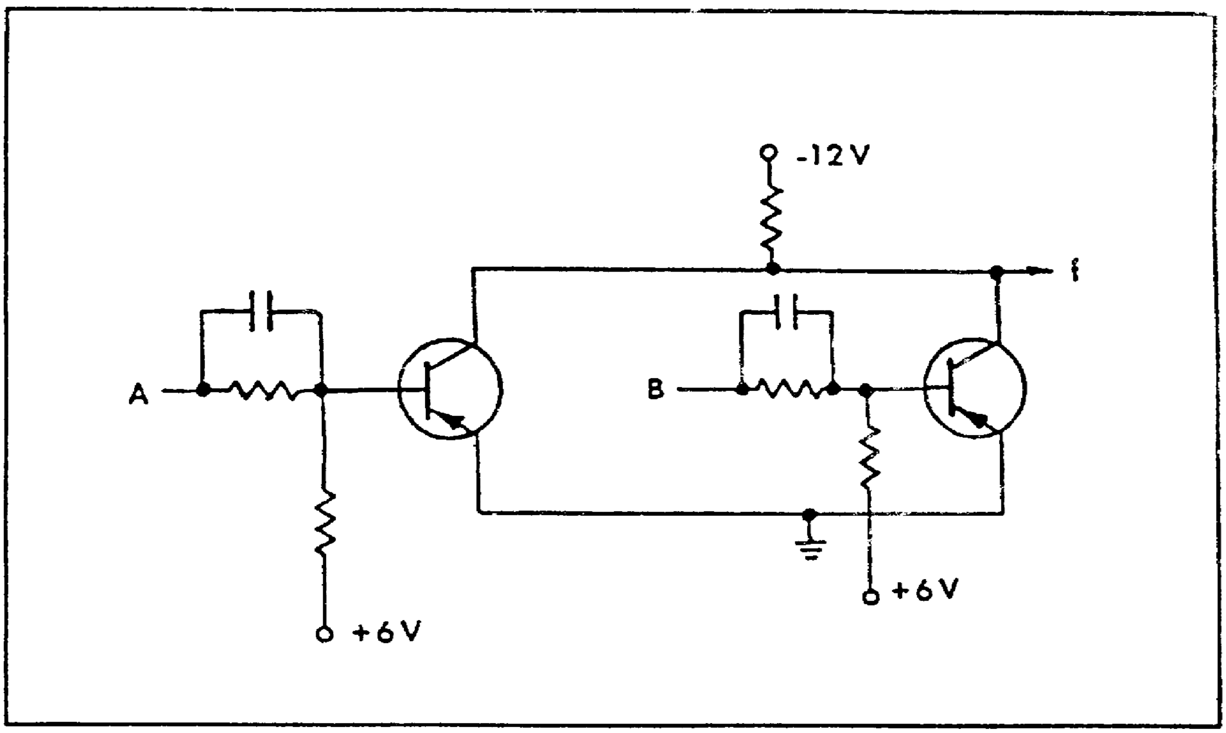


COMBINATION A	B	X
H H L L	H L H L	H L L L
H H L L	H L H L	L L H L
H H L L	H L H L	L H L L
H H L L	H L H L	L L L H
H H L L	H L H L	H H H L
H H L L	H L H L	H L H H
H H L L	H L H L	H H L H
H H L L	H L H L	L H H H

b. *Transistor Gates*. The AND and OR gates may use transistors instead of diodes. There is a limit to the number of diodes that can be connected; this is because diodes do not have an infinite back impedance or zero forward impedence. As a result, the output of one gate is only strong enough to drive one or two other diodes. The transistor is used to provide signal amplification. The transistor in the AND or OR gates is often operated near cutoff and saturation.

These two extremes in operation represent the two logic state outputs. In figure 53, a two input ANP gate is shown using two transistors.

FIGURE 53. TWO-TRANSISTOR "AND" GATE.

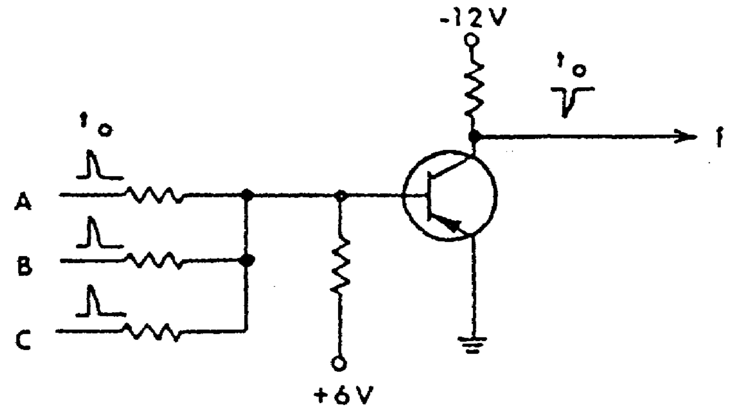


If either transistor is conducting, the output will be at ground. To get the output to switch to 12 volts, both transistors must be cut off.

To simplify, only two inputs are used in figure 53. In practice, any number of inputs, from two upward, can be used. Either negative positive negative or positive negative positive transistors can be used in the OR and AND gates.

Figure 54 (on the following page) shows a multiple input into a single transistor amplifier. This AND gate a.1ows resistor inputs to be used. Due to the transistor, the output will be inverted as shown.

FIGURE 54. TRANSISTOR "AND" GATE WITH INVERTED OUTPUT.



The gate shown in figure 53 (on the previous page) requires a transistor for each input. For multiple inputs, this type of gate becomes relatively expensive. Figure 54 shows a multiple-input gate consisting of only one transistor, each input being applied through a resistor. This circuit retains the advantage pf increased power output and impedance matching at a low cost.

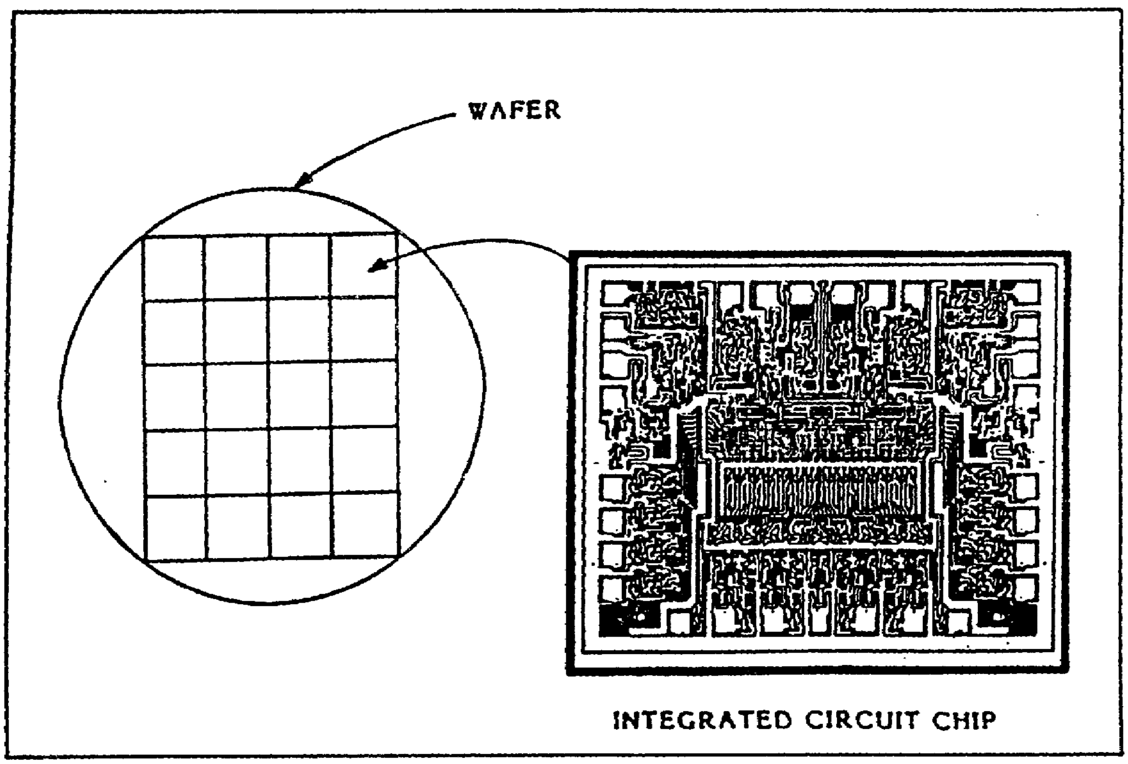
We have now considered the basic digital processes and their use in the construction of more advanced processes, namely digital circuits. In modern electronic technology, gates are realized by transistors; the transistors of several gates and their connecting signal paths are packaged in integrated circuits. The number of gates placed into an integrated circuit is used to categorize the degree of integration as follows:

Small Scale Integration (SSI)	1 to 10 gates
Medium Scale Integration (MSI)	hundreds of gates
Large Scale Integration (LSI)	thousands of gates
Very Large Scale Integration (VLSI)	over 100,000 gates

Integrated circuit technology advanced extremely fast during the 1970's and has lead to LSI and VLSI components which can include entire central processing units, extremely large flip/flop memories and ether advanced integrated processes.

How these integrated circuits are built, and what they look like, is complex. In very general terms the transistors and connections of integrated circuits are placed onto a substance called a wafer, usually by photographic means. The source for the photographic process is a picture of the transistors and connections of the circuit, called the mask. In fact, many copies of the circuit mask are placed into the wafer, which appears as indicated in figure 55.

FIGURE 55. INTEGRATED CIRCUIT FABRICATION.

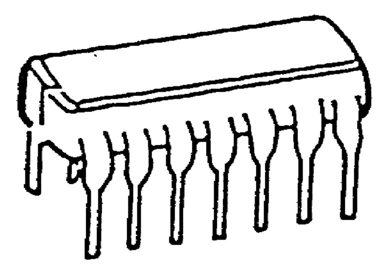


Each individual integrated circuit is called a chip. The material used for the wafer, as well as the photographic process used to realize the integrated circuit, can vary and thus several technologies for fabrication have evolved. The density of transistors permitted per chip and the circuit propagation times vary, based upon the selected technology.

When the wafer is produced, the chips are tested by an automatic testing device and only "good" chips are selected for use. The good chips are then broken away from the wafer by a cutting device and are mounted into a capsule, called a dual in-line package (DIP), which is shown in figure 56.

The word "dual" comes from the fact that there are two rows of pins which provide the "ports" for the DIP process input and output signals. Inside of the DIP, the integrated circuit is connected to the pins by extremely small wires. The DIP is now a process ready for inclusion in a system of cooperating processes.

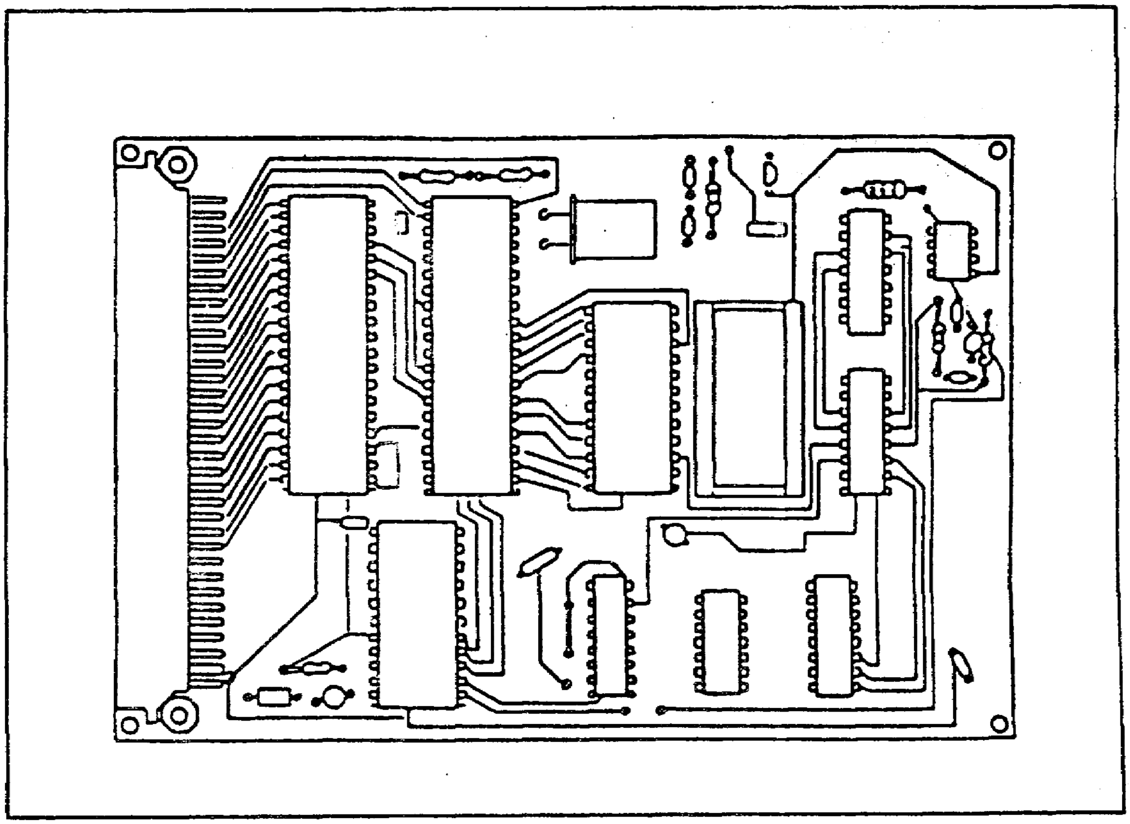
FIGURE 56. DUAL IN-LINE PACKAGE (DIP).



In most uses of integrated circuits, the DIPs are mounted onto a printed circuit board (PC-board) which contains signals connecting the DIPs as shown in figure 57 (on the following page).

The "ports" of the printed circuit board used for receiving and sending signals are located at the edges and are called edge connectors. Printed circuit boards may then be incorporated, as processes, into a more advanced system of cooperating processes. However, a single PC-board may well contain a complete computer system, including the processors for the memory, central processing unit and input/output controller processes, and the buses (buses are defined as the transmission channels used internally in the computer system) that connect these processes. The peripheral devices are then connected by cables to the edge connectors. Some of the edge connectors are used for attaching power cables to the PC-board where the power is provided by a power supply. The power is distributed over the PC-board to the integrated circuit components.

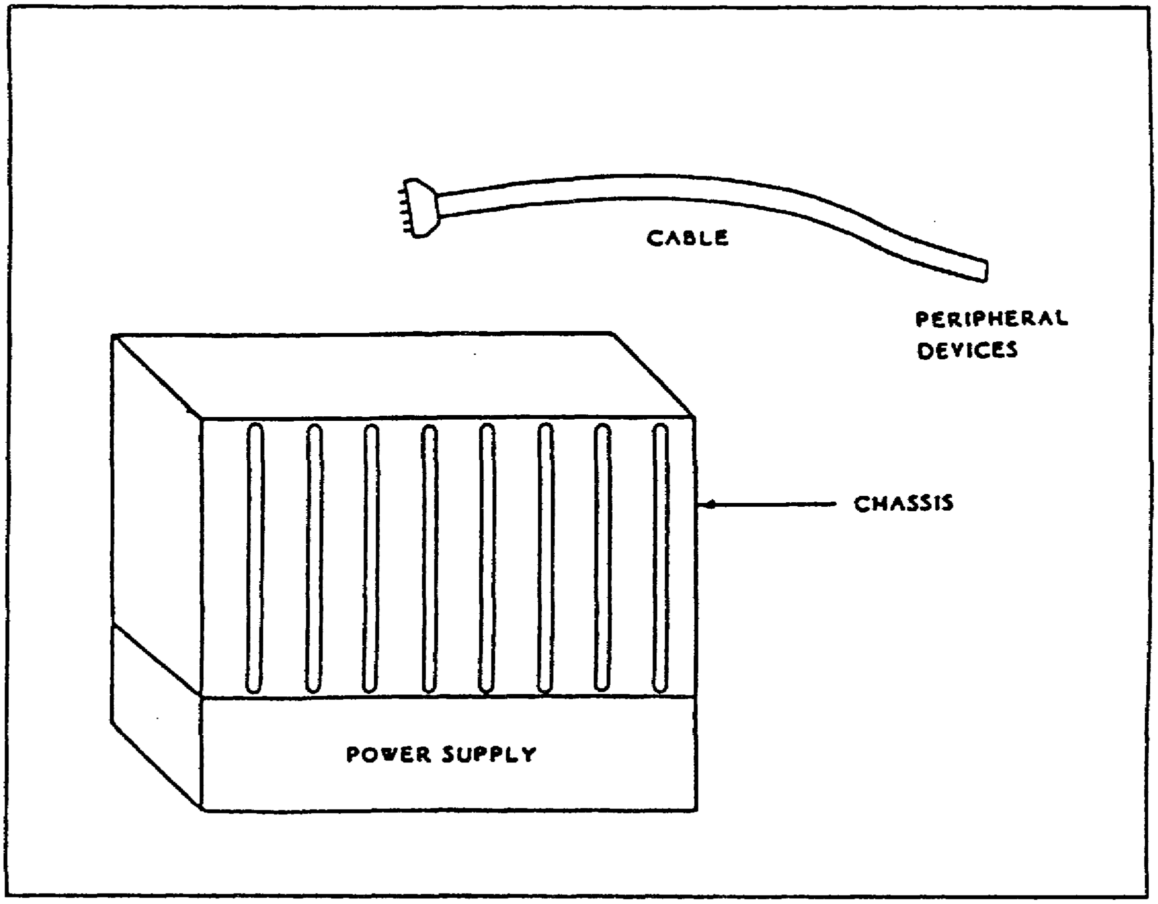
FIGURE 57. PRINTED CIRCUIT BOARD (PC-BOARD).



