SUBCOURSE **SS0605** | EDITION **7**

LOGIC CIRCUITS AND DEVICES

(DEVELOPMENT DATE: 30 SEPTEMBER 1987)

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

US ARMY RADIO/TELEVISION SYSTEMS SPECIALIST
MOS 26T SKILL LEVEL 1 COURSE

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LOGIC CIRCUITS AND DEVICES

(Developmental Date: 30 September 1987)

SUBCOURSE NO: SS0605-7

US Army Signal Center and Fort Gordon
Fort Gordon, Georgia

Five Credit Hours

General

The Logic Circuits and Devices subcourse requires a basic understanding of Boolean mathematics. This subcourse is designed to teach you knowledge and skills for performing tasks related to operation and operator's maintenance of electronic equipment. Information is provided on all the gates and their operations. The operations go from the simplest (turning on a light switch) to the most complex array of gates (satellite communications). The subcourse is presented in three lessons, each lesson corresponding to a terminal objective as indicated below.

Lesson 1: DESCRIBE THE ELECTRONIC PARAMETERS OF LOGIC

TASK: Describe and identify logic symbols and positive and negative logic.

CONDITIONS: Given the difference between positive and negative logics, and the use of symbols.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test questions covering the information given in this lesson.

Lesson 2: DESCRIBE LOGIC SYSTEMS

TASK: Describe and identify how logic gates are combined and the changes of their outputs.

CONDITIONS: Given information about logic gates, describe the difference of some systems and their outputs.

STANDARDS: Demonstrate competency of the task skills and knowledge by completing a series of truth tables and by correctly responding to 80 percent of the multiple-choice test questions relating to logic systems.

Lesson 3: DESCRIBE BASIC LOGIC CIRCUITS

TASK: Identify the switches, diodes, transistorized gates, and circuit symbols found in schematics.

CONDITIONS: Given data relating to switches, diodes, transistorized gates, circuit symbols, and schematic diagrams.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test questions relating to switches, diodes, transistorized gates, and circuit symbols found in schematic diagrams.

This subcourse is designed to give you a working knowledge of logics, but not to fix or repair equipment without additional knowledge of electronics.

This subcourse supports the following MOS 26T tasks: (STP 11-26TI3-SM-TG, September 1985)

113-575-0021	Troubleshoot and Repair a Television Receiver
113-575-0038	Troubleshoot and Repair Video Pulse Distribution Amplifier
113-575-0040	Troubleshoot and Repair a Sync Generator
113-575-0041	Troubleshoot and Repair a Character Generator
113-575-0042	Troubleshoot a Reel-to-reel Audio Tape Recorder/Reproducer
113-575-0043	Troubleshoot a Color Television (TV) Camera
113-575-0044	Troubleshoot a 3/4-inch Video Cassette Recorder/Reproducer (VCR)
113-575-0045	Troubleshoot a Television Transmitter
113-575-0046	Troubleshoot a Television (TV) Video Switcher
113-575-0049	Troubleshoot a Time Base Corrector
113-575-2040	Perform Functional Check of a Color Television (TV) Film Chain Camera
113-575-2041	Perform Functional Check of a Color Television (TV) Camera System
113-575-2042	Perform Functional Check of a Color Television (TV) Studio Camera Colorplexer
113-575-2043	Perform Functional Check of a Color Television (TV) Studio Camera
113-575-2044	Perform Functional Check of a Small Format Television (TV) Recording System, Using a 3/4-inch Video Cassette Recorder/Reproducer (VCR)
113-575-2045	Perform Functional Check of a Time Base Corrector (TBC)
113-575-2047	Perform Functional Check of a Television (TV) Transmitter
113-575-3029	Perform Daily Maintenance on a 3/4-inch Video Cassette Recorder/Reproducer (VCR)

113-575-3031	Perform a Complete Color Convergence of a Color Television (TV) Receiver
113-575-3033	Perform Measurement of the Visual and Audio Transmitter Carrier Frequency
113-575-3035	Perform Daily Maintenance of a Television (TV) Video Switcher
113-575-3036	Perform Preventive Maintenance of a Character Generator
113-575-4010	Replace a Color Picture Tube (CRT)
113-575-4011	Replace Faulty Television (TV) Studio Camera Cable
113-575-4012	Replace RF Transmission Lines Between Antenna and RF Modulators
113-575-8017	Perform Alignment Check of a Wave Form Monitor

***** IMPORTANT NOTICE *****

THE PASSING SCORE FOR ALL ACCP MATERIAL IS NOW 70%.

PLEASE DISREGARD ALL REFERENCES TO THE 75% REQUIREMENT.

TABLE OF CONTENTS

Whenever pronouns or other references denoting gender appear in this document, they are written to refer to either male or female unless otherwise noted.

INTRODUCTION TO LOGIC CIRCUITS AND DEVICES

1. The terms "logic" and "logically" probably cause you to think of common sense, expected results, and rational decisions. These definitions or synonyms are the same ones connected with the word logic when the term is used in electronics. The term "logic" in electronics describes operations and symbols of operations that follow a predetermined set of rules.

2. Transistorized circuitry and integrated circuits (IC) are being used more and more in new equipment. Many of these circuits, especially those that function in a binary manner, are standardized. They belong to specific classes of circuits depending on their function. As a result, symbolic logic is now used not only with computers but also with data processing equipment, communications equipment - in almost every area in the electronic field.

3. To more easily understand the logic diagrams of existing equipment, you must have a thorough knowledge of binary logic. You should recognize the symbols when they are used, know the meaning of each symbol, and know the rules governing their functions.

4. This subcourse has the information you need to learn and apply the principles of symbolic logic to military equipment. It is based on military standards of symbolic logic. Of course, once you have learned the rules of binary logic thoroughly, any symbol variations you encounter in nonmilitary or older nonstandard logic will be very easy to understand. You will only have to recognize new symbols - the function of the circuits they represent and the binary rules they follow will remain the same.

LESSON 1
DESCRIBE THE ELECTRONIC PARAMETERS OF LOGIC

TASK

Describe and identify logic symbols and positive and negative logic.

CONDITIONS

Given the description of positive and negative logics, and the use of symbols.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test questions covering the information given in this lesson.

REFERENCES

None

Learning Event 1:
IDENTIFY THE USE OF POSITIVE AND NEGATIVE LOGIC CIRCUITS

1. Symbols are used to present basic binary circuits because the symbols are time savers. Each logic symbol represents an entire circuit. By using the symbols, large schematics of electronic equipment can be reduced to smaller prints called logic diagrams. You no longer have to trace a signal through a complicated schematic if a logic diagram is available. Logic diagrams are more concise and easier to read and understand.

2. For example, suppose that after studying the circuit shown in Figure 1-1 you find that it has a set pattern of operation. Each time you press two buttons the circuit operates and the bell rings. Once you have studied the schematic and learned how the circuit rings the bell, there is no need to trace through the entire schematic each time the two buttons are pressed. You know why the bell rings; now you need to know when it rings.

a. Replacing the entire schematic with one symbol, as shown in Figure 1-2, you can then say, "If you know the inputs, you can predict the output." Each time you see that symbol you will recognize it as a bell-ringer circuit and, logically, closing two input switches will ring the bell.

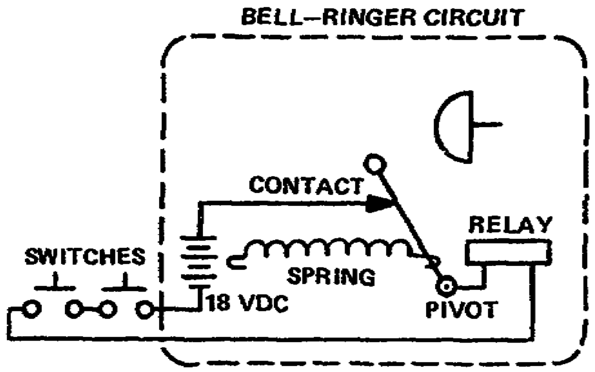


Figure 1-1. A schematic diagram

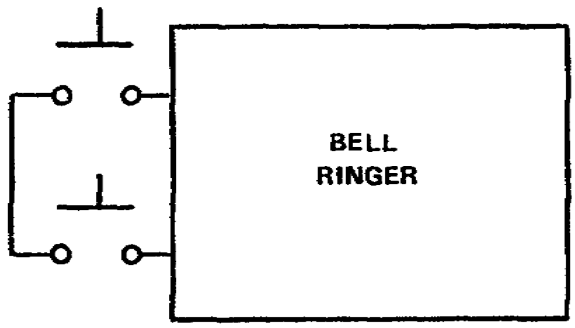


Figure 1-2. A symbol to replace the schematic

b. Imagine expanding this idea to many different circuits, each represented by a symbol. It means less time to trace through a large diagram, more consolidated prints (less room required for each circuit,) and a lot less confusion of lines (wires) on the diagram. A logic diagram is just a print with each circuit represented by a symbol instead of a schematic. The symbols are connected together by lines to show how the output of one circuit connects to the input of another.