In larger computer systems, the hardware logic and memories may be distributed over several PC-boards, each with their own edge connectors used for power contacts with a power supply and connections with related processes contained on neighboring PC-boards. In this case, the PC-boards are placed in a chassis. One or more input/output channels are connected to appropriate PC-board processes in the input/output controller logic. One or more peripheral devices may be connected to each input/output channel. These construction concepts are illustrated in figure 58 (on the following page).

In all computer system applications, the computer system is only one process, part of a larger system of cooperating processes. This is very obvious in process control applications. In this environment, the single board computer has revolutionized process control design. Further, single board computers are small enough to 1e included in a typewriter and this has enabled the development of "word processing" systems.

FIGURE 58. A MULTI PC-BOARD COMPUTER SYSTEM.



This concludes the discussion of the world of digital circuits and the creation of digital processes which are the foundation of computer systems. For those who will specialize in a computer systems profession, this discussion should have provided an important platform; whereas, the layreader will have a good idea of what lies at the bottom of computer technology.

PRACTICAL EXERCISE 1

1. Instructions

Read the scenario and respond to the requirements that follow the scenario.

2. Scenario

You are SSG John Landers - a typical kind of man; married, with two kids, and have a nice house in a suburban development just outside APG. As a 63N, your former duties have primarily been involved with automotive maintenance of the M60 series tank --not the most exciting work in the world, but you like it and the pay is not bad.

It's Friday morning--payday. Along with thousands of other NCO's, you eagerly await payday activities to commence, neither knowing or caring that your pay voucher (LES) for the prior month was analyzed, your earnings calculated, and your check printed by a computer.

At 1145 hours, your section chief returns from the Division Staff meeting with the long awaited word that payday activities would begin, which was followed by the usual race to the parking lot. Now, before you hit the NCO club, you have to stop at the bank. As you wait in line, you can't help but notice the strangely shaped black numbers at the bottom of your paycheck and on the deposit slip from your checking account. The numbers are printed with a special magnetic ink and allows the bank's computer to read the documents.

Finally, it's your turn. You insert your plastic bank card into the slot in the 24-hour automated teller and type in your personal code number. You push a button marked "Checking Account Deposit," and drop your paycheck into the proper slot. You then push two other buttons indicating your desire to withdraw some cash from your savings account, and the machine dispenses the money. This 24-hour teller is a small, special-purpose computer.

Returning to your new Chrysler, after leaving the bank, it informs you that you are "low on gas". This bit of vital information was brought to you through the use of computer circuitry which sensed that your tank was low on fuel, and relayed the information to a computer "chip" which audibly informed you of your fuel situation. Your credit card covers the cost of a full tank of gas. You leave behind a copy of the sales slip which will eventually be read by the oil company's computer as it compiles future bills.

You decide against going to the club, and decide to head for home. You are enthusiastically greeted by your wife, whom you met through a computer dating service.

The computer, directly or indirectly, affects almost every phase of our modern way of life; except for a few hermits, it is difficult to find an individual who bas .ever heard the word "computer" or handled (but not bent, folded, spindled, or mulitated, of course!) a data processing card. Yet, to the average person, the computer is shrouded by myth and mystery.

3. Situation

You have recently been reassigned as an instructor, at Aberdeen Proving Grounds, to instruct digital electronics. Your NCOIC tasks you with preparing a pre-test questionnaire dealing with binary numbers, Boolean algebra, diode logic gates, and digital circuits, to evaluate initial soldier proficiency in these subjects.

Requirement

Below is a list of pre-test questions that will provide you with a general understanding of this proficiency. You are now faced with creating an answer sheet for these questions.

a. There are two general types of computers. Digital is one general type of computer. Name the other general type of computer.

b. Name two basic advantages of a digital computer.

c. Magnetic tape reader, print readers, and analog-to-digital converters are all examples of input devices. Name another input device.

d. Any decimal number consists of a series of digits -0,1,2,3,4,5,6,7,8,9. What is the series of digits that make up a binary number?

e. Define coding in its relation to binary and decimal number.

f. The American Standard Code for Information Interchange (ASCII) is a 7-bit code that is used for what purpose?

g. Describe the basic logic of Boolean algebra.

h. The diode circuit equivalent of switch contact in series (AND circuit) and switch contacts in parallel (OR circuit) are commonly referred to as gale circuits. Name how both of these gates are classified?

i. Clock pulses control the operations that are performed within a digital computer. The response and operating time of computing elements can be measured in nanoseconds. What is the duration of a nanosecond?

j. Describe how flip/flops are used in a computer system.

LESSON 1. PRACTICAL EXERCISE - ANSWERS

Requirement

a. Analog.

b. Speed and accuracy.

c. Keyboard, punched card readers, and punched tape readers.

d. 0, 1.

e. Coding is used to describe the conversion of a decimal number to its binary equivalent.

f. The code that is used in data transmission and intercommunication between a computer and its peripheral devices, such as a printer, monitor, and keyboard.

g. Boolean algebra is based on the proposition that any expression can be made meaningful with two values (true and false).

h. Diode logic circuit.

i. One billionth of a second.

j. Flip/flops are memory elements that retain their 0 or 1 state while power is supplied to the computer system.

LESSON 2

PROCEDURES FOR SOLDERING, DESOLDERING, AND REPAIR OF DEFECTIVE ELECTRICAL/ELECTRONIC CIRCUITS, INCLUDING INSPECTION STANDARDS

TASK 1. Identify the procedures used to solder, desolder and repair defective electrical/electronic circuits.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Soldering is one of the oldest and most widely practiced methods of joining metals. The process has undergone a revolutionary change in the electronics industry, where solders are required to join hundreds of components on printed circuits. Soldering is utilized on microcircuits to provide joints as small as 150 microns. (Microns are defined as a unit of length equal to one-millionth of a meter.) Soldered joint reliability is required for applications ranging from automotive radiators to the most sophisticated computers, in environments that range from households to outerspace.

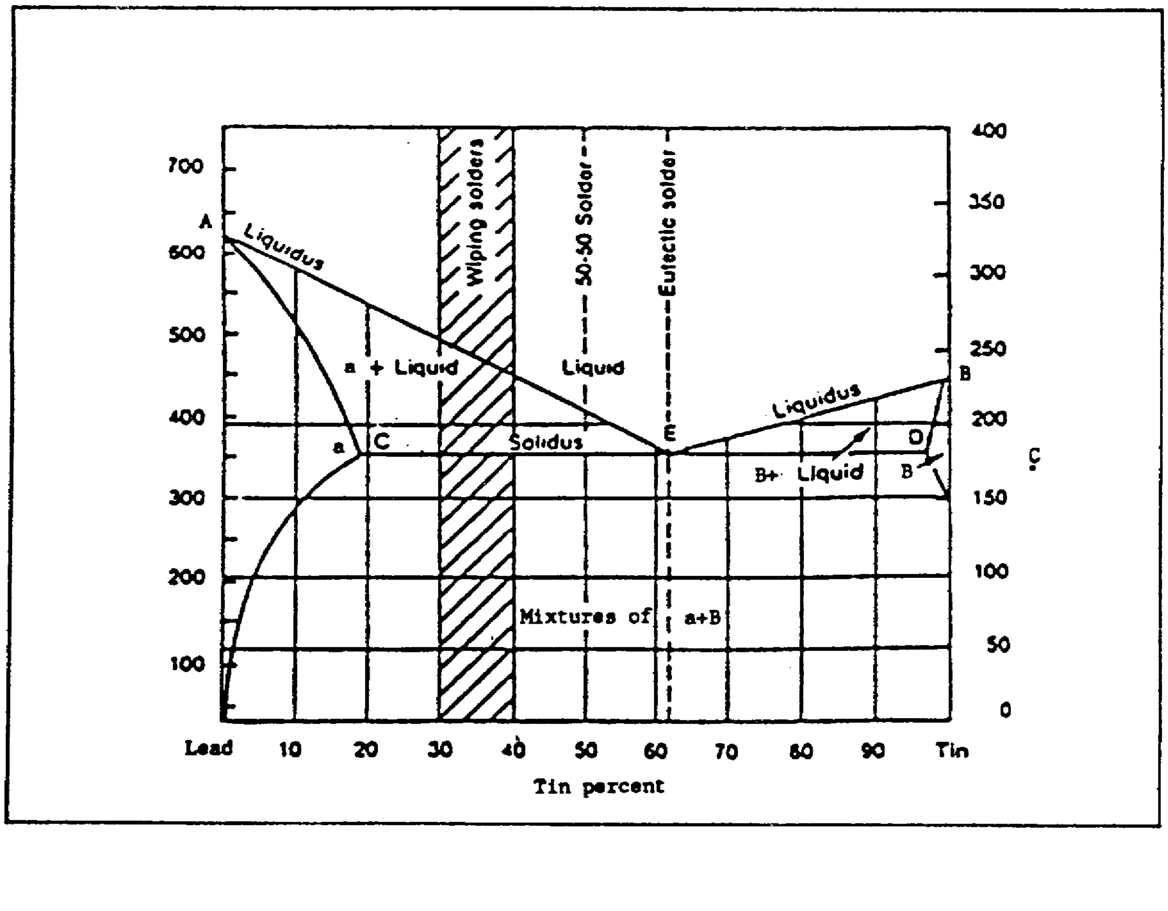
Repair of electrical and electronic military equipment requires high quality soldering. Using unacceptable soldering procedures will result in unsatisfactory electrical connections, resulting in high electrical resistance, excessive heat causing additional circuit damage, or excessive solder flow, bridging adjacent circuits.

New technical information has been generated on solders, their interaction with base metals, and the properties of soldered joints. It is the intent of this section of the subcourse to inform you of these many advances and new data, together with the fundamentals of the soldering process.

2. Materials for Soldering Connectors and Terminals

a. *Solder*. A better understanding of the nature of solder, and how to select one for a specific application, can be obtained by examining the melting characteristics of metals and alloys. Pure metals transform from a solid to liquid state at a specific temperature. The melting of alloys is more complicated because they may melt over a temperature range. Any alloy system can best be studied by examining a phase diagram, which shows the melting characteristics in relation to chemical composition.

FIGURE 59. PHASE DIAGRAM FOR TIN-LEAD ALLOY.



(1) *The Tin-lead Diagram*. The tin-lead phase diagram is shown in figure 59, on the previous page.

The terms used are defined as follows:

- o The SOLIDUS temperature is the highest temperature at which a metal or solder is completely solid (curve ACEDB of figure 59).
- o The LIQUIDUS temperature is the lowest temperature at which a metal or solder is completely liquid (curve AEB of figure 59).

Melting point and flow point are terms which have been in common use for generations, but they have not always been applied with the same meaning. For this reason, the terms "solidus" temperature and "liquidus" temperature, which can be more clearly defined, will be used.

As shown in figure 59, 100% lead has a melting point of 327 degrees C (621 degrees F)(point A); whereas, 100% tin has a melting point of 232 degrees C (450 degrees F)(point B). It will be observed that the tin-lead solders, containing from 19.5% tin (point C) to 97.5% tin (point D); have the same solidus temperature, 183 degrees C (361 degrees F).

At temperatures between the solidus and liquidus lines, the solder is partially melted. The region between the solidus (ACEDB) and liquidus (AEB) lines is called the "melting range.

(2) *Tin-lead Solders*. The tin-lead alloys are the most widely used solders and are used for joining most metals. Capillary attraction, as a force to fill gaps with solder, does not function with clearances greater than 0.25 mm (0.010 in). All cleaning and soldering processes may be used with the tin-lead solders and fluxes of all types are used with these solders. The selection is dependent on the type of metals to be joined. The treatment of the flux residues is dictated by the flux used. These solders have good corrosion resistance to most of the common media. Some characteristics of the tin-lead solders are shown in figure 60, on the following page.

The 40% tin/60% lead solder has become a very commonly used general purpose solder. It is used as a resin-cored wire for radio and television applications.

FIGURE 60. TIN-LEAD SOLDER.

ASTM Alloy Grade	Fed. Spec. QQ-S-571	Tin % Desired	Lead % Nominal	Antimony % Minimum	Antimony % Desired	Antimony % Maximum	Silver % Desired	Melting Range Solidus °C	Melting Range Solidus °F	Melting Range Liquidus °C	Melting Range Liquidus °F
70A		70	30	–	–	0.12	–	183	361	192	378
70B	Sn 70	70	30	0.20	–	0.50	–				
63A		63	37	–	–	0.12	–	183	361	183	361
63B	Sn 63	63	37	0.20	–	0.50	–				
	Sn 62	62	36	0.20	–	0.50	2				
60A		60	40	–	–	0.12	–	183	361	190	374
60B	Sn 60	60	40	0.20	–	0.50	–				
50A		50	50	–	–	0.12	–	183	361	216	421
50B	Sn 50	50	50	0.20	–	0.50	–				
45A		45	55	–	–	0.12	–	183	361	227	441
45B		45	55	0.20	–	0.50	–				
40A		40	60	–	–	0.12	–	183	361	238	460
40B	Sn 40	40	60	0.20	–	0.50	–				
40C		40	58	1.8	2.0	2.4	–	185	365	231	448
35A		35	65	–	–	0.25	–	183	361	247	477
35B	Pb 35	35	65	0.20	–	0.50	–				
35C	Sn 35	35	63.2	1.6	1.8	2.0	–	185	365	243	470
30A		30	70	–	–	0.25	–	183	361	255	491
30B	Pb 30	30	70	0.20	–	0.50	–				
30C	Sn 30	30	68.4	1.4	1.6	1.8	–	185	364	250	482
25A		25	75	–	–	0.25	–	183	361	266	511
25B		25	75	0.20	–	0.50	–				
25C		25	73.7	1.1	1.3	1.5	–	184	364	263	504
20B	Pb20	20	80	0.20	–	0.50	–	183	361	277	531
20C	Sn 20	20	79	0.80	1.0	1.20	–	184	363	270	517
15B		15	85	0.20	–	0.50	–	227	440	288	550
10B	Sn 10	10	90	0.20	–	0.50	–	268	514	299	570
5A		5	95		–	0.12	–	270	518	312	594
5B	Sn 5	5	95	0.20	–	0.50	–				
2A		2	98	–	–	0.12	–				

The 60A and 63A solders are generally referred to as fine solders, used wherever temperature requirements are critical. These solders are most commonly used for wave and dip soldering of electronic assemblies. All methods of cleaning, fluxing, and heating may be used with these solders.

The 70A solder is a special purpose solder used where high tin content is necessary. All soldering techniques are applicable.

b. *Flux*. Only rosin flux shall be used in all soldering operations. The use of liquid rosin type flux is permissible for applications such as the removal of excess solder from a joint by wicking into stranded conductor wire, and for soldering with solid solder. Where dual usage of cored and solid solder is required, core flux and liquid flux must be compatible. Thinners compatible with the flux shall be used.

Noncorrosive fluxes all have rosin as their common ingredient. Rosin has unique physical and chemical properties which make it ideal as a flux. It melts at 127 degrees C (260 degrees F) and remains active in the molten state up to 315 degrees C. The active constituent of rosin (abietic acid) is inert in the solid state, active when molten, and returns to an inactive state when cooled. Thus, it is widely used in electrical and electronic environments because the flux residue is noncorrosive and nonconducitive. Three types of rosin fluxes are in common use--nonactivated, mildly activated, and activated rosin.

(1) *Nonactivated Rosin*. Nonactivated rosin consists of rosin plasticized with an inert plasticizer for core solder, or dissolved in an inert solvent as a liquid flux. No additives for the purpose of increasing flux activity are used. This is the mildest of the rosin fluxes, and only extremely clean and solderable metals can be soldered reliably with nonactivated rosin. Federal specification QQ-S-571 designates this type as R.

(2) *Mildly Activated Rosin*. Because of the slow fluxing action of nonactivated rosin, mildly activated rosin is also used. It contains additives which improve the fluxing action of the rosin but leaves residues which are noncorrosive and nonconducting. Mildly activated rosin is used in

high reliability electronic assemblies, and removal of the flux residue is optional. Mildly activated rosin can be plasticized for core solder or dissolved in an organic solvent to provide a liquid flux. Federal Specification QQ-S-571 designates this type as RMA.

(3) *Activated Rosin*. The activated rosin fluxes are the most active of all, and depend on the addition of small amounts of complex organic compounds for their increased activity. Fluxes of this type are designated RA.

The use of activated rosin as a noncorrosive flux is based on the requirement that the activator is decomposed by heat and that the residue is not electrically conductive or corrosive. High production-line speeds have demanded more highly active fluxes, but the question of harmful flux residues is still a matter of debate in critical applications where corrosion resistance is the foremost consideration.

(4) *Selecting the Flux*. The following factors influence the choice of flux:

- o The assembly being soldered.
- o Accessibility of the part for cleaning after soldering.
- o Solderability of the base metals.
- o Rate of soldering required.

(5) *Heating Method*. It is good practice to use the mildest flux that will do the job (figure 61 on the following page). The soldering of complicated electrical equipment requires the choice of a noncorrosive flux, since corrosive residues cannot be tolerated and postcleaning is virtually impossible. Corrosive fluxes can be used when the parts can be thoroughly washed after soldering.

Although the base metal is usually the primary factor in flux selection, the converse is also sometimes the case. Thus, with electrical components, difficult-to-solder metals are precoated with metals such as silver, tin, cadmium and copper to permit the use of rosin fluxes.

FIGURE 61. FLUX SELECTION.

Type	Composition	Carrier	Uses	Temperature stability	Ability to remove tarnish	Corrosiveness	Recommended cleaning after soldering
Inorganic Acids	Hydrochloric hydrofluoric orthophosphoric	Water, petrolatum paste,	Structural	Good	Very Good	High	Hot water rinse and neutralize; organic solvents
Salts	Zinc chloride, ammonium chloride, tin chloride	Water, petrolatum paste, polyethylene glycol	Structural	Excellent	Very Good	High	Hot water rinse and neutralize; 2% HCl solution; hot water rinse and neutralize; organic solvents
Organic Acids	Lactic, oleic, stearic glutamic, phthalic	Water, organic solvents, petrolatum paste, polyethylene glycol	Structural, Electrical	Fairly Good	Fairly Good	Moderate	Hot water rinse and neutralize; organic solvents
Halogens	Aniline hydrochloride, glutamic hydrochloride, bromide derivatives of palmitic acid, hydrazine hydrochloride (or hydrobromide)	Same as organic acids	Structural, Electrical	Fairly Good	Fairly Good	Moderate	Same as organic acids
Amines and amides	Urea, ethylene diamine	Water, organic solvents, petrolatum paste, polyethylene glycol	Structural, Electrical	Fair	Fair	Noncorrosive normally	Hot water rinse and neutralize; organic solvents
Activated rosin	Water white rosin	Isopropyl alcohol, organic solvents, polyethylene glycol	Electrical	Poor	Fair	Noncorrosive normally	Water base detergents; isopropyl alcohol; organic solvents
Water white rosin	Rosin only	Same as activated	Electrical	Poor	Poor	None	Same as activated water white rosin but does not normally require post cleaning

3. Precleaning and Surface Preparation

Proper surface preparation is essential to successful soldering. The more frequent precleaning methods are mechanical abrasion, degreasing, acid cleaning, and etching. (Acid cleaning and etching will not be covered in this subcourse.)

a. *Mechanical Preparation*. Various abrasive techniques are frequently employed to clean metallic surfaces before soldering. They are effective and economical methods, but have one definite limitation: particles of the abrasive may become embedded in the surface being cleaned. The abrasive materials (sand, grit, ceramic, steel wool, etc.) are generally not solderable. Although the surface may appear to be clean, if sufficient abrasive particles to significantly reduce the anchorage area have been embedded in the surface, the result is reduced solderability. A simple solderability test should be performed following abrasive cleaning.

b. *Degreasing*. Organic films, such as oils and greases, are frequently encountered on the surface of metals to be soldered. Such oils and greases must be removed because they prevent wetting action (wetting is defined as adhesion of a liquid to a solid surface) by the flux and solder. Degreasing may be accomplished by immersion of the parts in a liquid or suspension of the parts in vapors of a suitable solvent.

(1) *Cleaning Solvents*. Solvents to be used for the removal of grease, oil, and other dirt from the parts prior to soldering, as well as flux residues from the joint area, are divided into two groups as follows:

(a) *Non-flammable*.

- Tetrachloroethylene (perchloroethylene) - electronic grade.
- Trichloroethylene - electronic grade.
- Or any of the products approved by the procuring activity.

(b) *Flammable*.

- o Ethyl alcohol conforming to 0-E-760, Grade l, class A.
- o Isopropyl alcohol conforming to TT-I-735 - 99% pure.

Impingement of the solvent upon the surface significantly improves the efficiency of the cleaning process. Considerable mechanical removal of the soil can be obtained by agitation, ultrasonics, brushing, or in any manner impinging the solvent upon the surface to be cleaned.

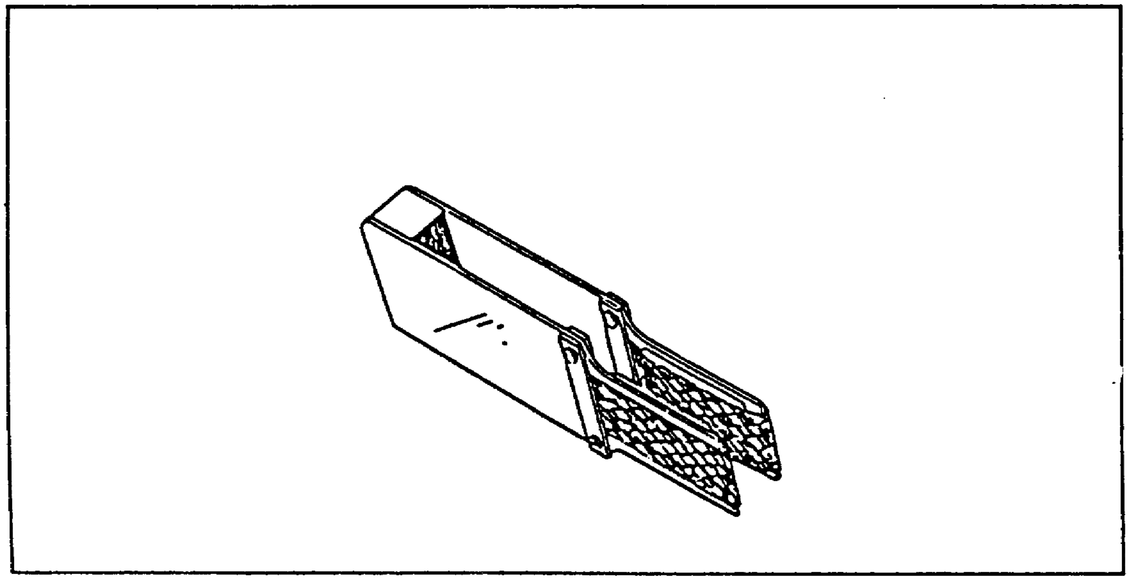
If parts and assembly can be totally submerged in the cleaning fluid without damage, this is the preferred method. In those cases where only brushing with the liquid cleaner is permissible, residues may be left in place. All residues from liquid fluxes should be removed.

With liquid cleaning there is always some soil in the cleaning solvent solution. It is impractical to remove all the liquid cleaner from the surface. Any cleaner remaining will evaporate from the surface cleaned and, being nonvolatile, the soil that was in the solution will remain on the object cleaned. To prevent this condition and obtain a higher level of cleanliness, vapor degreasing is used. The parts to be cleaned are suspended in vapors of a boiling cleaning solvent. Because the parts are colder than the vapors, the vapors condense to a liquid, dissolve the soil, and drip off the parts. When the parts have reached vapor temperature, condensation ceases and dry parts may be removed from the vapor degreaser. If a large enough quantity of cleaner of sufficient solvency strength condenses on the parts, the result is clean, dry parts. The effectiveness of the degreasing can easily be determined by dipping the part in a liquid; if the liquid uniformly adheres to the surface, the part is clean.

(2) *Tools and Materials for Cleaning*. Tools and materials for cleaning component leads, contact areas, gold plating, and soldering iron tips shall be as specified herein.

(a) *Component Lead Cleaning*. Component leads shall be cleaned with an efficient cleaning tool. Such a tool can be constructed by using 1/2 inch tinned copper shielding braid mounted in a spring-type tool, as pictured in figure 62. Knives, emery cloth, sandpaper, and other abrasives should not be used.

FIGURE 62. TYPICAL COMPONENT LEAD CLEANING TOOL.



(b) *Soldered Areas*. A medium-stiff natural or synthetic bristle brush, or a lint-free industrial cleansing tissue, dipped into an approved solvent, should be used to remove excess flux following solder solidification. Wire brushes, knives, emery cloth, sandpaper, and other materials that produce a harsh abrasive action shall not be used.

(c) *Gold Plating*. For removing gold plating from solder areas, use a pencil-style white typewriter eraser. It should be used with a brush attachment.

4. Equipment, Tools, and Application

a. *Pliers*. Pliers used for cutting conductor wire and component leads shall be smooth (all serrations removed from plier jaw prior to use). They shall shear sharply and consistently produce a clean, smooth, cut surface along the entire cutting edge. Small long-nosed pliers, or tweezers, may be used for attaching or removing conductor wire and component leads.

b. *Bending Tools*. Bending and shaping of bare leads shall be accomplished with any tool, including automatic bending tools which will not cut, nick, or in any way damage the leads or insulation. The lead will be supported next to the component body. Needle nose pliers shall have rounded edges and should not be serrated.

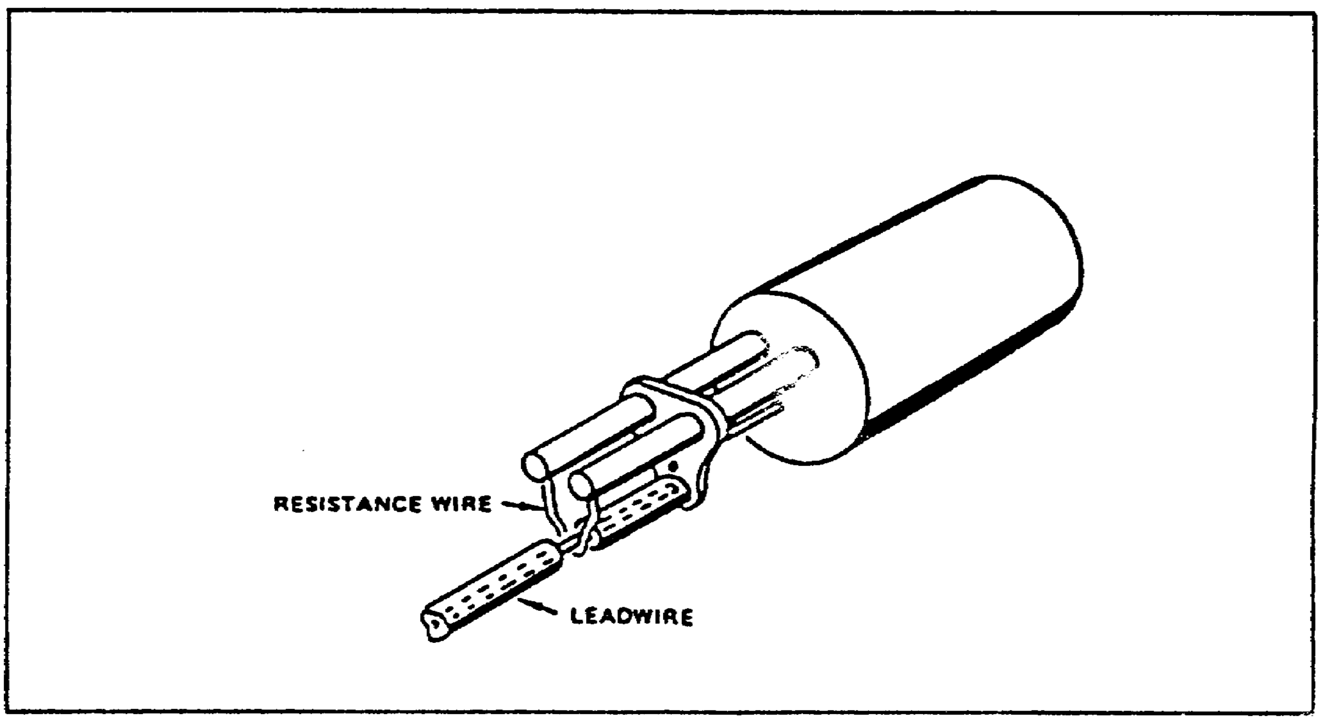
c. *Clinching Tools*. Clinching tools should be made of a material which will not damage printed circuit conductors or component leads. The tools should be used in such a manner as to prevent damage to the printed circuit conductors or component leads.

d. *Brushes and Steel Wool*. Wire brushes and steel wool should not be used. Medium stiff natural or synthetic bristle brushes may be used for cleaning.

e. *Insulation Strippers*.

(1) *Thermal Strippers*. Thermal-type insulation strippers are recommended for stripping insulation from stranded wire (figure 63). When required for personnel safety, an exhaust hood and fan ventilation system should be used to exhaust toxic fumes, such as polytetrafluoroethylene or polyvinyl chloride when thermal stripping. All excess or molten insulation must be removed after thermal stripping.

FIGURE 63. TYPICAL THERMAL STRIPPER.



(2) *Precision Cutting-type Strippers*. Hand or die cutting-type strippers are used to strip glass braid and may be used in lieu of thermal strippers for removal of other insulation. Cutting-type strippers which permit operator adjustment are not to be used. Strippers should be periodically checked for proper die hole size and operation and replaced when found defective.

f. *Soldering Iron Tips*. Only iron clad tips are to be used.

g. *Solder Irons*. Solder iron size (tip size and shape, voltage and wattage rating) and temperature are to be selected and controlled for optimum performance in relation to the work to be performed. Transformer-type solder guns should not be used.

Temperature-controlled soldering irons are acceptable, provided sensing of temperature is at the soldering iron tip.

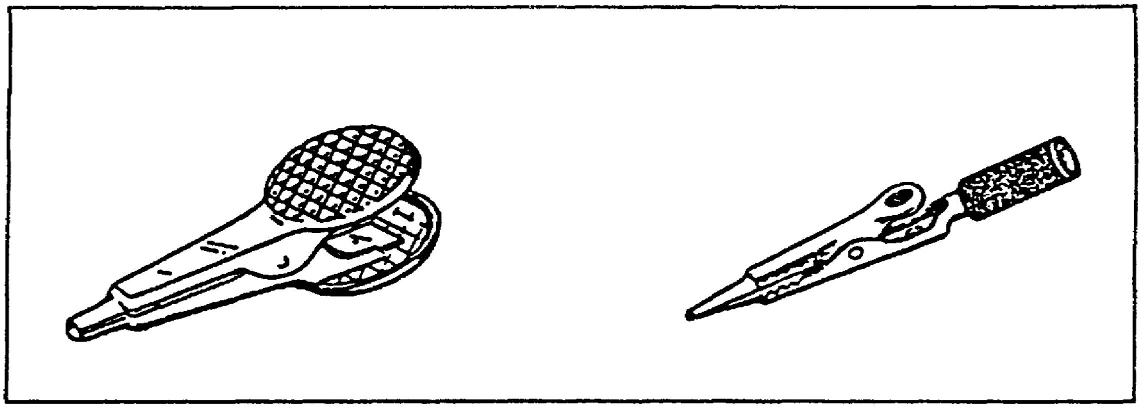
h. *Soldering Iron Holder*. A solder iron holder shall be provided for the soldering iron used. A cage-type holder that leaves the soldering iron tip unsupported is preferred. The holder should be such that the iron handle is protected from rising heat. The holder should assist in maintaining proper iron temperature.

i. *Soldering Tools*. Tools must not cut, nick, or in any way damage leads. Forked type tools, generally referred to as soldering aids, may be used, provided they are of the non-metallic type.

j. *Thermal Shunts*.

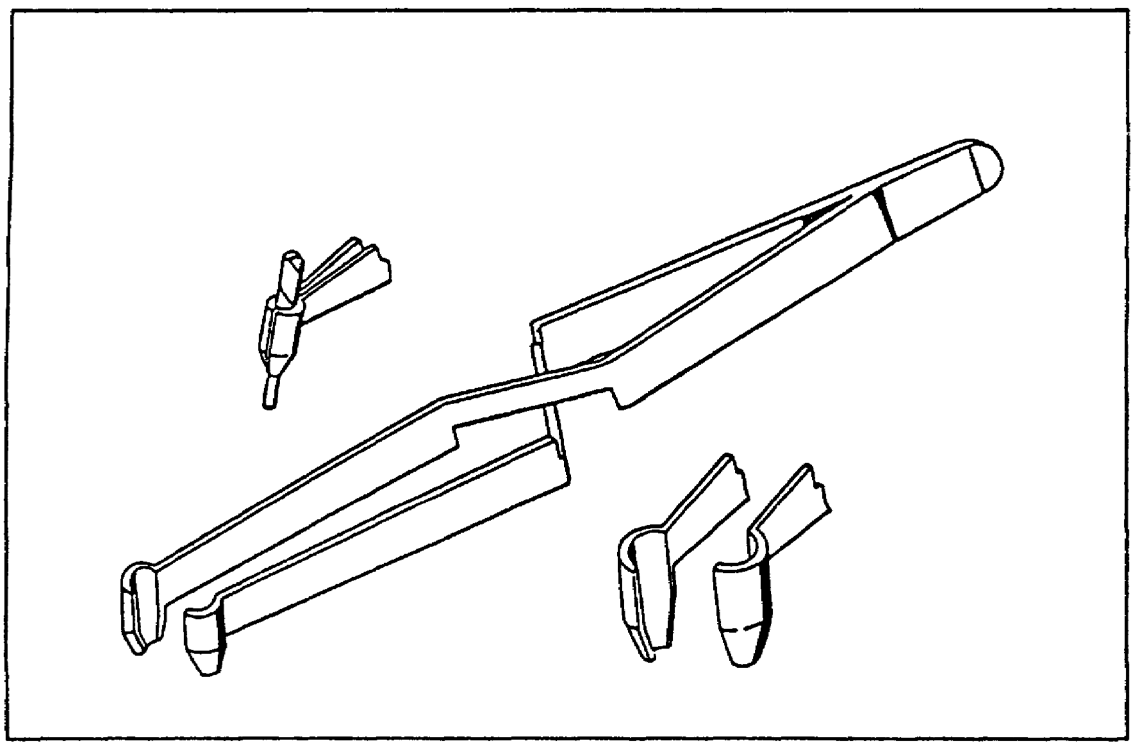
(1) *Thermal Shunts, or Heat Sinks*. These tools (figure 64 on the following page) used as necessary to protect heat-sensitive components, such as semiconductors, crystal devices, meter movements, insulating materials, etc., from damage due to heat while soldering. Thermal shunts are to be of such material, size, shape, and design as to permit rapid application and removal with minimum interference to the soldering procedure, and to provide rapid heat removal from the area being soldered. Thermal shunts should be held in place by suitable means, such as friction or spring tension, which will prevent damage to the surface and insulation of the wire, and to the component being soldered.