Learning Event 2:
DESCRIBE NEGATIVE AND POSITIVE LOGIC CIRCUITS

1. Positive and negative logic circuits are basic circuits that are used to build positive and negative logic systems. The terms "negative" and "positive" refer only to the relative voltage level of a signal. These terms do not refer to the actual voltage level of either a binary 1 or a binary 0.

2. For example, the two signal voltages in either a positive or a negative logic system may be either negative or positive. Or one of the signals may be negative and the other positive. The important point is that you should always be careful not to confuse the references to logic levels with the references to voltage levels. It does not matter if a circuit uses negative or positive voltage.

3. The term positive logic means that the circuit being referred to uses the more positive of two signal voltages to represent binary 1.

a. For example, if the two signal voltages in a system happen to be 0 and +6 the more positive of the two is +6. In this case then the +6-volt signal represents binary 1.

b. If the voltages are -6 and -12, the -6 is more positive. In this case the -6 represents binary 1.

4. From the above examples, you can see that a system using positive logic may not even use a positive signal. A positive logic system is one that is classified or defined as a system in which the more positive signal represents binary 1.

5. Since positive logic is defined as a system using the more positive of two signals to represent binary 1, it follows that negative logic must be a logic system that uses the more negative of two signal voltages to represent binary 1.

6. The more negative of two voltages such as -6 and -12 is obviously the -12 and thus it represents binary 1. In a system using +6 and +12 volts, the +6 is the more negative of the two and represents binary 1.

Learning Event 3:
IDENTIFY STATE INDICATOR AND INVERTER SYMBOLS

1. There are many different pairs of voltages in use and in some applications, such as communications, the levels are different in each piece of equipment. Therefore, common titles are used to identify the two signals' conditions regardless of their actual levels. The system we will discuss here is the most popular one and the least confusing. The two signal levels are simply called high and low, and are the same as 1 and 0.

a. The more positive of the two voltages is the high (H) and the more negative of the two voltages is the low (L). This method has a great advantage in that it does not matter what the two voltages are, one is always more positive than the other. Even if signal levels change from one equipment to the other, the high and low concept can still be applied.

b. The method also allows us to discuss symbols and the circuit functions they represent, without regard to which voltage represents a binary 1 and which voltage represents a binary 0.

2. The military standard logic uses small circles called state indicators at the inputs and outputs of the logic symbols. The lines entering and leaving a symbol represent its input and output, the presence or the absence of a circle on each line specifies what the active signal condition is for that connection.

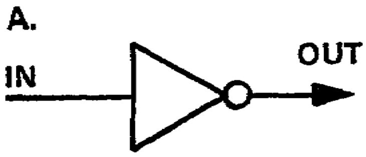
a. The presence of a circle indicates that at that point in the circuit the relatively low (L) voltage is the active state of the signal. A circle on an input to a symbol means that a low is required to activate or "turn on" that circuit. A circle on the output means that the output is a low when the circuit is activated or "turned on."

b. The absence of a circle indicates that at that point in the circuit the relatively high (H) voltage is the active state of the signal. The absence of a circle on an input to a symbol means that a high is required to activate or "turn-on" the circuit. Absence of a circle on the output means that the output is high when the circuit is activated or "turned on."

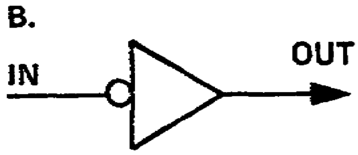
NOTE:

> The circle is always a part of a symbol. It is never used alone on a line to indicate signal levels or any other fact.

c. The state indicator allow us to predetermine the input signals required for any circuit and the circuit's output level without regard to the function of the circuit. This fact will be correct regardless of the symbol. As we discuss each symbol, we will use the shape of the symbol to determine its circuit function, and the state indicators (circles) to determine the inputs required and the output produced.



IN	OUT
H	L
L	H



IN	OUT
H	L
L	H

Figure 1-3. An inverter symbol

3. When a binary circuit produces an output that is exactly the opposite of the input, it is called an inverter. The symbol for an inverter is shown in Figure 1-3. The inverter symbol is the only symbol that will have one input and one output. All others will have two inputs or more. The inverter is considered a NOT gate.

4. The state indicator (circle) is shown as part of the inverter symbol on either its input or its output. It depends on whether the output is considered active when it is high or when it is low. Both versions of the symbol indicate that when the input is high the output is low and when the input is low the output is high. A comparison of the truth tables in Figure 1-3 proves this to be true.

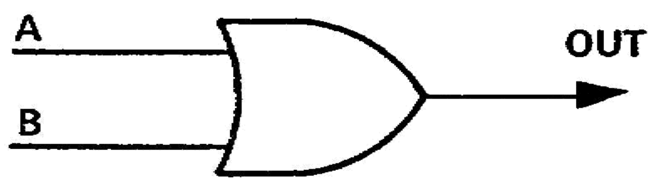
5. An inverter performs the function of negation on signals and negates the Boolean expression of the input signals. Boolean algebra is a system of mathematical logic, using the function AND, NOT, and OR. In the Boolean system, AND is represented by multiplication, NOT by complementation, and OR by addition. So X and Y is written XY or X • Y, NOT X is written X', and X OR Y is written X + Y. Boolean functions are used in the design of digital logic circuits. A simple term such as B at the input to an inverter becomes $\overline{B}$ at the output. An expression such as A + $\overline{B}$ becomes A + B after an inverter. Simplifying this expression, ($\overline{A}$ + $\overline{B}$) = (AB), we find that A + B becomes AB when it is inverted. This shows that an inverter negates the function, as well as the signal conditions in an expression.

Learning Event 4:
IDENTIFY THE OR AND THE AND SYMBOL

1. A circuit that performs an OR function is one that has at least two separate input connections and is activated or enabled by any one of them. The term "enable" is a common way to describe the action of the signal that activates a gate. In binary logic, input signals don't usually force gates to produce an output; rather the input signals allow or enable a gate to produce an output. We usually think of input signals as either inhibiting a circuit or enabling it. Any signal that prevents a gate from producing its active output is called an inhibit signal; and, the signal that ultimately allows a gate to produce its active output is called an enable signal.

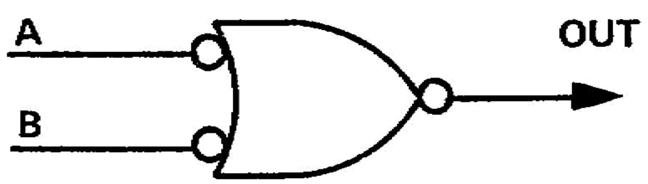
a. The standard logic symbol for an OR circuit is shown in Figure 1-4. In the case of two inputs (A, B) to an OR gate, the circuit is activated or enabled by a specified input level to either input A or input B. When the circuit is enabled it produces a specified output level. The Boolean expression for the output is A + B.

A.



A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	H

B.



A	B	OUT
L	L	L
L	H	L
H	L	L
H	H	H

Figure 1-4. OR circuit symbols

b. OR gates with more than two inputs connections are very common and we describe them in the same way as the two input OR gate. The OR gate is activated if input A or B or C etc. is active. If more than one input is active the result is the same, the circuit still produces an output. From this characteristic we determine that this symbol represents an inclusive OR, the conditions that cause an output include the condition where more than one input is active. Another way of describing the circuit operation is "it produces an output if any one or more inputs is active."

2. Always remember that it's the shape of the signal that tells you the function and in this case the symbols in Figure 1-4 represent OR gates. The presence or absence of state indicators (circles) only specifies which voltage level (high or low) is required on each input and which level is produced.

a. Look at A of Figure 1-4. The absence of circles means the active signal is a high. We know, then, that the inputs require a high to enable the circuit because there are no circles on either of them. The absence of a circle on the output means that the gate produces a high output when it is active or enabled. From this we can say that the circuit requires a high in, to produce high out. But a high on which input? The symbol shape is "OR" so a high on input A or B or both causes a high out. Each of these conditions is shown in the truth table of Figure 3-17 on page 32.

b. The symbol in B, Figure 1-4, has circles on the input and output but the shape is still the same so it's still an OR gate. A circle means a low is the active signal so this gate requires a low on A or B or both to produce a low output. The truth table in part B shows that the same four conditions as in part A result in different output conditions. Obviously the circuits represented are both OR circuits. The difference is that one operates as an OR function of the relatively high signal, and the other as an OR function of the relatively low signal.

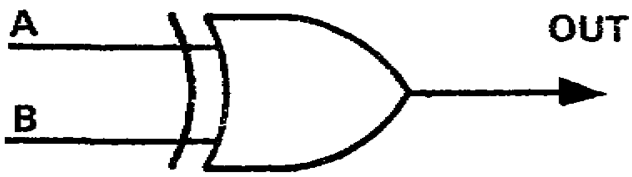
3. It's important that you realize we are discussing the function of circuits without looking at a schematic and knowing only how they respond to input signals. The circuits could be designed several different ways and still perform the same function. Thus, the inclusive OR symbol used here represents any and all inclusive OR circuits.

4. The exclusive OR is a variation of the OR symbol. The circuit it represents is still an OR circuit and performs an OR function; that's why the shape of the symbol is the same.

5. In A, Figure 1-5, for example, the gate requires a high on either input A or B just as the inclusive OR does. The gate is "exclusive" in that it will not be enabled (produce an output) if both inputs are high. A complete description of exclusive OR operation is "either A or B but NOT BOTH."

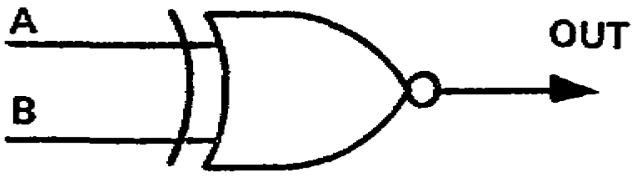
a. Look at either of the truth tables in Figure 1-5. They show that the required output is produced only when the inputs are not the same (not both high or both low.) The circuit represented by the symbol in part A produces a high (no circle on the output) when it is enabled. Its truth table indicates that it is enabled only when the inputs are not the same. When the inputs are both high or both low, the gate is inhibited and the output is low. The symbol in part B performs the same function but produces a low when it is enabled. The Boolean expression for the output of this type of gate is written either $A\overline{B} + A\overline{B}$ or A✓B.

A.



A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	L

B.



A	B	OUT
L	L	H
L	H	L
H	L	L
H	H	H

Figure 1-5. Exclusive OR symbols

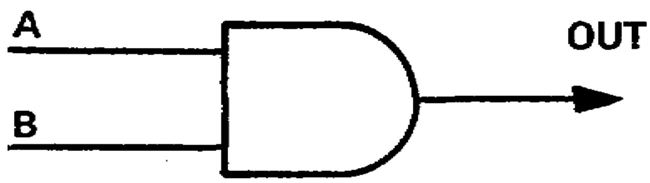
b. One use of the exclusive OR circuit is as a detection circuit in binary operations. For example, two signals that are always identical during normal operation can be compared by connecting them to the inputs of an exclusive OR circuit. As long as they are the same (either both high or both low) the circuit will not be activated. However, if one of the signals fails or is incorrect, the gate is enabled and the resulting output indicates that an error has occurred.

6. A circuit that performs an AND function is one that produces an output only when all inputs are active. Its operation can be described as producing an output either when A AND B are both active or when all inputs (A AND B AND C etc) are active.

7. The symbol for this type of gate is shown in Figure 1-6. As in the other symbols, its shape indicates its function and state indicators tell you which level is considered the active signal. In A, Figure 1-6, the symbol represents a circuit that produces a high output if and only if all inputs are high. The one in part B produces a low output if and only if all inputs are low. This symbol (in either form) performs the Boolean function of AND; its output is expressed as $A \bullet B$ or AB.

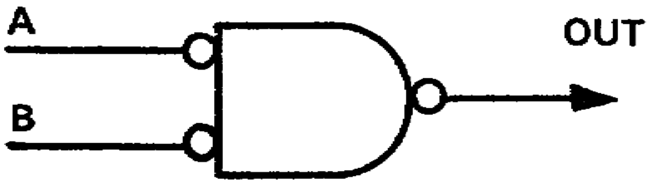
8. Since an AND gate requires that all inputs be active before it produces an active output, the last input signal to become active is called the enable signal. The other input (inputs, if there are more than two) is called the "prime" signal because it "primes" the gate or gets it ready for the last input signal to enable the gate. For AND gates that require high at the input, the first high input signal(s) primes the gate and the last high signal enables it.

A.



A	B	OUT
L	L	L
L	H	L
H	L	L
H	H	H

B.



A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	H

Figure 1-6. AND gate symbols

LESSON 1
PRACTICE EXERCISE

1. What are the minimum inputs of an OR gate?

   a. 0 or 1
   b. 1 or more
   c. 2 or more
   d. 3 or more

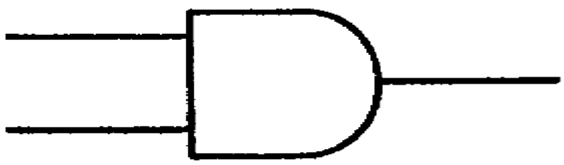
2. Any signal that prevents a gate from producing its active output is called?

   a. Enable signal
   b. Positive signal
   c. Inhibit signal
   d. Negative signal

3. Provided with two high inputs, which of the following gates will provide a high output operation?

   a. Inverter
   b. Exclusive OR
   c. NOR
   d. AND

4. What is the name of this symbol?



   a. AND
   b. OR
   c. NAND
   d. NOR

5. In a system using +6 and +12 which is the more negative?

   a. +12 volts
   b. Neither, they are both plus
   c. +6 volts
   d. Add them together for plus 18

6. Which number is used to indicate a binary high?

a. 1
b. 0
c. 4
d. 5

LESSON 2
DESCRIBE LOGIC SYSTEMS

TASK

Describe and identify how logic gates are combined and the changes of their outputs.

CONDITIONS

Given information about logic gates, describe the differences of some systems and their outputs.

STANDARDS

Demonstrate competency of the task skills and knowledge by completing a series of truth tables and by correctly responding to 80 percent of the multiple-choice test questions relating to logic systems.

REFERENCES

None

Learning Event 1:
DEFINE A LOGIC SYSTEM

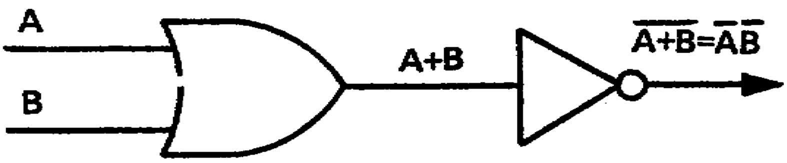
1. The term "system" is used two different ways in binary logic. Logic system is used to mean an entire piece of equipment and groups of equipment that work together. It is also used to mean combinations of the basic symbols into groups that each perform a complete function.

2. When the term logic system is used in connection with equipment, it refers to the voltages that are used as signal levels and indicates which voltage represents a binary 1. A negative logic system uses negative logic, and a positive logic system uses positive logic.

3. Systems as discussed in this portion are simple combinations of the basic symbols into groups. By this definition, a group of gates that performs addition is a system; a group of gates that monitors several signals and initiates an alarm if any signal fails is also a system.

Learning Event 2:
IDENTIFY AN OR GATE AND THE INVERTER COMBINATION

1. Adding an inverter to the output of an OR gate is a widely used technique for varying the basic functions of OR and NOT. The OR-inverter combination is so useful that it has been given a name of its own -- NOR gate. The OR gate, Figure 2-1, performs an OR function of the input signals and the inverter negates or "nots" the results. Hence, the name NOR (NOT OR). On a separate paper, complete the truth table in Figure 2-1 for the output of the inverter. Compare your results with Figure 3-17.

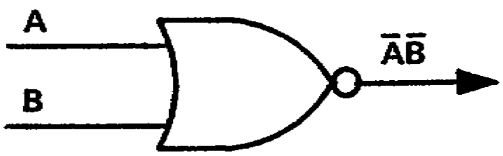


A	B	OUT
L	L	
L	H	
H	L	
H	H	

Figure 2-1. OR gate and inverter

2. A single circuit, and a single symbol to represent it, will also perform a NOR function: the symbol is shown in Figure 2-2. Compare the Boolean expression at the output of the gate with the output expression in Figure 2-1; they are identical and the function is also identical.

3. According to the rules for state indicators, the gate in Figure 2-2 produces a low if any input is a high. Thus, to obtain a high output both inputs must be low; it produces a high out when neither A or B is a high.



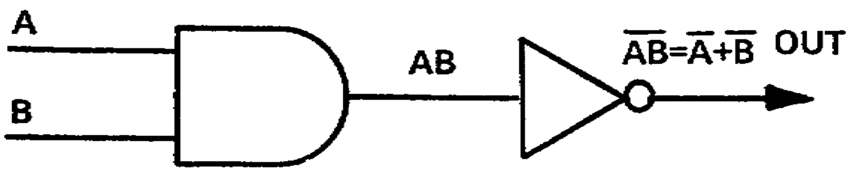
A	B	OUT
L	L	H
L	H	L
H	L	L
H	H	L

Figure 2-2. NOR gate symbol and truth table

4. Compare the truth table for the NOR gate in Figure 2-2 with the truth table you completed for Figure 2-1. They are the same which proves the symbols represent circuits that perform the same function. Do not, however, associate the circle on the output of the NOR gate with an independent inverter. The circle does not represent an inverter, it is only a state indicator. The NOR circuit inverts the signal. It is not an OR gate followed by an inverter.