FIGURE 64. TYPICAL THERMAL SHUNTS.



(2) *Anti-wicking Tools*. Approved type anti-wicking tools (figure 65), marked with conductor gage size, shall be used when required.

FIGURE 65. ANTI-WICKING TOOLS.



5. General Soldering Technique

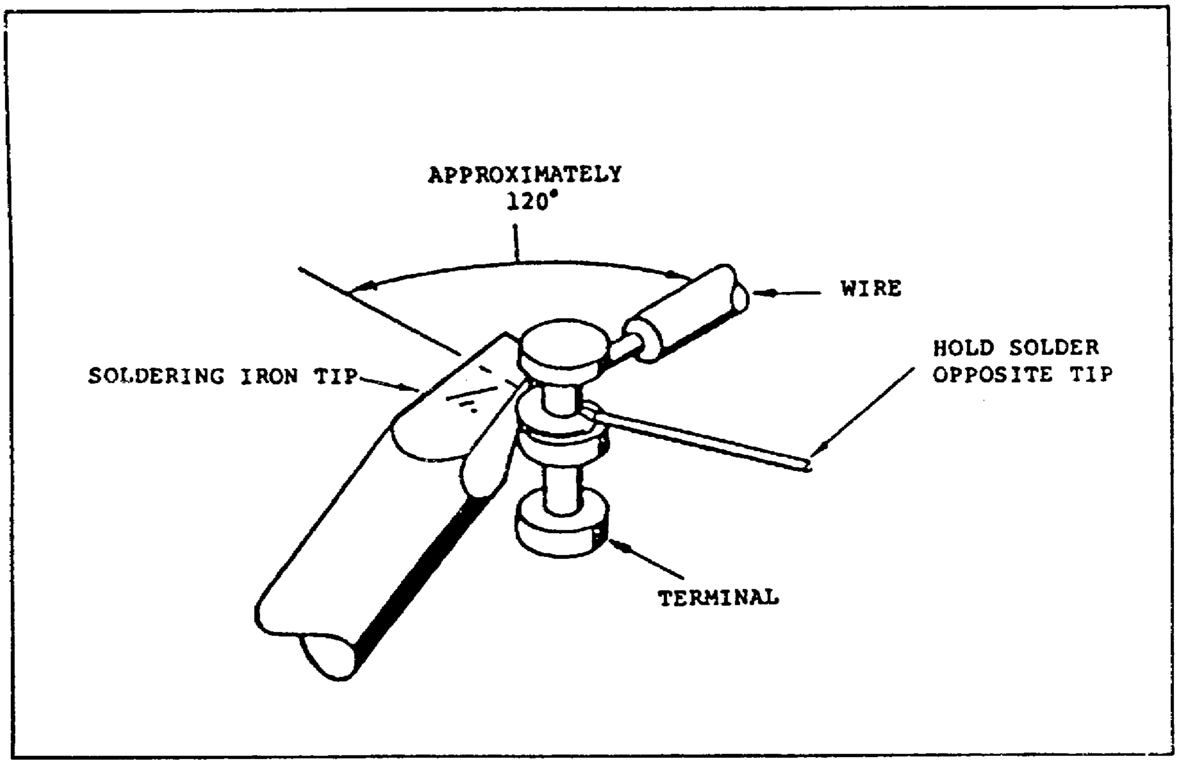
a. *Securing Conductors*. Wires and leads should be held snugly and rigidly to terminals in such a manner that there will be no motion relative to each other during the soldering operation and during cooling and solidification of the solder.

b. *Heat Application*. Apply the soldering iron tip to the connection area in such a manner that maximum heat will be transferred to the parts to be soldered and maximum protection afforded to insulation and parts that will be adversely affected by excessive heat. Thermal shunts should be used wherever necessary for the protection of insulation and heat sensitive parts. The connection area shall not be overheated. (See figure 66 and table 15.)

TABLE 15. PREFERRED SOLDERING IRON TIP TEMPERATURE

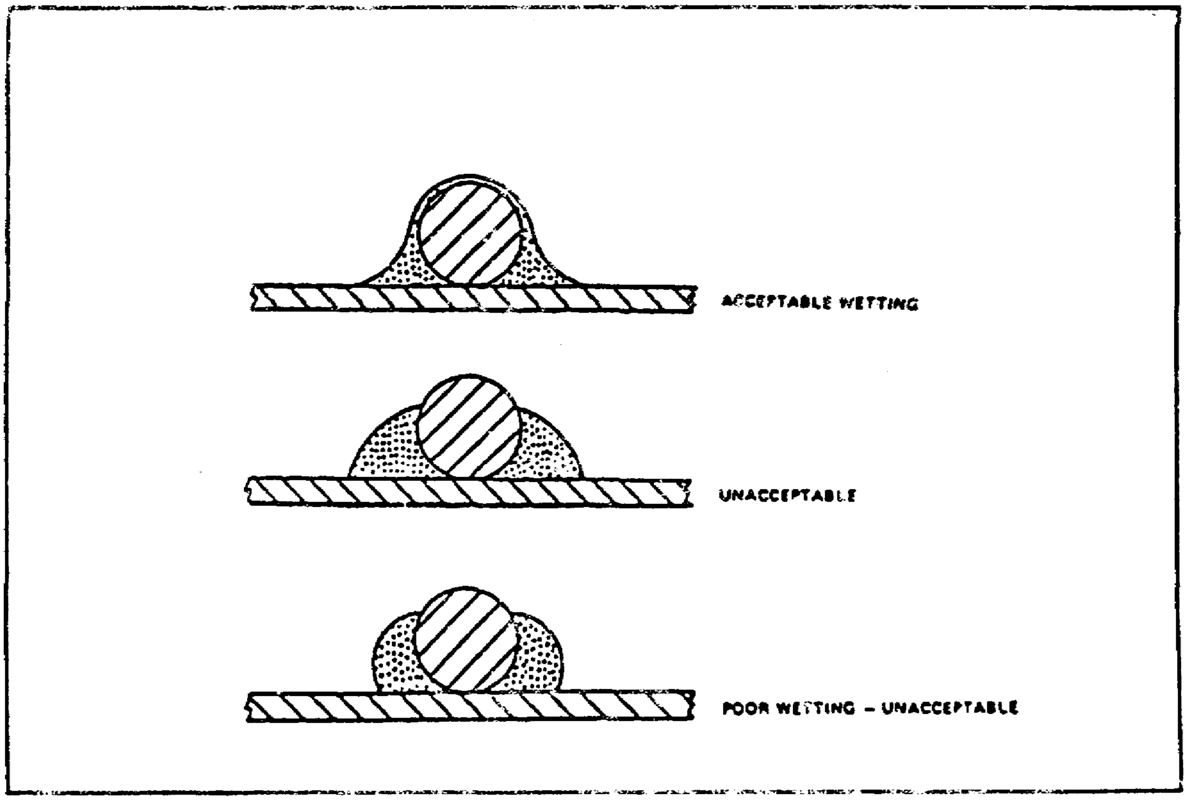
Flexible Printed Wire	**475 degree F. min.**
Printed Circuit Boards	**475 degree F. min.**
Terminals and Lugs	**500 degree F. min.**

FIGURE 66. POSITIONING SOLDERING IRON AND APPLYING SOLDER.



c. *Solder Application*. Solder should be applied to the joint when temperature of the joint will readily melt the solder. Solder is not to be applied at the junction of the soldering iron tip and the parts to be joined, nor shall solder be melted on the soldering iron tip and allowed to flow over the parts to be joined. Solder should cover the top of the conductor, and 8 concave fillet shall be formed between the lower half of the conduction and the terminal. The contour of the terminal and the strands in the conductor should not be completely obscured by solder. Forced cooling of the solder is prohibited (figure 67).

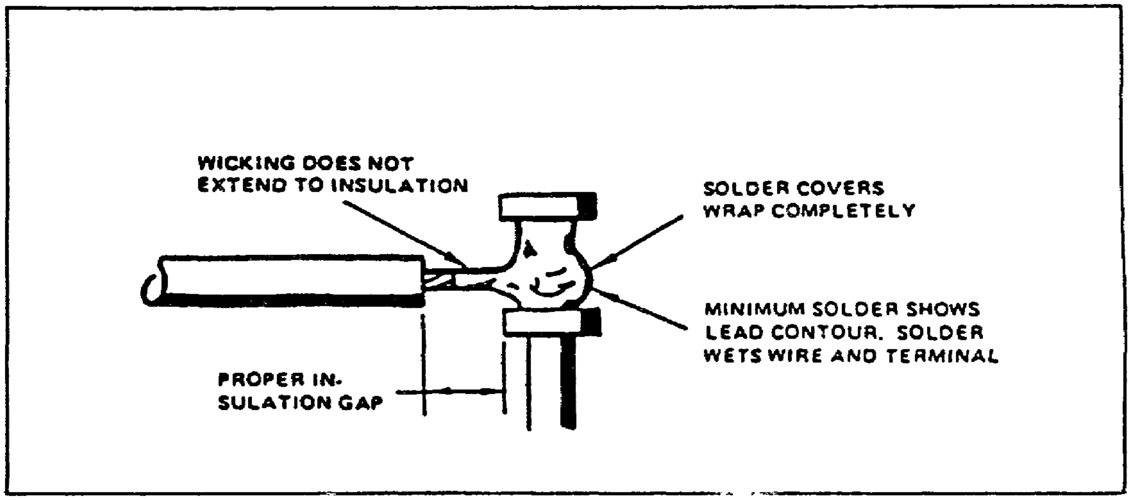
FIGURE 67. WETTING EXAMPLES.



(1) *All Terminals Except Solder Cup*. Sufficient solder shall be applied to form a slight concave fillet between the terminal and each side of the wire. The contour of the wire is to be visible after soldering. Excessive solder which completely obscures the wire and terminals is not permitted (figure 68 on the following page).

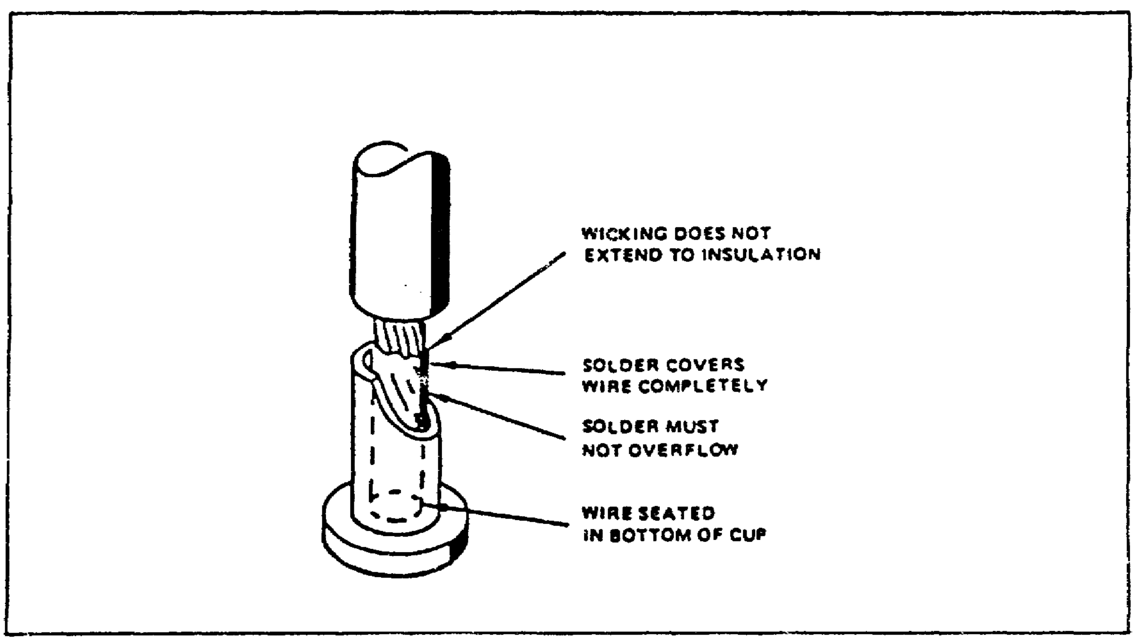
(2) *Solder Cup Terminal*. The solder cup should contain a sufficient amount of precut solder to completely fill the cup when the solder is melted and the tinned wire is inserted. Sufficient heat must be applied after the cup is filled with solder to assure that the flux has boiled up and out of the bottom of the cup. It is desirable that continuous soldering iron contact be maintained throughout the soldering operation. The solder should follow the contour of the cup entry slot and must not spill over, or adhere to the sides of the cup.

FIGURE 68. TERMINAL SOLDERING.



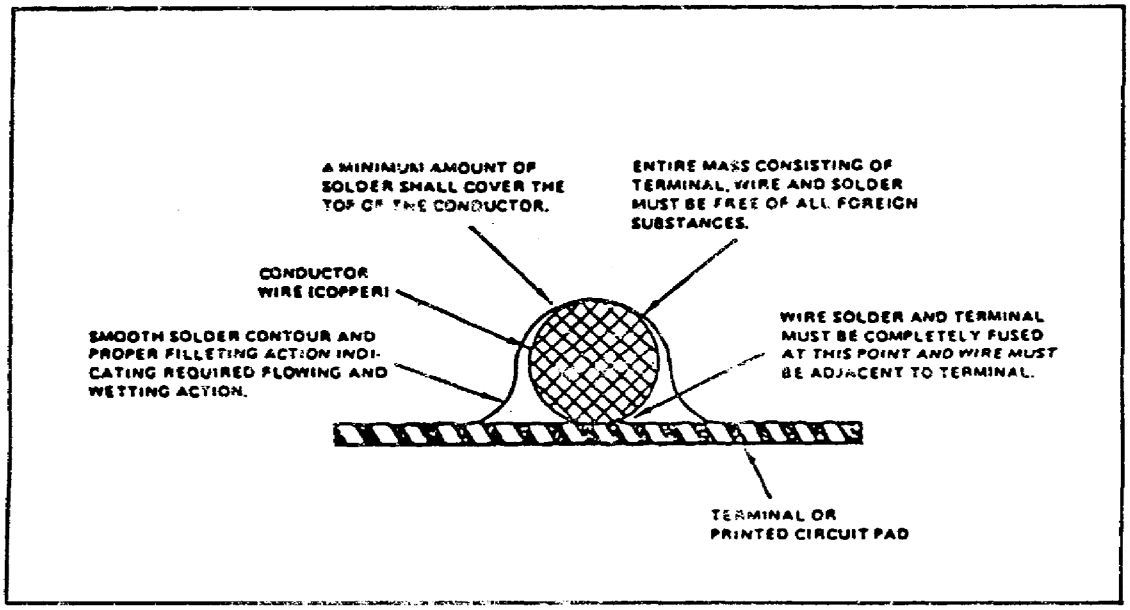
Connection may be made with either a resistance or conduction type soldering iron. When a conduction type iron is used, the slight tinned effect, occurring at the point, where the tip contacts the base of the cup, is normal and shall not be cause for rejection, provided there are no peaks, globules, or excessive buildup of solder. Buildup or overflow of solder on a hollow terminal must not be in such excess as to cause a short circuit between pins of either conductors; excess solder must not interfere with the mechanical function of the terminals (figure 69).

FIGURE 69. SOLDER CUP SOLDERING.



(3) *Printed Circuit Soldering*. The quantity of solder used must not be more than is required to completely cover the joint area without completely obscuring the contour of the strands in the wire, or the terminal. Solder fillets, where the parts being soldered join, should taper gradually to a feather edge (figure 70).

FIGURE 70. PRINTED CIRCUIT SOLDERING.



(4) *Movement*. The parts being joined should be held together in such a manner that the parts will not move in relation to one another during the soldering operation, nor after removing the soldering iron, until solder solidifies.

(5) *Cooling*. There must not be forced cooling of the soldered joint. After soldering, the soldered joint should not be disturbed until the solder has completely solidified and then not be stressed until it has completely cooled.

(6) *Reworking*. During soldering operations, a solder joint that is not initially satisfactory, should be allowed to cool to room temperature prior to the reapplication of heat, unless a beat sink is being utilized to dissipate the heat generated by the extended heat time. Connections which have been resoldered must meet the original soldering requirement.

(7) *Flux Residues*. After the joint has cooled, all the flux should be removed, using a noncorrosive solvent.

(8) *Solder Spatter*. There should be no solder spatter on other surfaces.

6. Preparation for Soldering

a. *Semiconductor Soldering Procautions*. Although transistors and diodes are, in most cases, sturdy for the job for which they are designed, there are some conditions that semiconductors will not tolerate. For example, the static electricity buildup in the body of a solderer or assembler while walking on a nonconductive surface may be sufficient to send a damaging pulse through a diode when discharged. In order to prevent such damage, persons coming into contact with such devices should have a means of grounding themselves prior to touching or assembling the semiconductors. Only grounded soldering irons should be used.

Semiconductors are low-voltage devices and cannot withstand high voltages; therefore, using personnel should periodically check their soldering irons for leakage voltage. The soldering iron should be replaced if there is enough leakage voltage present to damage a transistor or diode. It is also possible that such a condition may not immediately damage a semiconductor, but may contribute to a future breakdown. This damage may later manifest itself as a latent equipment failure. The manufacturer of the diodes or transistors can often provide leakage voltage tolerance limits.

Some types of wire wrappers, automatic soldering machines, and similar inductively driven devices, can develop transients which exceed the voltage which can safely be applied to semiconductors. When such devices are used in production or maintenance, if semiconductors come in contact with these tools, they must be lifted away before being turned on or off.