Learning Event 3:
IDENTIFY AN AND GATE AND THE INVERTER COMBINATION

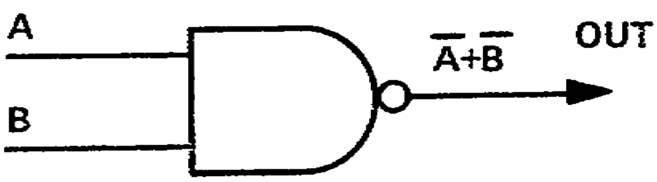
1. Connecting an inverter to the output of an AND gate, Figure 2-3, produces another function that is very useful. The function is NOT AND, commonly called NAND. The function is NOT AND because the AND gate performs and AND function of the input signals, then the inverter negates or "nots" the result. On a separate paper, complete the truth table in Figure 2-3 for the output of the inverter. Compare your result with Figure 2-2.



A	B	OUT
L	L	
L	H	
H	L	
H	H	

Figure 2-3. AND gate and inverter

2. The NAND function is so often used in equipment that, like the NOR gate, it has its own symbol: an AND gate symbol with a state indicator circle on the output and no indicators on the inputs as in Figure 2-4. But, because the function is the opposite of AND, it is called NOT AND. Compare the truth table in Figure 2-4 with the one you completed in Figure 2-3; they should be identical. Thus, with the proper use of the state indicators, we have a single symbol to represent the inverter AND function. A complete description of the operational characteristics of the gate is: all highs in, a low out; and low in, a high out. Another way of stating the NAND function is that the circuit produces a high output if the inputs are NOT ANDed (not both high).



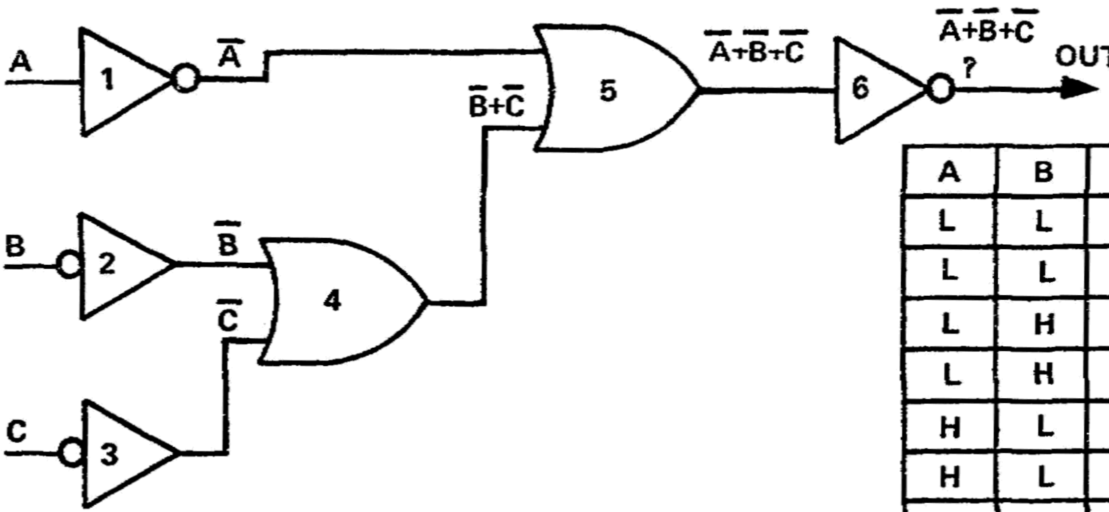
A	B	OUT
L	L	H
L	H	H
H	L	H
H	H	L

Figure 2-4. NAND gate symbol and truth table

Learning Event 4:
EXPLAIN HOW COMBINATIONS OF GATES CAN CHANGE FUNCTIONS

1. Logic systems can be designed many different ways to produce a specific result. The circuit arrangement selected usually depends on the equipment designer. There is seldom a "best" way of designing any binary system. Your job as a technician is to analyze and understand systems that already exist, not to design systems. Very often, however, you will find that a careful analysis of a system or partial system is the only way to prove its true operation.

2. Look at the system in Figure 2-5 for an example. At first glance it appears to perform an OR function of several inverted signals. If however, you use Boolean algebra, the system can be simplified and proved to be performing an entirely different function. Simplify the final expression and what remains? A 3-input AND function of ABC. The function is not at all what it first seems to be; the function, at least for the output we are considering, represents an ANDing of the inputs.



A	B	C	OUT
L	L	L	L
L	L	H	L
L	H	L	L
L	H	H	L
H	L	L	L
H	L	H	L
H	H	L	L
H	H	H	H

Figure 2-5. A small system

3. A truth table confirms our analysis of the function. The only input combination that enables the circuit to produce a high output is when A, B, and C are all true (high). Trace each combination listed in the truth table through the gates to be sure you understand the results.

4. Normally, this circuit would not have been designed this way if only the ABC output was to be used; a single AND circuit would have been used instead. However, peculiar arrangements of basic circuits such as this one often occur within large logic diagrams, usually because other combinations of the same input signals are required to satisfy other gates.

a. We could, for example, have an output tapped off gate 4 to use only the B + C function somewhere else. And perhaps the individual outputs of inverter 1, 2, or 3 are needed for driving other gates. A single AND gate would not provide these various output combinations.

b. Using Boolean algebra for labeling and simplifying will often enable you to clarify large sections of circuits when you study logic diagrams just as we simplified this small one.

LESSON 2
PRACTICE EXERCISE

1. What is it called when single combinations of basic symbols are grouped together?

   a. Logic system
   b. Logic gates
   c. Logic diagram
   d. Logic group

2. When an inverter is attached to an OR gate, what is the circuit called?

   a. NAND
   b. NOR
   c. OR-exclusive
   d. Inverter

3. When two highs are applied to the input of an NOR gate, what is the output?

   a. Low
   b. High
   c. Both A and B
   d. Neither A or B

4. Which two combinations make a NAND gate?

   a. AND and OR
   b. AND and Inverter
   c. AND and NOR
   d. AND and Exclusive OR

5. What is one advantage of using Boolean algebra for labeling circuits?

   a. There is no advantage
   b. It makes logic study easier
   c. It clarifies large sections of circuits
   d. It allows the use of a slide rule in computations

LESSON 3
DESCRIBE BASIC LOGIC CIRCUITS

TASK

Identify the switches, diodes, transistorized gates, and circuit symbols found in schematics.

CONDITIONS

Given data relating to switches, diodes, transistorized gates, circuit symbols, and schematic diagrams.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to 80 percent of the multiple-choice test questions relating to switches, diodes, transistorized gates, and circuit symbols found in schematic diagrams.

REFERENCES

None

Learning Event 1:
IDENTIFY A TWO SWITCH AS A LOGIC OR GATE

1. There are many circuits that perform the function of an OR gate. One of the simplest is a circuit with two parallel switches and a lamp, Figure 3-1. The circuit is an OR gate because of the switch arrangement in the voltage supply to the lamp. If either switch A or B is closed, the lamp will light. Either A or B will connect +6 volts to the lamp and, since the other side is grounded, current will flow, lighting the lamp.

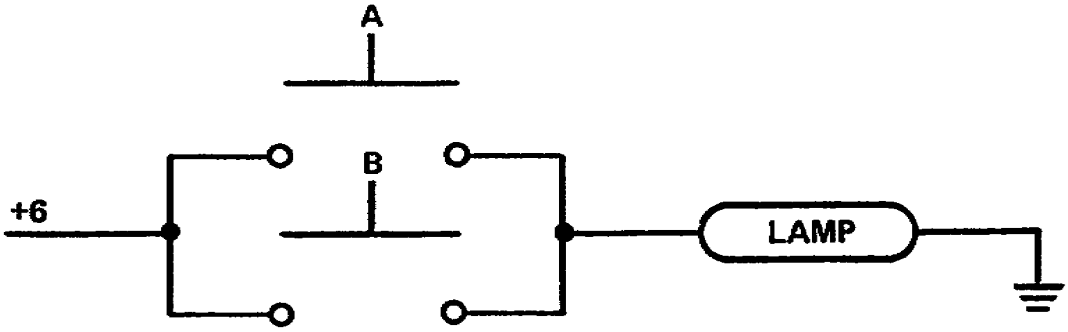


Figure 3-1. Two switches as an OR gate

a. Considering the light from the lamp as the output, let's relate the whole circuit to either positive logic or negative logic OR gate. We've already determined that it follows the rules of an OR gate but how can we say that it represents one type of logic or another? Look at the voltage input and consider the circuit operation again, first as a positive logic.

b. When both switches are open there is no voltage or 0 volts connected to the lamp and there is no output-light. The two operating voltages then are +6 and 0 volts and, since positive logic requires that the more positive voltage is the binary 1 or active signal, this circuit operates as positive logic because we have a positive output (light) when we have a positive input.

2. By changing the operating voltage to the switches, we can easily show the same circuit as a negative logic OR gate. When either switch (or both) is closed, the negative voltage lights the lamp. Since the more negative voltage produces an output, the circuit follows the rules of a negative OR gate: any one or more low inputs produces an output.

3. There is one other fact about the OR symbol that we should relate to the schematic. An OR gate can have any number of input connections and still follow the rule that any one (or more) active input produces an output.

4. Look at Figure 3-1 again and imagine more switches connected in parallel with A and B. Close any one switch and the lamp still lights. It's still an OR gate no matter how many switches are connected in parallel.

5. A functional circuit (diode or gate) that is used in many applications can be almost as simple as the circuit in paragraph 1. Figure 3-2A shows a simple circuit that functions as a positive logic OR gate and Figure 3-2B shows a similar circuit that functions as a negative logic OR gate.

a. For A, Figure 3-2, let's say the operating voltages are +6 and 0 volts. When either A or B is connected to +6 volts, the associated diode is forward biased. Current flows from ground through the resistor, through the diode to the voltage source (the input). Since almost all the resistance in the circuit is the resistor, it will drop all of the voltage. Therefore, the voltage at the output will be +6 volts, the same as the input.

b. It might be easier to see if you imagine each diode as an automatic switch. When zero volts is connected to both inputs, the switches are open and the voltage below the resistor (0 volts) is the output level. When +6 volts is applied to an input, the associated switch closes and the +6 volts is connected straight through to the output.

6. Part B, Figure 3-2, shows a negative OR gate with 0 and -6 volts as the operating voltages. It is exactly the same as part A except for the position of the diodes and the input voltages. When one or more inputs is low (-6), the diode(s) is forward biased and the output is low (-6). The six volts are dropped across resistor R1. When all inputs are high (binary 0) the output is high.

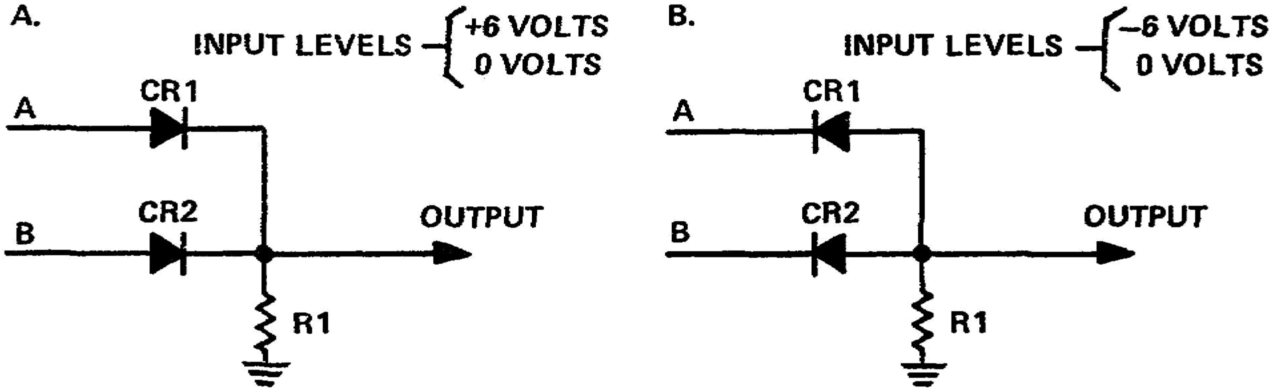


Figure 3-2. Diode OR gates

7. Thus far, we haven't used a circuit that is really complicated enough to warrant using a symbol to replace the whole schematic. But now let's examine a complex OR circuit that might be used in electronic equipment, the basic transistorized OR gate.

8. Part A, Figure 3-2, shows a single positive OR circuit schematic. By itself it may look very complicated, but imagine having as many as 20 or more of these, plus other required circuits, on a schematic! The advantage of using a simple symbol to represent each becomes obvious. Each OR circuit performs the same function on the inputs. Once we determine how one circuit works, we can substitute a small symbol for the entire circuit. The advantage: much smaller and less complicated diagrams.

a. You're probably wondering why we bother using something so complicated to do the same thing as the simple diode OR gate circuit. Well, there are other reasons but the primary reason is to get voltage. Using the diode CR gate, we get only what we put into it, or even slightly less.

b. For example, if the input signal to the diode OR gate is +3.5 volts, the output will be +3.5 volts or less. However, by using the transistorized OR gate of Figure 3-3, we can also get amplification. The same 3.5-volt input can produce a required 6-volt output. The advantage: a constant amplitude output signal even with a weakened input signal.

9. Using 0 and -6 volts as the applied signal voltages, let's first check out the circuit operation with no active inputs: binary 0 (C volts) is applied to both inputs A and B.

a. There is no current through R1 and the base of Q1 is at ground (0 volts).

b. Q1 is an NPN transistor. With 0 volts on its base and emitter, Q1 is cut off (any current under these conditions is so negligible we'll call it cutoff). At cutoff, Q1 has no effect on the voltage divider R2-R3.

c. Current from ground to +6 volts establishes a voltage of +2 volts at the junction of R2 and R3, due to the voltage drop across R3. The +2 volts is applied to the base of Q2.

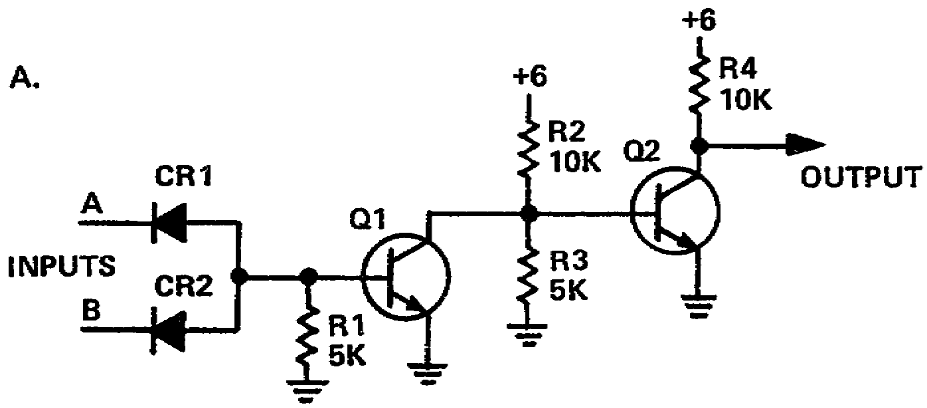
d. Q2 is also an NPN transistor. A positive voltage on the base with respect to the emitter causes Q2 to conduct heavily. The transistor conducts at saturation or maximum current. Current through it would not increase even if we increased the positive voltage on its base.

e. The current path is from ground, through Q2 and R4, to the +6 volt supply. A transistor in saturation offers so little resistance to current that we can consider its resistance zero, and all of the voltage is dropped across R4. The collector of Q2, and, therefore, the output, is at 0 volts.

f. You can think of the operation of transistors in binary circuits as if they were switches. Their condition is normally either cutoff or saturation, similar to a switch when it is open or closed. When a switch is open (cutoff), there is no current. When the switch is closed (saturation), it has no resistance.

g. Looking at the circuit in A, Figure 3-3, we have found that with all inputs at 0 the output is 0. This fact proves the circuit is an OR gate for at least one condition.

A.



B.

A	B	OUT
L	L	L
H	L	H
L	H	H
H	H	H

Figure 3-3. Transistorized positive OR circuit

10. Using highs and lows on the OR circuit for the condition we completed above, we would apply the high (H) designation to the +6 volt level and the low (L) designation to the 0 volt level. Looking again at the OR circuit in Figure 3-3 for the condition we've already discussed, we can say that with all lows (0 volt inputs) the circuit provides a low output. We've listed this in the first line of the truth table in B, Figure 3-3. In binary designation this is the same as saying that all binary 0s in cause a binary 0 out.

11. Now let's reexamine the schematic in A, Figure 3-3, with different input conditions. Assume that input A changes from 0 volts (L) to +6 volts (H).

a. When the signal at input A changes to +6 volts (H), diode CR1 is forward biased and +6 volts is developed across R1. The +6 volts at the top of R1 is felt at the base of Q1 and the forward bias on the base-emitter function drives the transistor not only into conduction but also into saturation.

b. In saturation, the collector of Q1 drops to 0 volts (L) and this changes the R2-R3 voltage divider. Q1 is in parallel with R3 and, in saturation, the low resistance of Q1 practically shorts out R3. It's like closing a switch that applies ground to the junction of R2 and R3. The current path is from ground, through the switch (Q1), and through R2 to the positive supply; R3 is bypassed.

c. The low at the R2-R3 function is applied to the base of Q2. With 0 volts on its base, Q2 stops conducting. When current in Q2 stops, its collector voltage rises to the level of the supply voltage (+6).

d. The high at the collector also appears at the output. Thus, with a high on input A, the output of the circuit is a high. This fact is shown in line 2 of the truth table. The OR gate proves correct with a second condition: one active input (H) causes an output (H). Expressed in binary, this is stated as a 1 in causes a 1 out.

e. Assume now that input A returns it to low and input B rises to a high. What will happen?