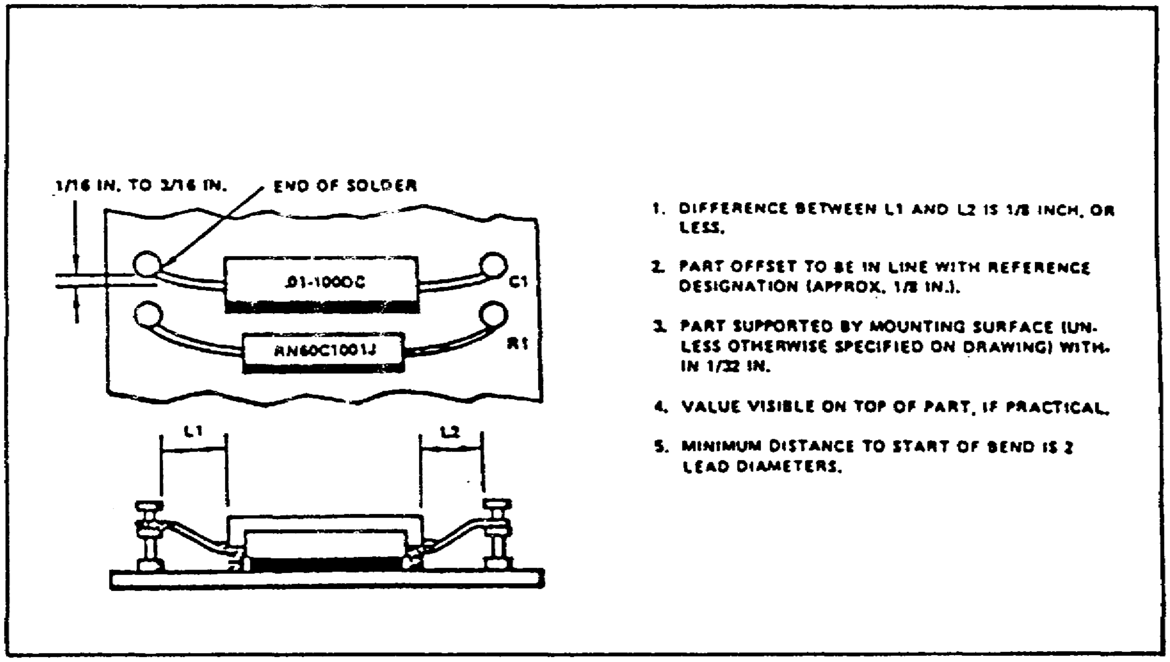
b. *Preparation of Conductors*.

(1) *Correct Lengths*. Wires and leads should be cut to required lengths prior to attachment.

(a) *Solid Hookup Wire*. Solid hookup, or "bus," wire should not be used, unless required by the design. When required, unsupported solid hookup of bus wire is not to exceed 5/8 inch in unsupported length between soldered connections. Wires which exceed this length are to be rigidly secured.

(b) *Stress Relief*. All wires and leads terminated as a solder connection should have sufficient slack, in the form of a gradual bend. In applications where multiple wires are routed from a common cable trunk to equally spaced terminals, the stress relief are to be uniform to prevent stress on any one wire (figure 71).

FIGURE 71. STRESS RELIEF IN COMPONENT MOUNTING.

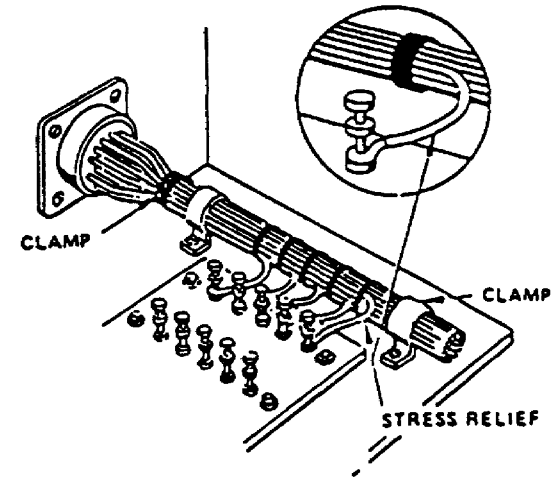


(c) *Service Loop*. Conductors routed from a harness or a cable to a terminal should have sufficient slack in the form of a slight bend for one service loop (figure 72 on the following page).

(d) *Component Leads*. Leads should have sufficient slack, in the form of a slight bend, to prevent strain at the terminal or component. Soldered components are not to impinge on adjacent circuitry.

(e) *Mechanical Support*. Solder joints should not be subjected to mechanical loads. Mechanical support shall be provided when component weight exceeds 1/4 ounce per load, for components, or wire bundles, by clamping, potting, embedding, or other means to prevent stresses on the solder joints.

FIGURE 72. STRESS RELIEF IN WIRING HARNESS.



(2) *Insulation Removal*. Insulation should be removed from conductors by use of thermal strippers or precision cutting-type strippers.

(a) *Mechanical Stripper*. When using precision cutting-type strippers, the cutter should be checked to ensure that the correct stripping hole is used for the corresponding wire size.

(b) *Arranging Stranded Wire Lay*. Stranded wire should be twisted in the direction of the lay during stripping operation, in order to maintain its original form after stripping. The lay of the wire strands are to be restored, if disturbed, without bare finger contact.

(c) *Damage to Insulation*. After stripping, the wire should be examined for insulation damage. Wires with damaged insulation are not to be used.

(d) *Damage to Wire*. After stripping, the wire should be examined with a magnifying glass with not less than 6X nor greater than 1OX magnification, to ensure that the wires have not been scratched, nicked, cut, scraped, broken, or otherwise damaged. Wires having any of these defects should not be used. Stripping or trimming of wires shall not be allowed on the solder line. Every effort should be made to cut the wires to proper length, strip, and tin prior to movement to assembly line.

(3) *Insulation Clearance*. The insulation should not touch the solder joint surface. The bare wire shall extend from the solder joint not more than 1/8 inch, or a distance equal to the outside diameter of the insulation of the wire, whichever is greater (figure 73).

FIGURE 73. INSULATION CLEARANCE.

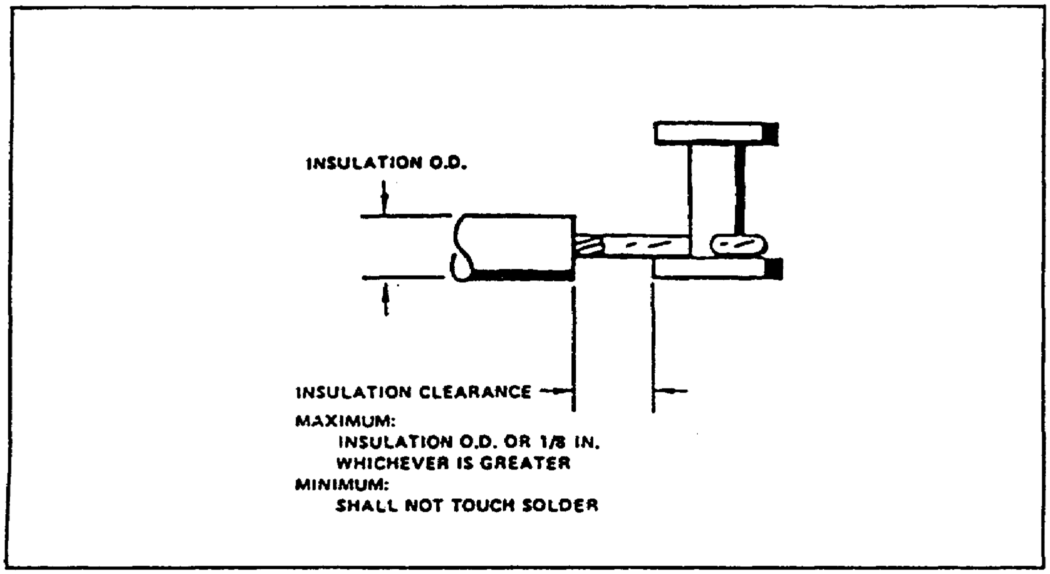
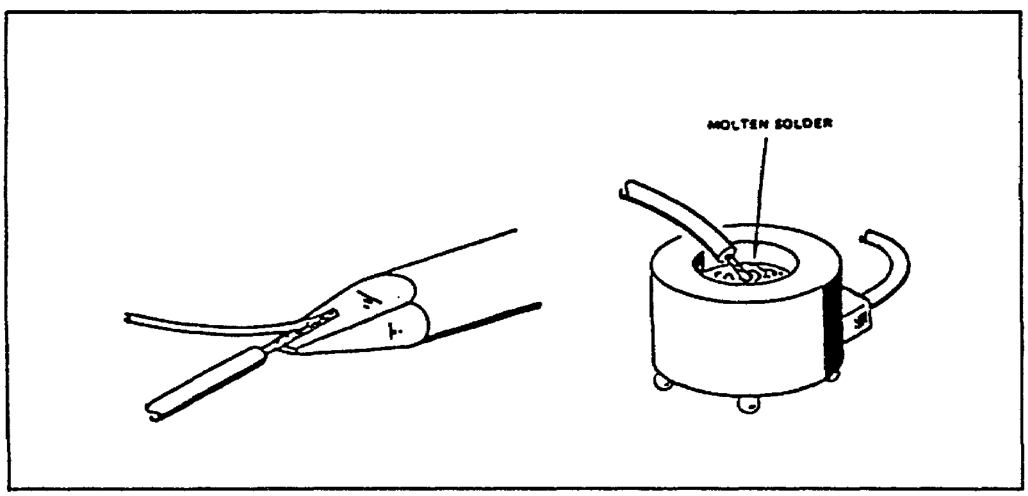


FIGURE 74. METHODS FOR TINNING (WIRE).



(4) *Tinning*. All portions of stranded wires which come in contact with the area to be soldered can be tinned by dipping the fluxed wire in a solder pot (figure 74). The reason wires must be tinned is to bond the strand together, to prime

the wire for soldering, and to give better heat transfer. The tinning should extend only far enough onto the wire to take full advantage of the area coming in contact with the connector, on solder joint. A thin coating of solder should be applied to all portions of the conductor wire coming in contact with the solder joint area. The solder then penetrates to the inner strands of stranded conductors. To permit inspection for nicks or cuts at the point of insulation termination, solder and wicking should not conceal the individual outer wire strands. A thermal shunt may be used to prevent this occurrence.

(5) *Wicking*. Wicking of solder up to the point of insulation termination is permitted, provided the wicking does not obscure the contour of the wires. To permit inspection for nicks or cuts at the point of insulation termination, a thermal shunt can be used to prevent solder wicking from obscuring the individual wire strands.

(6) *Cleaning and Bending*. Prior to attachment to terminals and soldering, solid tinned-component leads shall be retinned, or cleaned until the tinned surface has a bright, shiny appearance. The component leads should then be bent into the form required for the connections to be made. When cleaning or bending welded leads, the lead is firmly held, by a suitable tool, on the side of the weld away from the component body during the cleaning or bending operation. The radius of the bend is equal to, or greater than, twice the lead diameter. The minimum distance from component and seal to the start of the bend will be 1/16 inch. On components which have a welded lead, such as liquid electrolyte tantalum capacitors, the start of the bend will be 1/16 inch or more from the weld. The bending action is accomplished by bending the lead end. The lead should be supported next to the component body (figure 75 on the following page).

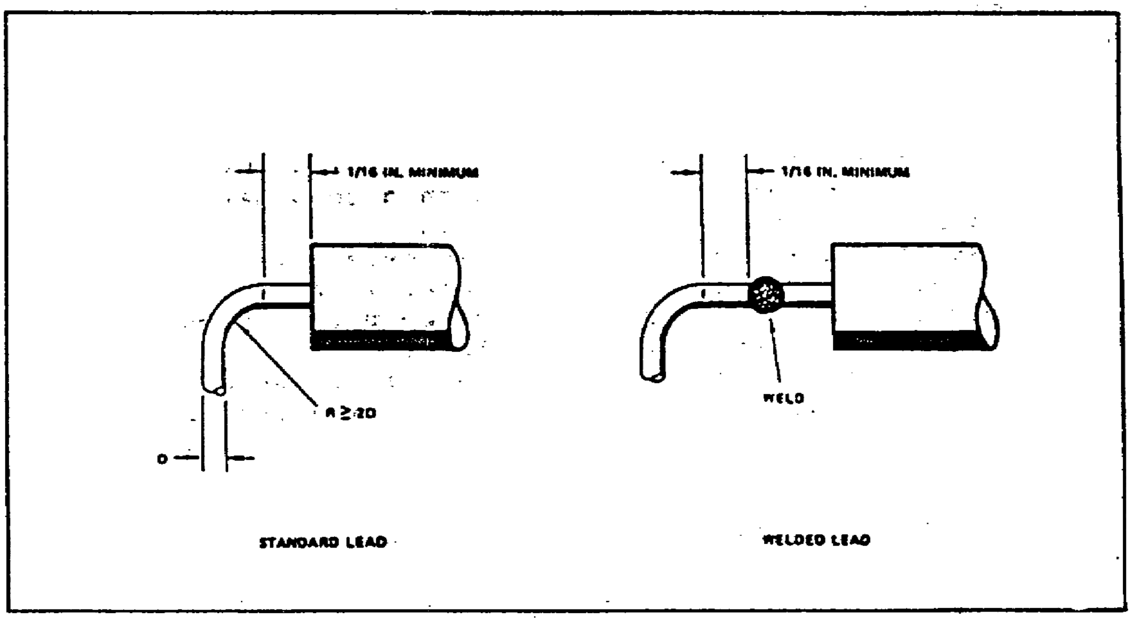
7. Mechanical Connection of Conductors to Terminals

a. *Insulation Tubing Application*. Insulation tubing is used for mechanical and electrical protection of soldered joints, wires, and leads and to protect wire harnesses and conductors against abrasion. Insulation tubing should be:

- o Installed over wires, leads, and harnesses prior to their attachment to terminals of relays, connectors, and similar items which are not protected by insulating grommets or potting.
- o Pushed back far enough from the terminal so as not to interfere with the securing and soldering operations.
- o Slipped back, after the solder has solidified and cooled and the joint cleaned, over the wires and terminals and, where applicable, heat shrunk.

After installation, the tubing should extend above the stripped portion of the attached conductor a distance equal to or greater than the tubing diameter.

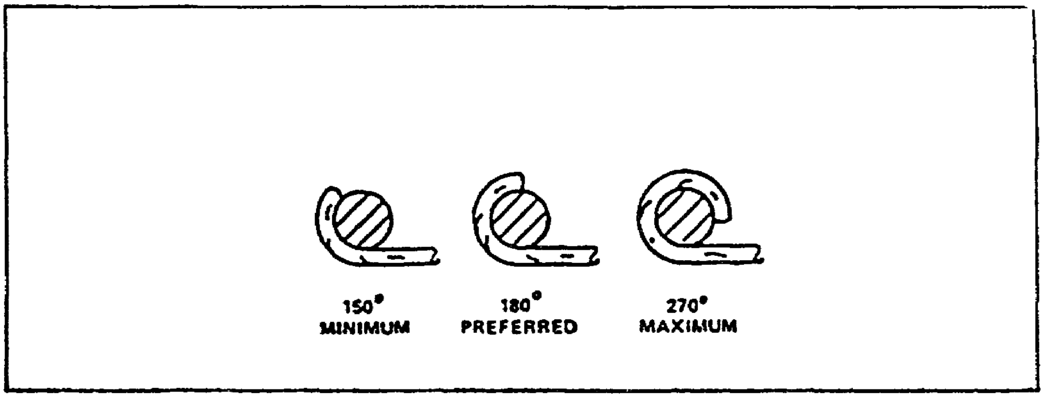
FIGURE 75. MINIMUM RADIUS BENDS.



b. *Mechanical Connections*. Conductors should be tangent to the terminal for the full curvature of the wrap or hook. The wrap of a conductor around a turret terminal is not to exceed 270 degrees, nor be less than 150 degrees. Insulation should not extend through or around any portion of the guide configuration on a terminal (figure 76 on the following page).

c. *Multiple Termination*. The number of connections per terminal should be in accordance with design specification. There cannot be overlapping of conductors. Each conductor is to be placed adjacent to the surface of the terminal. The wraps around a turret terminal may be clockwise or counterclockwise, but all wraps shall be in the same direction.

FIGURE 76. WRAP ANGLE LIMITS - TYPICAL TURRET TERMINAL.

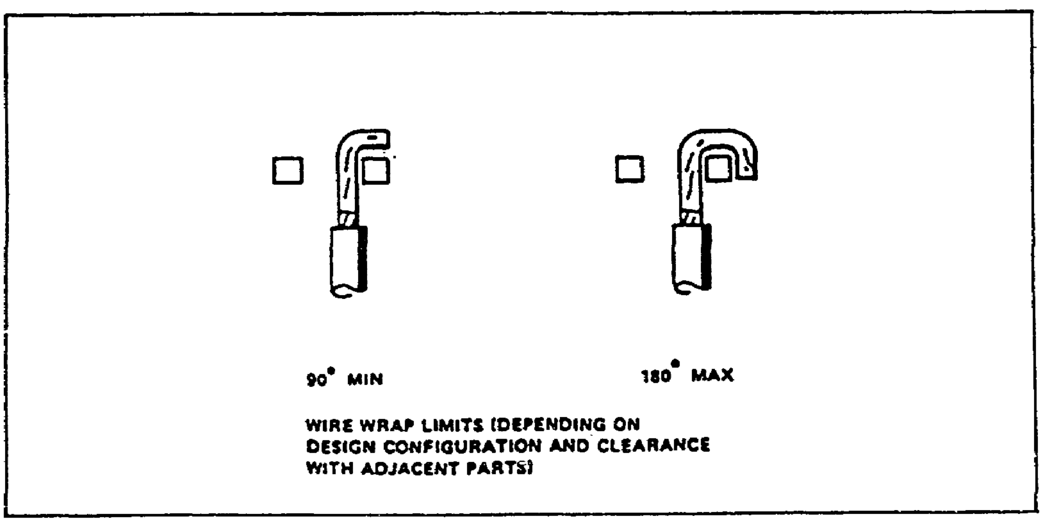


d. *Bifurcated Terminals*.