(1) A high on input B forward biases CR 2 and the high is applied to the base of Q1. Except for the diode used, the same action occurs as when input A received a high -; a high is applied to the base of Q1.

(2) From this point on, the operation is the same as before. Q1 goes into saturation and applies 0 volts to Q2. Q2 cuts off and the output is a high. Again a high in causes a high out. The third line of the truth table shows this condition. In general, any high (binary 1) into an OR gate causes a high (binary 1) out.

12. We have only one condition left to check through the schematic. What happens to the circuit if more than one input is a high? If the rules for OR gates hold true, the output should still be a high as indicated in line 4 of the truth table.

a. Having inputs A and B at +6 volts means that both CR1 and CR2 are forward biased. Resistor R1 still drops 6 volts and the +6 volts at the top of R1 biases Q1 into conduction.

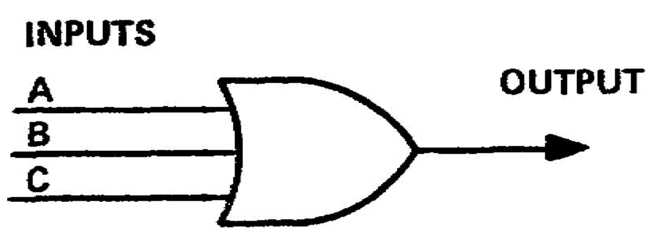
b. From here on its operation is the same. Saturation of Q1 drops its collector voltage to 0 and this drives Q2 into cutoff.

c. With Q2 cut off, the output is a high and the fourth condition completes the proof of the OR gate rule. We can now say that "any one or more high inputs causes a high output," or, "any 1 in causes a 1 out."

d. Since we've completely determined how the circuit works, we can replace it with a symbol. In Figure 3-4 for example, we can predict the output resulting from any given input combination because we know how the circuit works.

13. On a separate piece of paper, complete the fourth column of the truth table as a final check to assure yourself that you understand the OR gate. Remember that in positive logic each high is a binary 1 and each low is a binary 0. If you have any difficulty, refer back to the schematic in Figure 3-3 and imagine a third diode in parallel with the other two. The third diode provides the third input connection represented by input C, Figure 3-4. The correct solution is shown on Figure 3-17.

A.



B.

A	B	C	OUT
L	L	L	
L	L	H	
L	H	L	
L	H	H	
H	L	L	
H	L	H	
H	H	L	
H	H	H	

Figure 3-4. Positive OR gate and truth table

14. A transistorized negative logic OR gate is similar to the circuit in Figure 3-3 but is designed to follow the rules of negative logic. The difference compares to the difference between negative and positive logic diode circuits.

Learning Event 2:
IDENTIFY A TWO SWITCH AS AN AND GATE

1. A mechanical equivalent of an AND circuit can be shown just as easily as the first OR circuit we discussed. All we need is two switches and a light bulb. This time, however, we connect the switches in series instead of in parallel, as in Figure 3-5.

a. Once again we'll consider the light from the bulb as the output. When we explain how to light the lamp, we will have stated the definition of an AND gate.

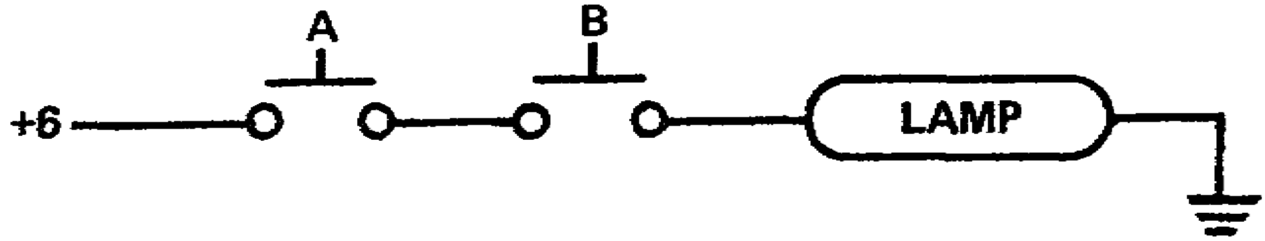


Figure 3-5. Two switch as an AND gate

b. Only if switch A AND switch B are closed is there an output - light.

c. Only with both switches closed will there be current from ground, through the bulb, to the voltage source.

2. If we call the switches "inputs" and consider them "on" when they are closed, then the circuit follows the rules we use to identify AND gates. If all the inputs are on, then the output is on, but if any input is off, then the output is off. Restated in logic circuit terminology: all is (highs) in, cause a 1 (high) out. With -6 volts instead of +6 the circuit is a negative logic AND gate: all 1s (lows) in cause a 1 (low) out.

3. A simple diode AND gate can be constructed with the same parts used for the OR gate - two diodes and a resistor. For example, compare the circuits in Figure 3-6 with the circuits in Figure 3-2. They are the same with one exception; resistor R1 is connected to -6 or +6 volts instead of ground.

a. The following are the four possible conditions that can appear at the input to the diode AND gate. We'll apply the conditions to a positive logic AND gate (B, Figure 3-6) with the voltage levels +6 volts as a high, or binary 1; and, 0 voltage as a low, or binary 0.

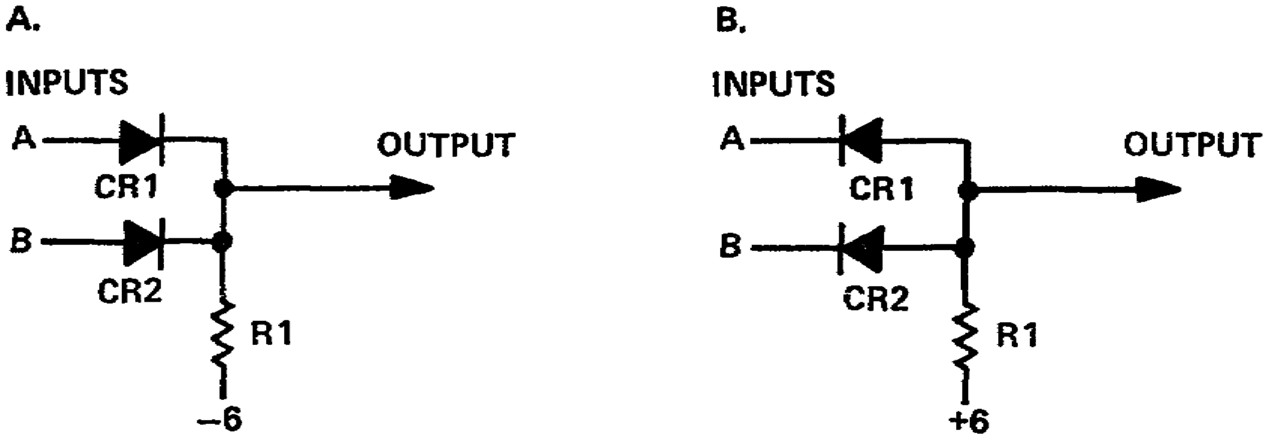


Figure 3-6. Diode AND gate

(1) When neither input is active (low on inputs A and B), the 0 voltage forward biases both diodes. Current flows from the inputs, (through resistor R1) to the +6 volt supply. The entire +6 volts are dropped across the resistor and there is 0 voltage at the top of R1 - the output. Two lows in cause a low out.

(2) When input A is low and input B is high, diode CR1 is forward biased. Current flows from input A, through R1 to the +6 volt supply. This holds the output at 0 volts and also reserve biases CR2 (negative anode, positive cathode).

(3) When input A is high but input B is low, diode CR2 is forward biased. This holds the output at 0 volts and reserve biases CR1.

(4) When both inputs are high, the output rises to the +6 volt value of the supply voltage.

b. Based on the results in (1) through (4) above, the only way to get a high output is to have all inputs high. In (1), (2), and (3) we proved that if any input is low, the output is low. Only (4) produced a high output; when input A is a 1 and input B is a 1, then the output is a 1.

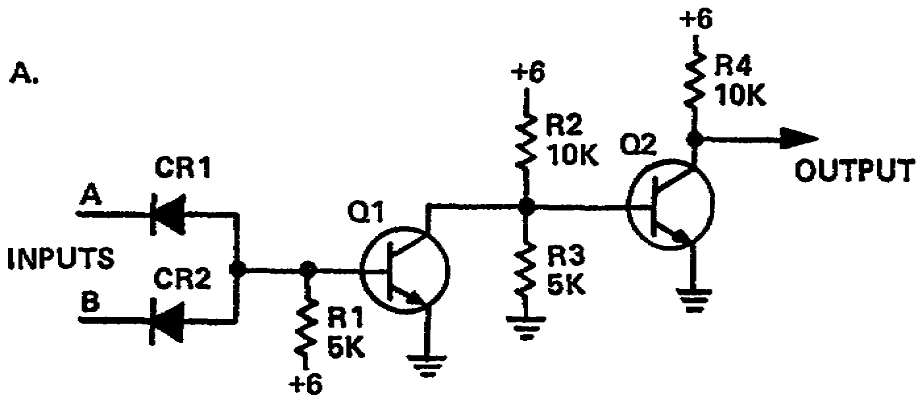
c. There is one possible exception in para 3a(4) above. If the voltage level at the inputs is less than the supply voltage, the output will be equal to the lower one - the input voltage. This occurs because anything less than +6 volts on any input forward biases the associated diode and causes it to conduct. The voltage at the output, then, is always equal to the input voltage, unless the input is greater than +6. Thus, a diode AND gate cannot restore signal levels. If voltage amplification is required, the diode gate must be replaced by a transistorized circuit that performs as an AND gate.

4. The negative logic diode AND gate in A, Figure 3-6, operates the same way as the positive gate but, of course, it follows the rules of negative logic - only if all inputs are low (-6) is the output low (-6). Any one high (0 volt) input to the negative logic AND gate caused a high output (0 volt).

5. Increasing the advantages or capabilities of anything usually increases its complexity and the AND gate is no exception. For example, the transistorized AND gate in A, Figure 3-7, is a positive logic AND gate. Although it may seem complicated, its operation is relatively simple.

a. From the inputs to the base of the transistor Q1, the circuit operation is identical to the diode AND gate; and, from Q1 to the output, is the same as the OR gate. (The negative logic counterpart to this circuit uses a negative logic diode AND gate.)

b. The only way to get a high to the base of Q1 is to have two highs on the input. When this condition exists, Q1 conducts and the 0 volts from its collector drives Q2 into cut-off. When Q2 is cut off, the output rises to the +6-volt supply voltage. Any low on the input is felt at the base of Q1 and cuts it off. The R2-R3 voltage divider then supplies a positive voltage to the base of Q2 which drives it into conduction and holds the output low. Check each of the conditions through the circuit to see if they agree with the truth table results (B, Figure 3-7).



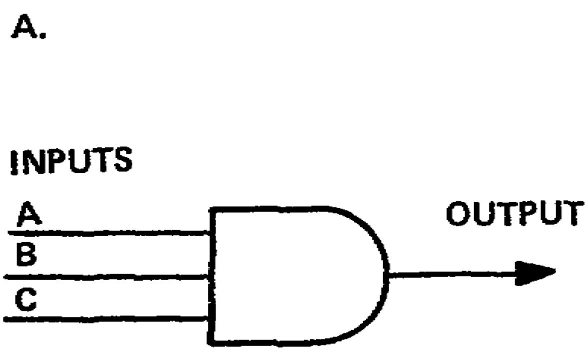
B.

A	B	OUT
L	L	L
L	H	L
H	L	L
H	H	H

Figure 3-7. Transistorized positive AND circuit

c. Any incoming positive signals that are lower than the operating level of the high (+6 volts in this case) will be restored to full amplitude by the circuit. For example, if two +4-volt signals are applied to the inputs in A, Figure 3-6, the high output will be +6 volts.

d. We can replace the entire schematic for this AND circuit with a symbol and still determine its output for any input condition. Look at the positive logic AND gate symbol in A, Figure 3-8. Now, follow the rules of an AND gate and complete the truth table in B, Figure 3-8. If you have any difficulty, refer to the schematic in Figure 3-7. When you complete the truth table, check your results with the answer on Figure 3-17.



B.

A	B	C	OUT
L	L	L	
L	L	H	
L	H	L	
L	H	H	
H	L	L	
H	L	H	
H	H	L	
H	H	H	

Figure 3-8. Positive AND gate and truth table

Learning Event 3:
DEFINE A NOR OR NAND CIRCUIT

1. Two switches and a lamp can be arranged as shown in Figure 3-9 to represent the NOR function. If neither A nor B is closed (on) there is current through the lamp and light as the output. However, if either or both of the switches is closed (on) the output will be off. A closed switch provides a path of lower resistance than the lamp, so the current flows around the lamp. For this arrangement, there would have to be a resistor between the power supply and the input point (labeled +6) to prevent a short to ground when a switch is closed.

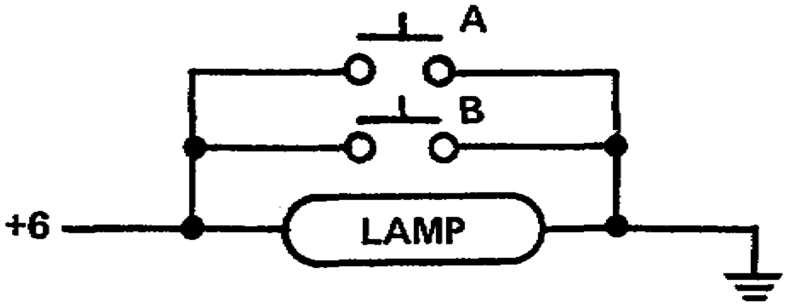
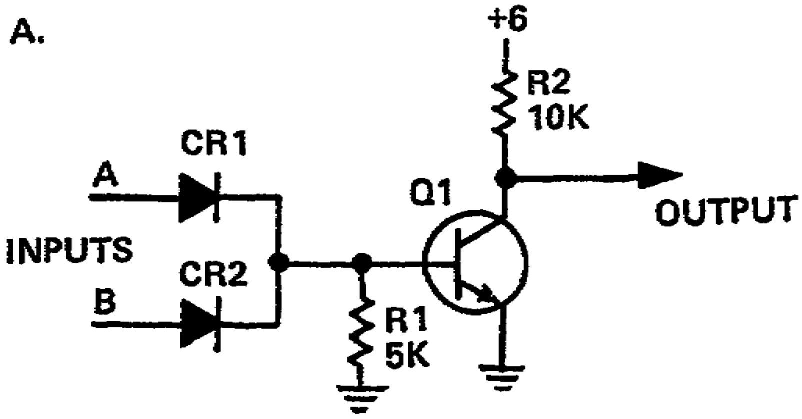


Figure 3-9. Two switches as a NOR gate

2. The transistorized NOR circuit shown in A, Figure 3-10, is less complicated than either the transistorized AND or OR gate. Only one transistor is required for the NOR circuit. We don't need two transistors because a NOR is just an OR with an inverter (NOT OR). The diodes (CR1, CR2) and resistor form a simple OR gate and Q1 is the inverter-amplifier.

a. When either input is a high, or both are high, the associated diode(s) is forward biased and the positive potential is coupled to the base of Q1. Q1 conducts and the output is a low. The three possible conditions of high inputs are lines 2, 3, and 4 of the truth table in B, Figure 3-10. Only when the inputs are both lows will the circuit provide a high output (line 1 of the truth table). A low on input A and a low on input B reverse biases both diodes and a low is established on the base of Q1. A low causes Q1 to cut off and the output is a high. The binary expression for this circuit would be: a 1 output if neither A NOR B is 1.

b. Notice that we get amplification or signal restoration from the NOR gate. For example, if the binary 1 inputs to this circuit have degenerated to +3 volts, the output will be corrected to +6 volts. (You can see now that the transistor Q2 in the OR circuit schematic (fig 3-3) is needed only to reinvert the output of Q1. Without it, the circuit is a NOR gate.)



B.

A	B	OUT
L	L	H
L	H	L
H	L	L
H	H	L

Figure 3-10. Transistorized positive NOR circuit

3. A NAND gate output is high when any one or more inputs are low or NOT ANDed. When all inputs are on, the NAND gate output is off. Charging this to voltage levels and considering only positive logic, we can say that a NAND gate output is high (binary 1) when any input is low (binary 0). Also, when all inputs are high the output is low.

4. The switches and lamp circuit can be arranged as shown in Figure 3-11 so that it follows the rules below. Here again, it is assumed that there is a resistor between the +6 VDC input and the power supply that would prevent a short when the switches are all closed.

a. As long as one or more switches is open (low), there is current through the lamp and there is an output.

b. When both switches are closed (high) current flows around the lamp and there is no output.