(1) *Terminal Fill*. Unless required by the design, terminal fill should be as follows:

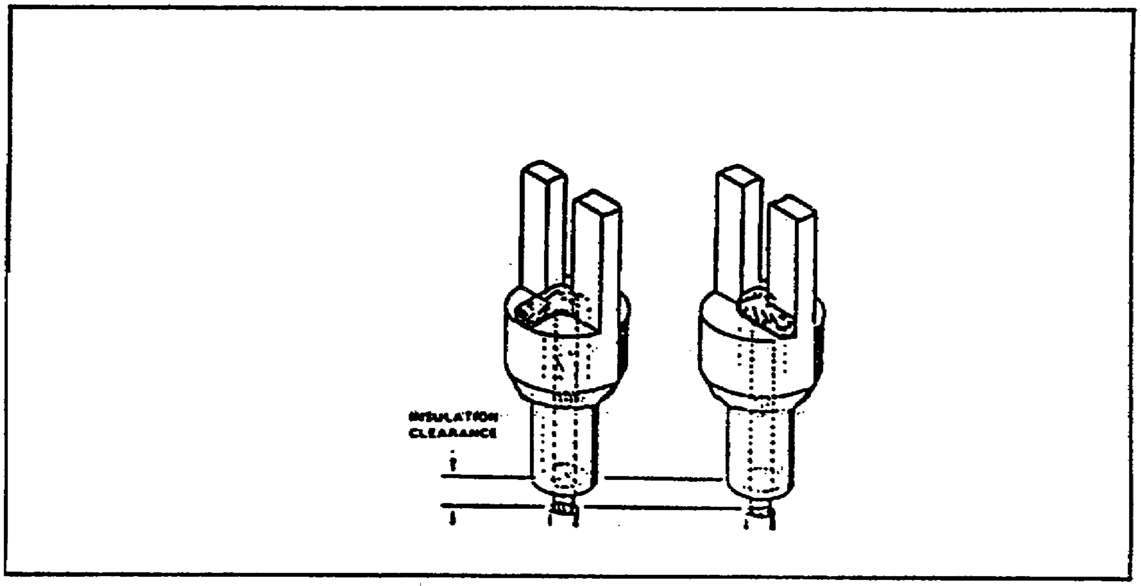
- o On bottom route and top route bifurcated terminals, a maximum of two conductors or wires should be permitted for each route.
- o On side route terminals, all conductors or wires shall be confined approximately within the lower 80% of the terminal (figure 77).

FIGURE 77. BIFURCATED TERMINAL WIRE WRAP.



(2) *Bottom Route*. Wires should terminate with a 90 degree bend and shall be soldered to the terminal shoulder. The insulation clearance will be measured from the point of entry of the wire into the terminal (figure 78).

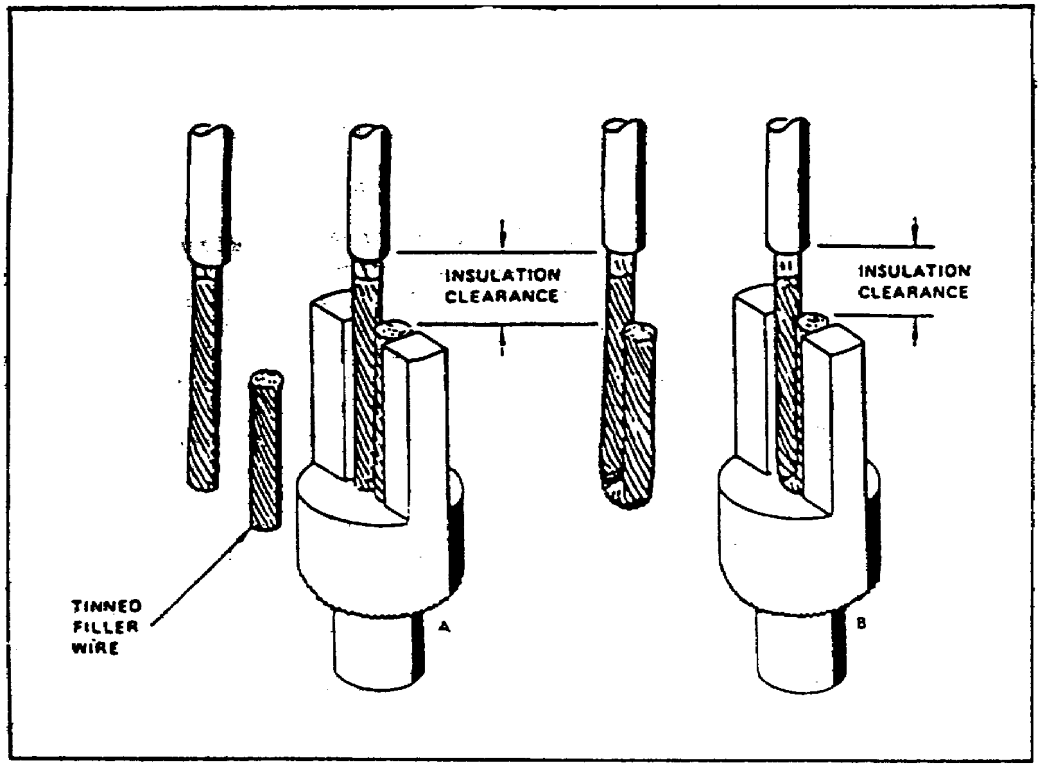
FIGURE 78. BOTTOM ROUTE CONNECTION.



(3) *Side Route*. The wire should enter the mounting slot at a right angle and terminate with a 90 degree bend. When more than one wire is connected to the terminal, the direction of the 90 degree bend on each additional wire will alternate. The first wire should be soldered to the base and the vertical post. Additional wires are soldered as close as possible to the preceding wire,, maintaining a clearance between the stranded wires equal to the thickness of the two insulations. The insulation on the first wire and all additional wires are to be a uniform distance from the terminal posts;. Insulation clearance should be referenced from the base.

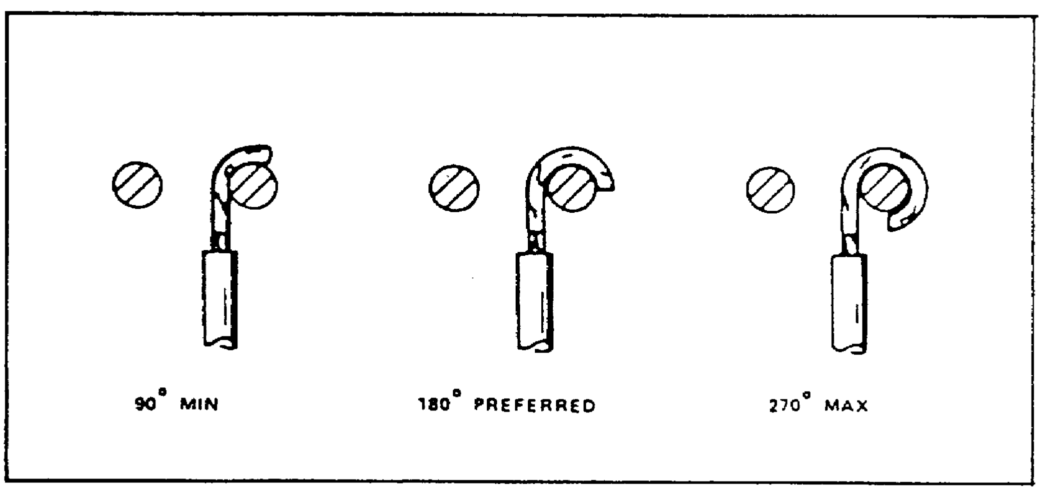
(4) *Top Route*. A large diameter wire which fills the gap should be inserted with no bend and shall require only fillets for retention. A tinned "filler" wire should be used to hold in position a small diameter wire which does not fill the gap. As an alternate, a small diameter wire may be bent into a U-shape and inserted, providing the combined diameter is sufficient to fill the gap. Insulation clearance is then measured from the point of entry into the terminal (figure 79 on the following page).

FIGURE 79. TOP ROUTE CONNECTION.



e. *Hook, Perforated or Pierced Terminals*. The bend to attach wires and leads to hook, perforated or pierced terminals, shall be between 90 degrees and 270 degrees. Insulation clearance should be as illustrated below, in figure 80.

FIGURE 80. WIRE WRAP LIMITS.



f. *Solder Cup Terminals*. The tinned wire or lead is not to be bent or formed for this application. All conductors terminating in a solder cup should bottom in the cup. Insulation clearance is to be referenced from the point of entry into the cup.

8. Shielded Cable Preparation

a. *Shield Removal for Ground Termination*. For shield ground terminations, a portion of the shield, shall be removed from the insulated conductor without damaging the individual strands of the shield. At a point approximately 1-1/2 inches back from the conductor end, mark the shield to indicate conductor breakout position. Loosen the shield by pushing it from the end toward the breakout point. Use a thin, bluntly pointed tool to separate the loosened strands of the shield wire and make a hole large enough to pull the conductor wire through. The individual shield strands must not be damaged by the tool. The shielding shall be pulled taut to smooth out any wrinkles of the shield. The loose end of the shield shall be twisted to ensure a snug fit at the junction of the shield and insulation, and to prevent the shield from creeping up the conductor. Shielding that has a ground termination must not be grounded by any method that requires soldering on shielding which is positioned directly over or around the insulated conductor (figure 81 below, and figure 82 on the following page).

FIGURE 81. SHIELD REMOVAL FOR GROUND TERMINATION.

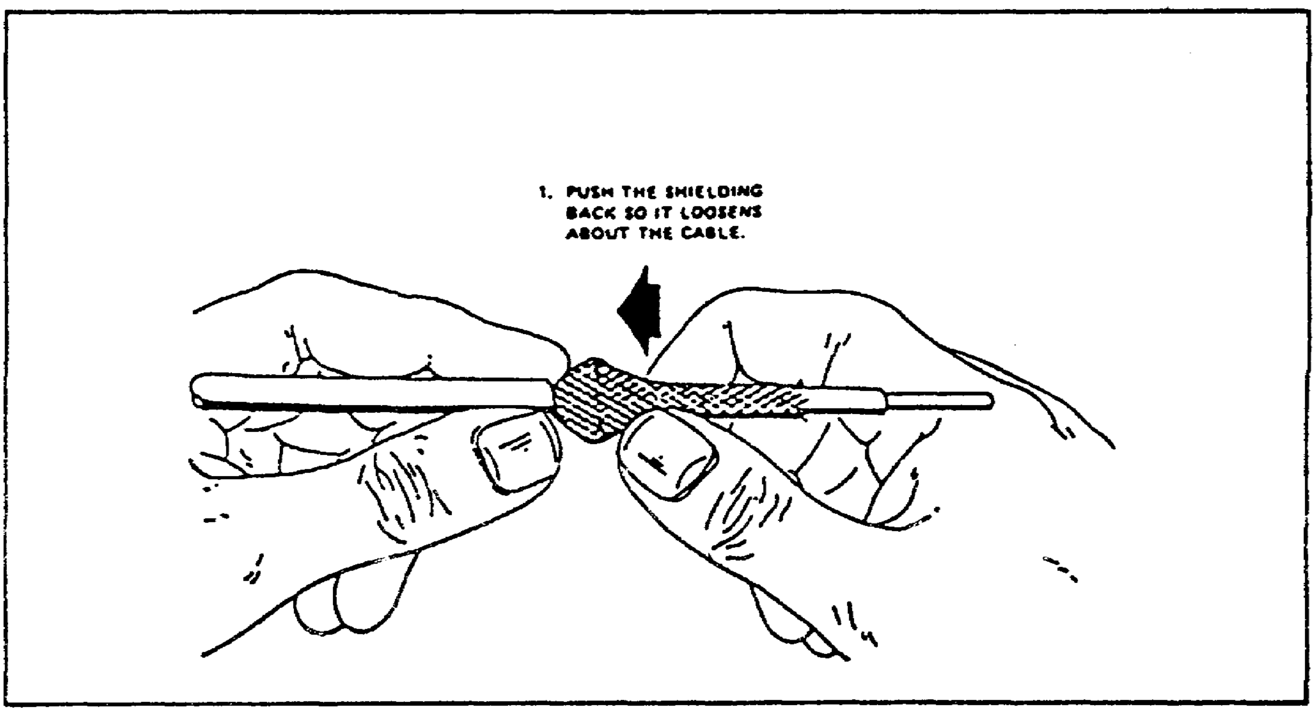
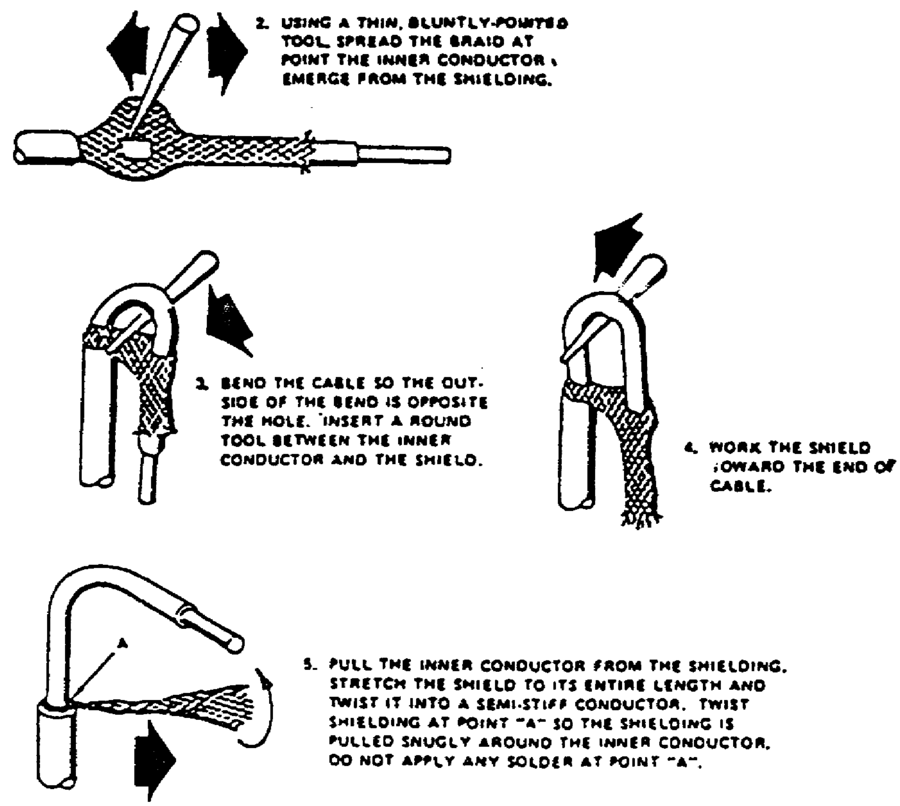


FIGURE 82. SHIELD REMOVAL FOR GROUND TERMINATION (CONT.).



b. *Termination of Ungrounded Shielding*. The raw edge of a braided shield that does not require a ground termination shall, at the point of termination, be insulated with insulation sleeving. The raw edge can be folded or peeled back on the shield. The insulation sleeving should be securely fitted over the termination, extending a minimum of 1/4 inch in both directions from the raw cut edge (figure 83 on the following page).

c. *Termination of Shielded Single Conductors in Twisted Pair or Twisted Shielded Triple*. When terminating shielded single conductors of multi-conductor cable, the twisted shield should be trimmed to approximately 1/2 inch from the breakout point and a piece of insulating tubing should be applied over the shield end conductor insulation approximately 1/2 to 5/8 inch long covering the cut end of the shield and the shield breakout point. Sleeving MIL-I-23053 shall be shrunk to a tight fit. Breakout points may be staggered to prevent excessive diameter buildup of multiple conductor cables (figure 84).

FIGURE 83. TERMINATION OF UNGROUNDED SHIELDING.

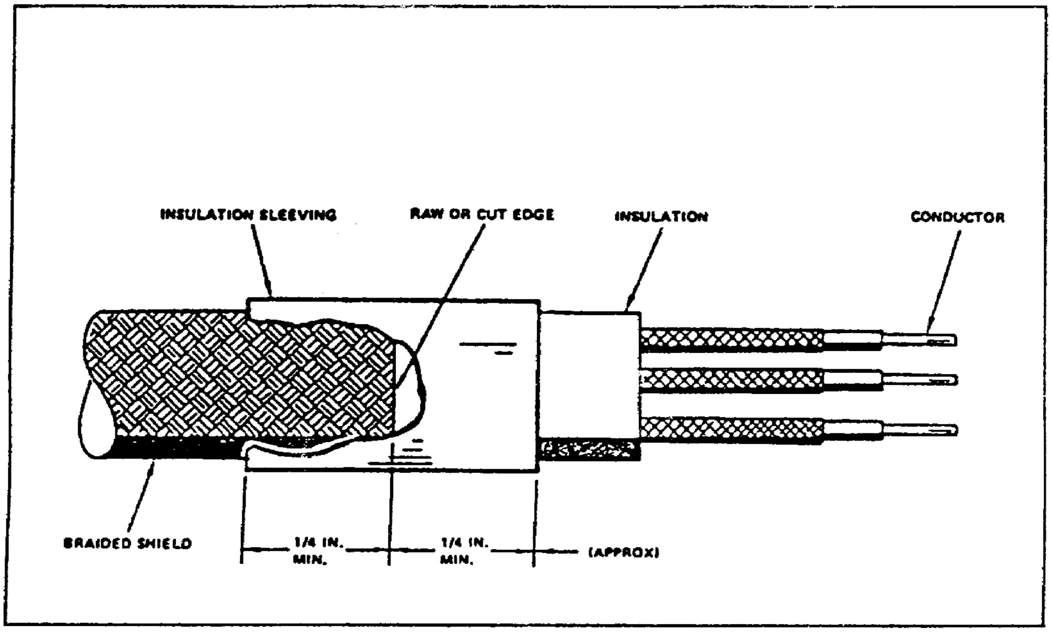
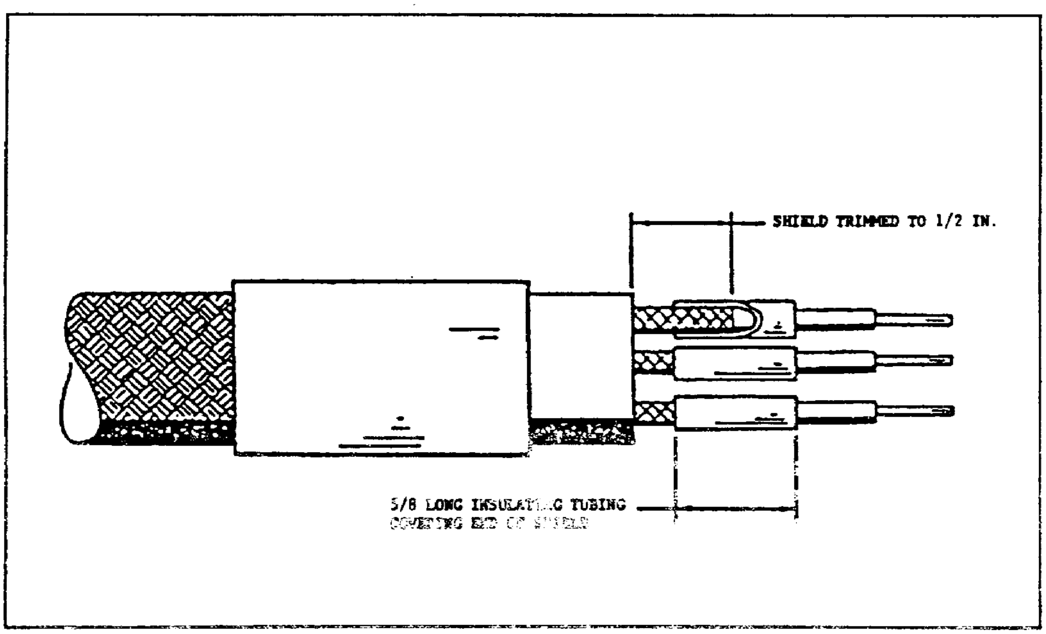
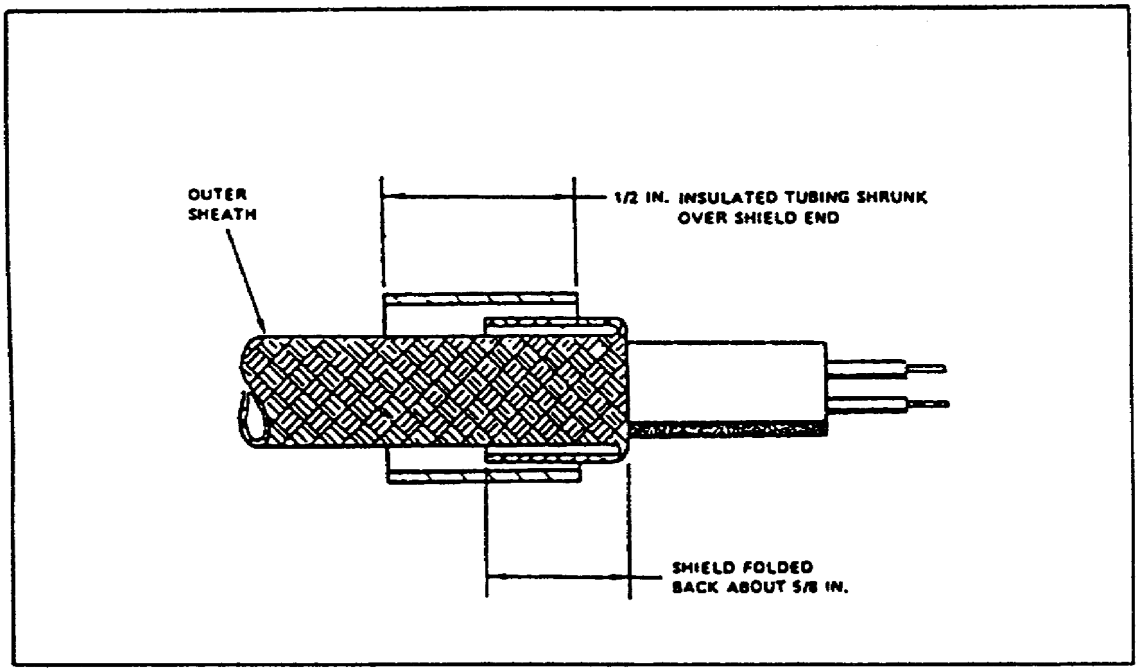


FIGURE 84. TERMINATION OF SHIELDED SINGLE CONDUCTOR IN MULTI-CONDUCTOR CABLE.



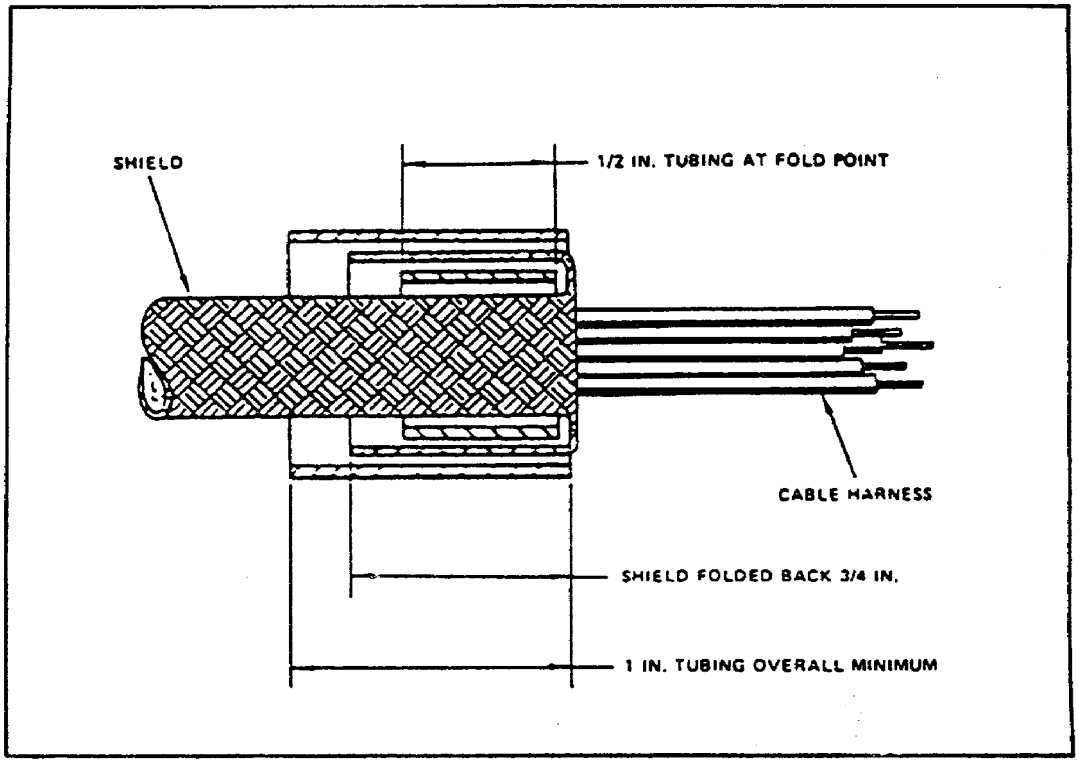
d. *Termination of Outer Sheathed Cables*. On outside type cables with a heavy outer sheath, the overall shield should be loosened by pushing back over the cable conductors. The shield will then be folded back over the sheath approximately 1/2 to 5/8 inch. A piece of heat shrinkable insulating tubing will then be applied over the folded back shielding and the sheath then shrunk in place. Tubing will completely cover the shielding and extend approximately 1/4 inch beyond the cut end of the shield and 1/4 inch beyond the fold back point on the shield (figure 85).

FIGURE 85. TERMINATION OF OUTER SHEATHED CABLES.



e. *Termination of Shields on Cable Harness*. Inside type cables or harness, having no outer sheath, will have a piece of heat shrinkable tubing applied, over the wire bundle, approximately 3/4 inch back from the cut end of the shield and extending approximately 1/2 inch. The shield will then be loosened by pushing the shield back over the conductors. The loosened shield will then be folded back over the previously applied tubing and pulled taut. A second piece of insulating tubing will then be applied over the folded shield and extended from the fold point on the shield to at least 1/4 inch beyond both the previously applied tubing and the shielding. The tubing will be shrunk into place (figure 86 on the following page).

FIGURE 86. TERMINATION OF SHIELDS ON A CABLE.

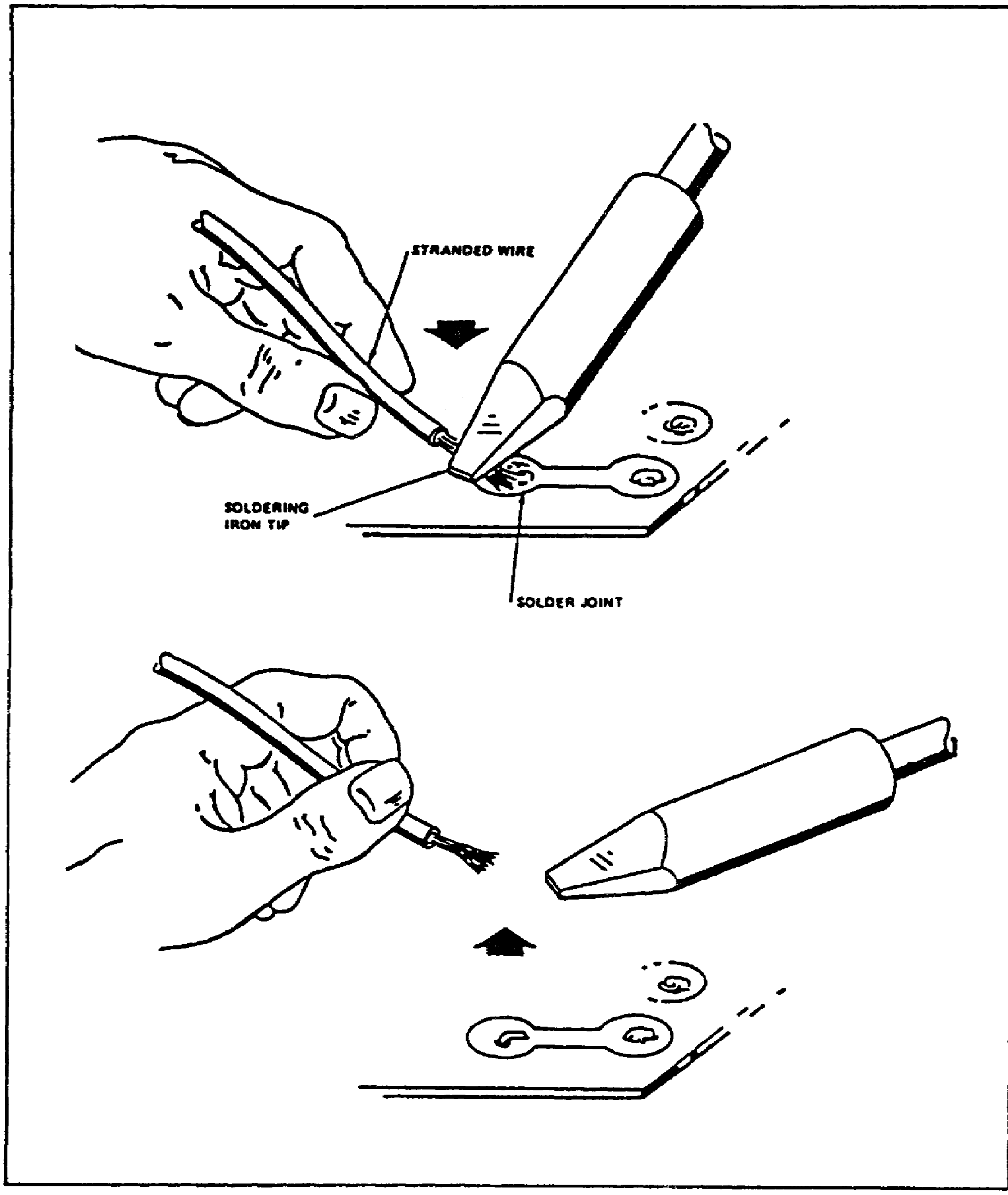


9. *Desoldering and Reworking Unsatisfactory Connections*. Solder connections which do not meet established inspection standards can be reworked by removing the solder (desoldering), cleaning the connection, and resoldering.

a. *Solder Removal by Wicking*. Solder should be removed only by wicking (figure 87 on the following page) using stranded wire (19 strand is preferable) or shielding braid, as follows:

- o Strip approximately 1/2 inch of insulation from the wire.
- o Dip the bare wire in liquid flux.
- o Place the fluxed wire on the solder connection and place the hot soldering iron tip on the wire, and;
- o Remove the tip and wire simultaneously as soon as the desired amount of solder has wicked onto the wire.
- o Clean surfaces to restore solderability.

FIGURE 87. USING WICK TO REMOVE SOLDER.



b. *Solder Removal Using Bulb Type Solder Extractor*.

(1) Squeeze bulb on solder extractor.

(2) Place tip of heated solder extractor on solder to be extracted.

(3) When solder becomes melted, slowly release solder extractor bulb to remove solder from connection.

(4) Remove solder extractor from solder connection.

(5) Remove solder from solder extractor by squeezing and releasing bulb several times.

It may be necessary to repeat this procedure to remove the required solder.

c. *Resoldering*. After the solder has been removed, the wires- and leads should be resoldered.

d. *Connection Reinspection*. Each resoldered connection should be inspected to insure proper connection.

LESSON 2

PROCEDURES FOR SOLDERING, DESOLDERING, AND REPAIR OF DEFECTIVE ELECTRICAL/ELECTRONIC CIRCUITS, INCLUDING INSPECTION STANDARDS

TASK 2. Identify inspection standards in accordance with MIL-STD 1460 (MU).

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Requirements for inspection of soldered joints are entirely dependent upon the application. Soldering operations are so diverse that many detailed military inspection standards have been developed. The inspection standards covered within this subcourse are based on MIL-STD 1460 (MU).

Inspection for soldering commences with analysis of materials, of geometric accuracy, of uniformity of fluxes, and assessment of surface conditions.

Solderability is probably the most difficult factor to define. Perfect surface condition and cleanliness are impractical, so soldering is always performed on an imperfect surface. Normal precautions in cleaning and preparation are essential, and yet the criteria for solderability remains somewhat subjective.

2. Inspection

a. *Visual*. One hundred percent visual inspection of all soldered connections should be performed in conjunction with appropriate community drawings and MIL STD 1460 (MU). A magnifying glass of no greater magnification than 10X, nor less than 6X, is to be used to aid visual inspection. Deviation from any of the requirements will be grounds for rejection.

(1) *Mark of Acceptance*. Soldered connections that comply with the requirements (where possible) may be identified by color coding with a nonfungus nutrient ink or paint that should not affect the electrical characteristics of the assembled circuitry. The coding is to be of contrasting color to the area it is applied. When applied, it should be limited in size but readily visible. For post type terminal connections, the coding shall be applied on the head of the terminal. Where receptacle or cup type terminals are involved, the coding is not to be applied on the solder joint.

b. *Mechanical*. A mechanical check of a soldered joint is necessary when required to supplement visual inspection. After a mechanical check is performed, the joint must be reworked, if required, to meet the requirements of MIL-STD 1460. Connections which are reworked must meet the original soldering requirement.

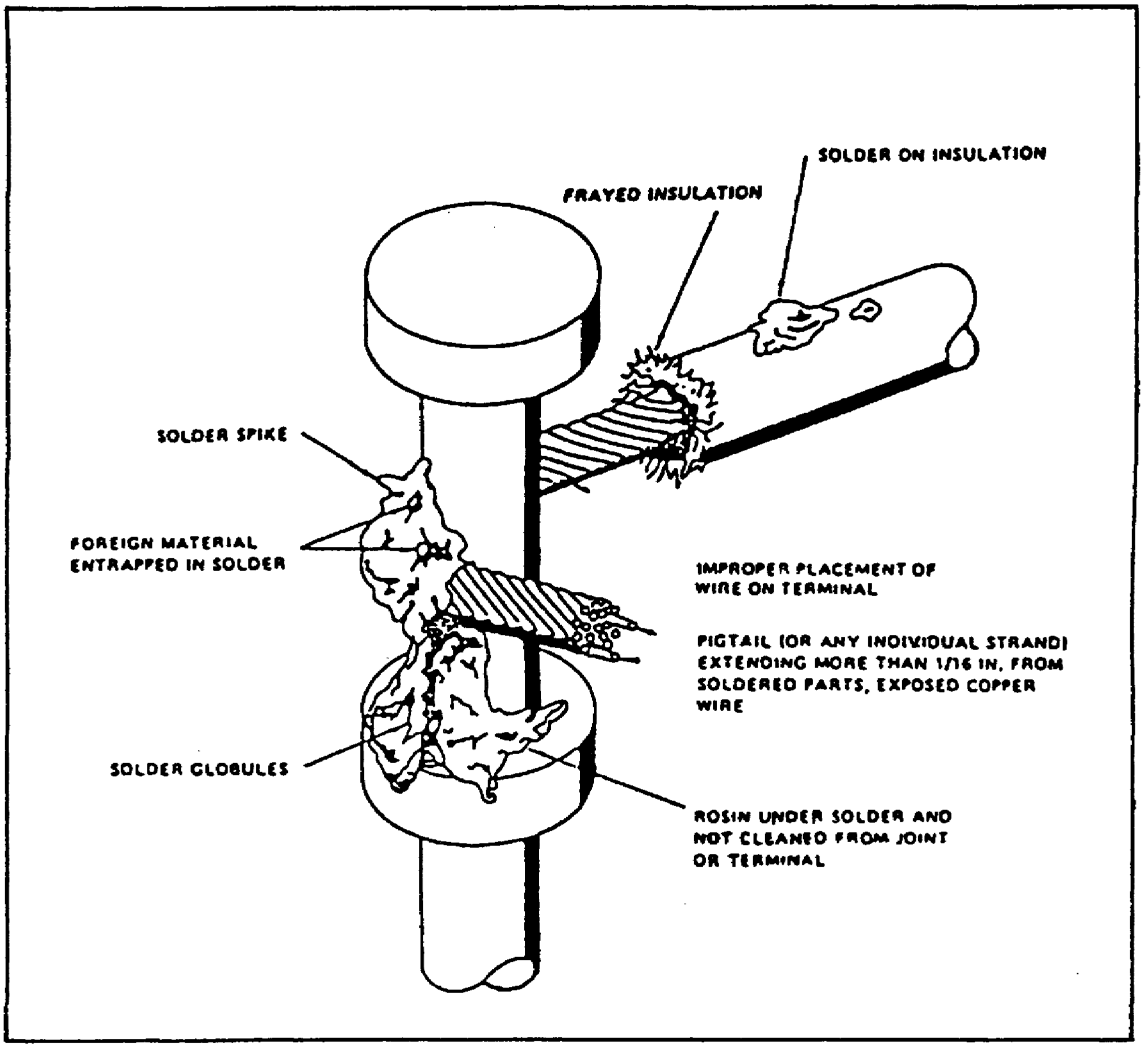
c. *Surveillance*. A surveillance program will be conducted to observe the control and disposition of nonconforming material. This includes periodic inspection of the work area, tools, materials, and procedures.

3. *Acceptance Criteria*. All soldered connections are to be inspected for conformance with the following conditions.

a. *Solder Connection*. The solder connection should have a smooth bright appearance, without porosity, cracks, pits that bottom out, or surface strain lines. Solder should cover the top of the conductor wire and concave fillet should be observed between the lower half of the conductor wire and the terminal. There can be no foreign material or threads of insulation embedded in the solder.

b. *Excessive Solder*. Beads of solder cannot project from the terminal and no solder should exist as runs on the outside of the terminal. There should be no solder splatter on the adjacent components or surfaces (figure 88). Solder is excessive if fillet does not reveal the outline of soldered component.

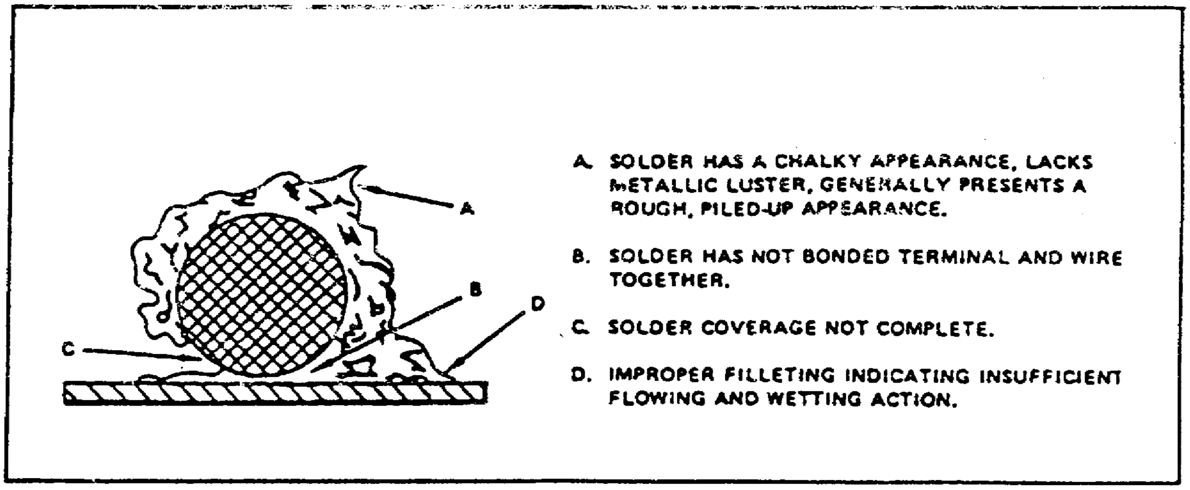
FIGURE 88. UNACCEPTABLE SOLDER JOINT.



c. *Cold Solder Joint*. The solder should adhere firmly and smoothly to parts joined. The joint cannot be chalky in appearance, lack metallic luster, nor should it have a rough, gritty, piled-up surface (figure 89 on the following page).

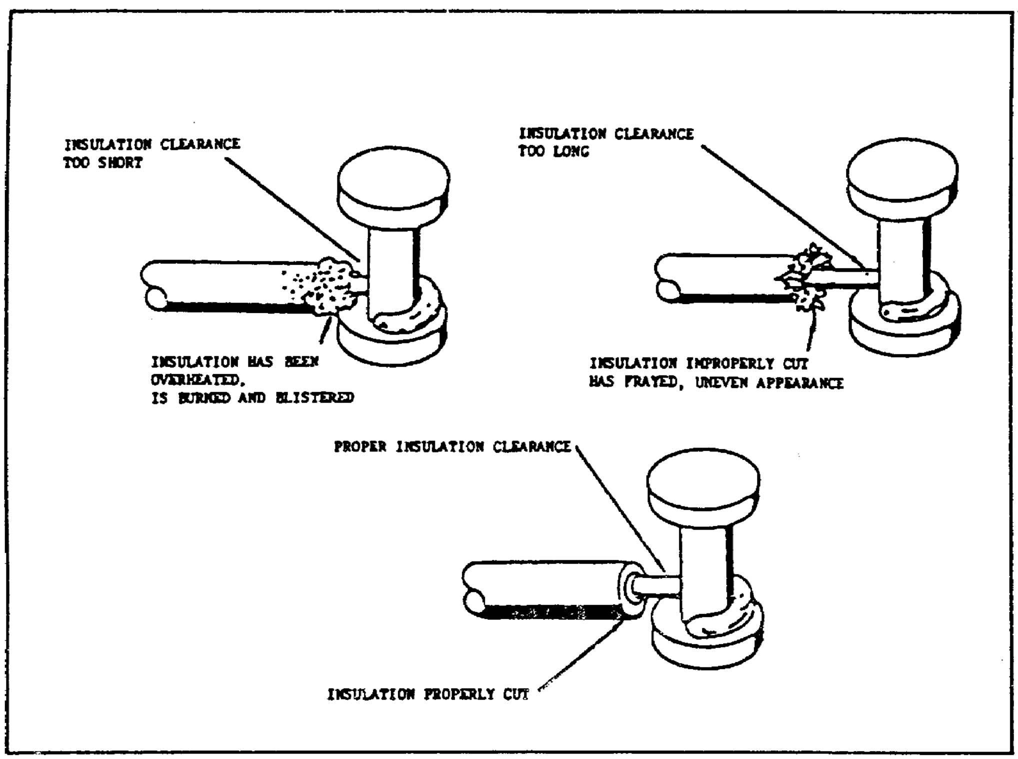
d. *Rosin Joint*. Flux cannot be trapped in the solder joint, nor should rosin flux residues hold the components together.

FIGURE 89. COLD SOLDER JOINT.



e. *Insulation*. The insulation should not be charred, frayed, split, or pinched through exposing the conductor wire. Slight discoloration of insulation shall not be considered cause for rejection. Insulation clearance must be in in accordance with the the example shown in figure 90.

FIGURE 90. INSULATION TRIM.



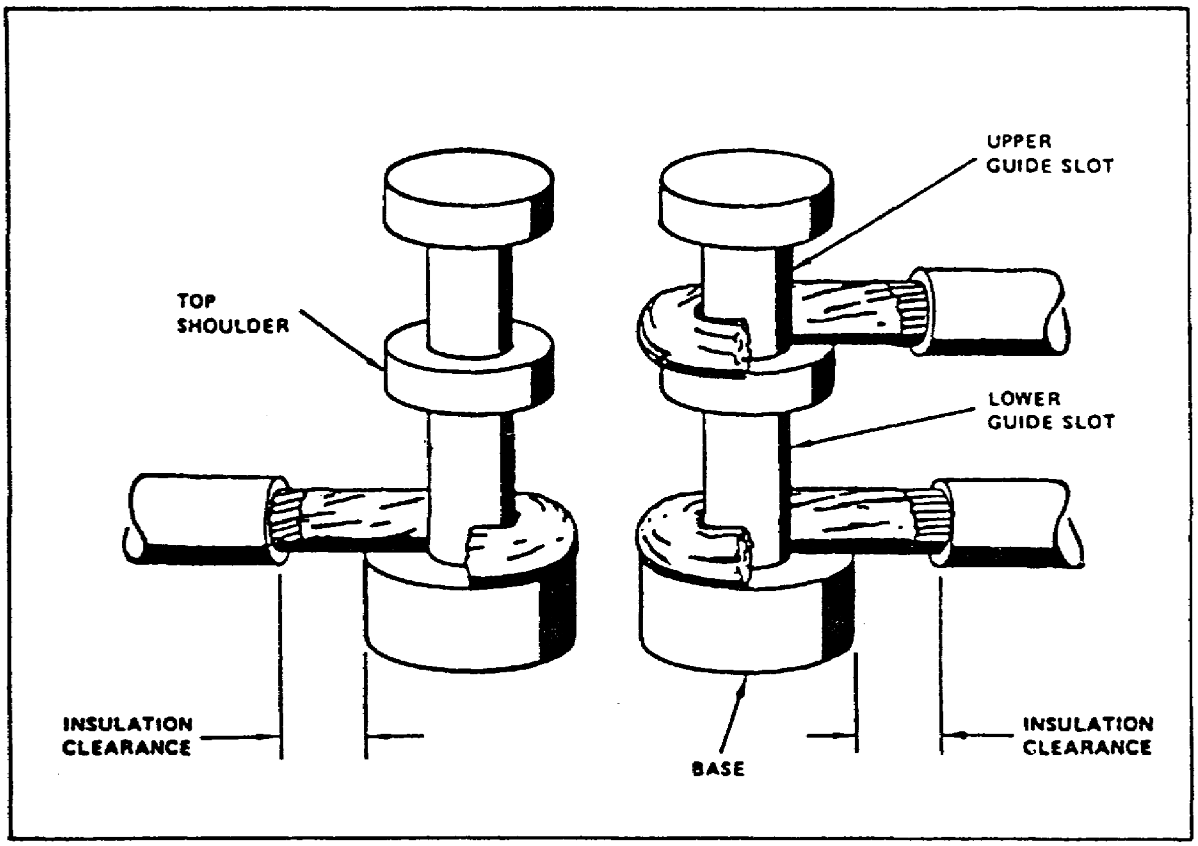
f. *Conductor Wire*. The wire must not be ringed, nicked, or cut; nor will there be any unsoldered strands. Wire diameter cannot be reduced. Exposed copper ends on the wire should be completely covered with solder, unless conformal coated.

g. *Capillary Action (Wicking)*. Wick length of solder on the wire strands should be visible and must not extend into the insulation

h. *Conductor Wire and Component Lead Tension*. All conductor wires and component leads going to a soldered connection should have slack in the form of an arc or gradual bend. Soldered components must not be in electrical contact with adjacent circuitry, or other components.

i. *Multiple Terminations*. The number of connections per terminal are to be in accordance with the drawing or specification. Each conductor wire should be adjacent to the surface of the terminal, not one overlapping another. Multiple connections on turret type terminals must be in accordance with figure 91.

FIGURE 91. TYPICAL TURRET TERMINAL USE.



4. Rejection Criteria

a. *General Criteria*. Evidence of any defect, including but not limited to the following, should be cause for rejection:

- Charring, burning, or other damage to insulation.
- Splattering of flux or solder on adjacent connections or components.
- Solder points (peaks).
- Pits, scars; or holes.
- Excessive solder which obscures the connection configuration.
- Excessive wicking.
- Loose leads or wires.
- Cold solder connections.
- Resin solder connection.
- Fractured solder connection.
- Cut, nicked, or scraped leads or wires; insufficient slack.
- Unclean connection (e.g. lint, residue, flux, solder, splash, dirt, etc.).
- Dewetting
- Insufficient solder.
- Visible bare primary conductor within the solder joint area.
- Clinched leads resulting in a reduction of the required spacing between conductors.
- Birdcaging.
- Splicing.
- Plated through holes not filled with continuous solder plug.

- Pads connected by plated through holes and eyelets connecting pads on multi-layer boards, or double sided printed circuit boards, show evidence of failure to wet the metallic surfaces.

- Use of unapproved tools or improper use of approved tools.

- Work area environmental controls improper.

- Use of improper materials.

- Solderers not certified.

b. *Printed Wiring Criteria*. In addition to the criteria specified above, evidence of any defects, including but not limited to the following, should be cause for rejection of printed wiring:

- Pits, scratches, pinholes, or undercutting that reduce the conductor cross-sectional area more than 20%.

- Separation of the conductor pattern from the base laminate.

- Blisters in the conductor pattern.

- Delamination of the base material.

- Wrinkles in the conductor pattern.

- Dirt, grease, or other foreign matter on the printed wiring.

- Scratched, abraded, or scraped finish that will change the electrical resistance.

PRACTICAL EXERCISE 2

1. Instructions

On a plain sheet of paper, write down the answers to the following questions. When you have answered them, turn the page and check your answers.

a. What do all noncorrosive fluxes have as a common ingredient?

b. What does the term "liquidus temperature" mean?

c. When selecting a solder flux, the assembly being soldered and the solderability of the base metal are two factors that influence the choice of flux. Name two other factors that influence the choice of flux.

d. Prior to the actual soldering process, the metal to be soldered should be precleaned. What is the purpose of degreasing?

e. Identify the only approved type of soldering tip that can be used for soldering.

f. Name a tool that is used to protect heat-sensitive components, such as semiconductors and crystal devices, from damage due to heat while soldering.

g. What is the preferred soldering iron tip temperature for terminals and lugs?

h. After a joint has been soldered together and allowed to cool, what is the preferred method for removing all flux from around the joint?

i. Name the most acceptable form of solder removal.

j. In compliance with inspection standards specified in MIL-STD 1460 (MU), a visual inspection of all soldered connections shall be performed with a magnifying glass. What is the minimum and maximum power for this instrument?

k. Name the acceptable inspection criteria for a soldered connection.

l. Name the acceptable inspection criteria for insulation.

m. There are 24 item descriptions regarding rejection criteria of a soldered connection. Name five of the rejection criteria descriptions.

LESSON 2. PRACTICAL EXERCISE - ANSWERS

a. Rosin.

b. Liquidus temperature is the lowest temperature at which a metal or solder is completely liquid.

c. (1) Rate of soldering required.

(2) Accessibility of the part for cleaning after soldering.

d. Grease and oil must be removed because they prevent wetting action by the flux and solder.

e. Iron clad soldering tip.

f. Thermal shunts or heat sinks.

g. 500 degrees F. minimum.

h. All flux will be removed, using a noncorrosive solvent.

i. Wicking.

j. No greater magnification than 10OX nor less than 6X.

k. The soldered connection shall have a smooth bright appearance, without porosity, cracks, pits that bottom out, or surface strain lines.

l. The insulation shall not be charred, frayed, split, or pinched through exposing the conductor wire.

m. (1) Charring, burning, or other damage to insulation.

(2) Splattering of flux or solder on adjacent connections or components.

(3) Solder points (peaks).

(4) Pits, scars, or holes.

(5) Excessive solder, which obscures the connection configuration.

(6) Excessive wicking.

(7) Loose leads or wires.

(8) Cold solder connections.

(9) Rosin solder connection.

(10) Fractured solder connection.

(11) Cut, nicked, or scraped leads or wires; insufficient slack.

(12) Unclean connection (e.g. lint, residue, flux, solder, splash, dirt, etc.).

(13) Dewetting.

(14) Insufficient solder.

(15) Visible bare primary conductor within the solder joint area.

(16) Clinched leads resulting in a reduction of the required spacing between conductors.

(17) Birdcaging.

(18) Splicing.

(19) Plated through holes not filled with continuous solder plug.

(20) Pads connected by plated through holes and eyelets connecting pads on multi-layer boards, or double sided printed circuit boards, show evidence of failure to wet the metallic surfaces.

(21) Use of unapproved tools or improper use of approved tools.

(22) Work area environmental controls improper.

(23) Use of improper materials.

(24) Solderers not certified.

REFERENCES

REFERENCES

The following documents were used as resource materials in developing this subcourse:

FM 11-72
MIL-STD 1460 (MU)