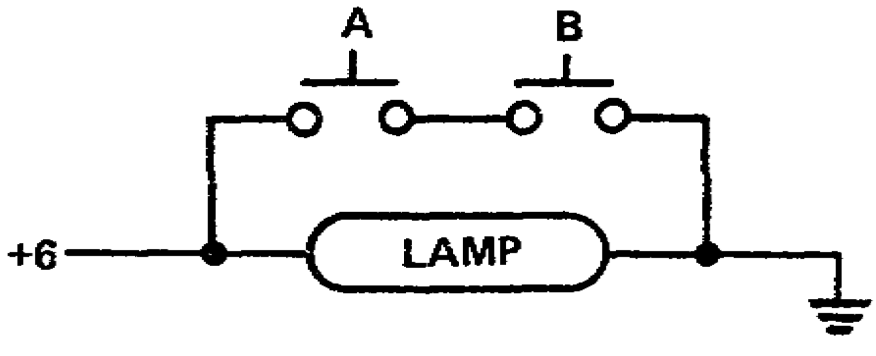
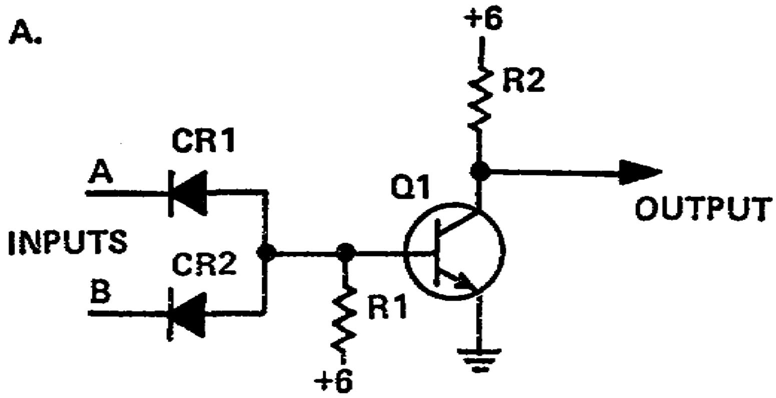


Figure 3-11. Two switches as a NAND gate

5. Part A, Figure 3-12, is a typical positive logic NAND circuit. It consists of a diode AND gate (CR1, CR2, R1) and a transistor (Q1) to invert the signal. The output is high when any of the inputs are low. These conditions are listed in the first three lines of the truth table (B, Figure 3-12).



B.

A	B	OUT
L	L	H
L	H	H
H	L	H
H	H	L

Figure 3-12. Transistorized positive NAND circuit

a. The low on an input causes the associated diode to be forward biased because the diodes are connected with their cathodes toward the input. The diode conducts and the low is coupled to the base of Q1, cutting it off. This allows the output to rise to a high. Any low into this circuit causes a high out.

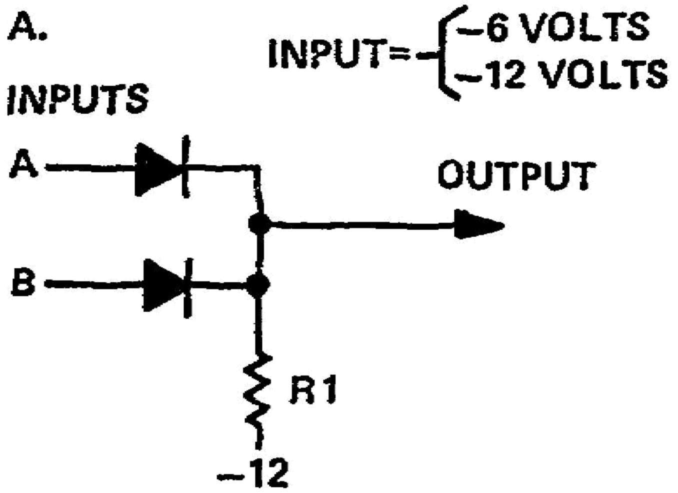
b. When all inputs are high, no input diode conducts. The positive supply voltage on R1 biases Q1 in conduction, causing a low output. This is shown in line 4 of the truth table. The schematic then follows the rules of a NAND gate. As long as the inputs are NOT ANDed, the output is high.

Learning Event 4:
COMPARE A NEGATIVE AND POSITIVE LOGIC CIRCUIT

1. While reading the preceding paragraphs, you may have sensed that there was something familiar about some of the circuits and truth tables. If you did, the feeling was justified, there are some redundancies.

a. A circuit that performs a particular function in positive logic can be the same as a circuit performing a different function in negative logic. In fact, they can be identical. And yet, they are represented by different symbols because the symbol only explains the circuit's function in some situation. Put the circuit in a different function and it would be represented by a different symbol. The symbol, after all, only tells you what the circuit will do under different input conditions, not how the circuit is physically constructed.

b. Now let's find out how this is possible. Look at the circuit in Figure 3-13 and be sure to notice the title. On a separate paper complete the truth table (part B) and draw a symbol to represent the circuit. Keep in mind that the symbol must accurately indicate the circuit's function for the type of logic (negative or positive) in use.

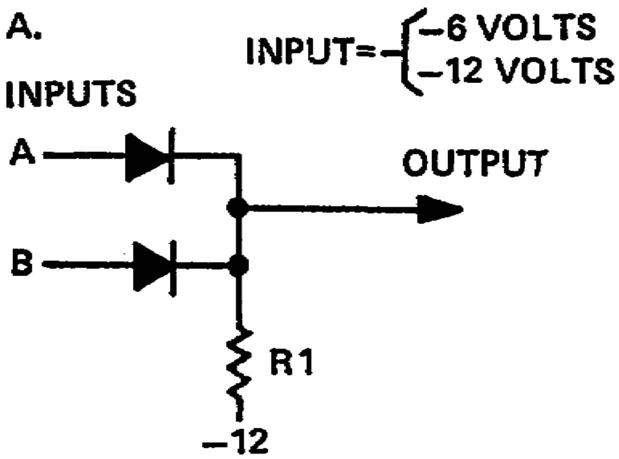


B.

A	B	OUT
L	L	
L	H	
H	L	
H	H	

Figure 3-13. Negative logic circuit

Now look at Figure 3-14. Again, specifically notice the title and then on a separate paper complete the truth table and draw a symbol to accurately represent it. Compare your results with the answers in Figure 3-17.



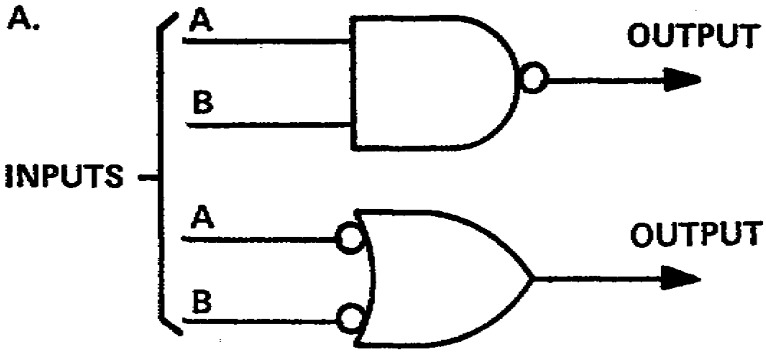
B.

A	B	OUT
L	L	
L	H	
H	L	
H	H	

Figure 3-14. Positive logic circuit

2. Figure 3-13 performs an AND function in negative logic, as indicated by the truth table, so it is represented by an AND symbol with circles at the inputs and output. Figure 3-14 performs an OR function in positive logic and is represented by an OR symbol with no circles on the inputs and output. But, comparing the two schematics we find that the circuits are identical. A negative AND gate, then, performs the same function as a positive OR gate. In most cases the schematics of the two gates are not identical but it is possible. The important thing to note here is that logically, a negative AND and a positive OR are equivalent; they have the same truth table. Conversely, a positive AND and a negative OR are also logically equivalent.

3. NAND and NOR gates can be compared the same way. A negative NAND is logically equivalent to a positive NOR as shown in Figure 3-15.

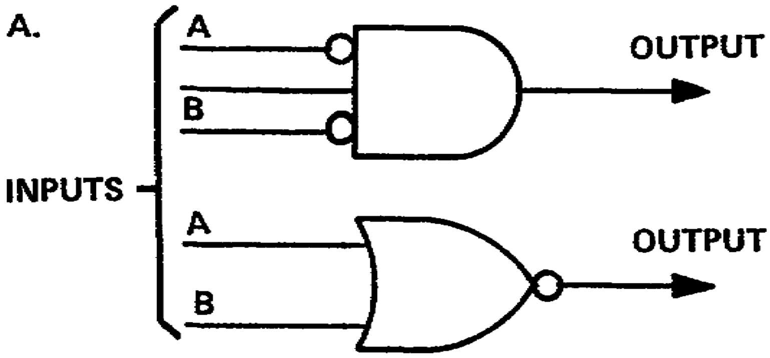


B.

A	B	OUT
L	L	H
L	H	H
H	L	H
H	H	L

Figure 3-15. Negative NAND equals positive NOR

4. The truth table (B, Figure 3-15) is identical for the two symbols in A of the figure. Likewise, a positive NAND and a negative NOR are logically the same. The symbols represented in A (fig 3-15) may or may not be the same, (i.e., the symbol may have a line over it in one case, or without a line in another), but the function is the same.



B.

A	B	OUT
L	L	H
L	H	L
H	L	L
H	H	L

Figure 3-16. Positive NAND equals negative NOR

a. The only reason for using a different symbol is to present the most accurate picture of the circuit function. In reality, NOR and NAND gates are not usually rigidly defined as we presented them.

b. The symbol used in a negative logic system may very well be a positive NOR or NAND. The symbol selected is the one that best describes the way the circuit is being used. This is especially true in control logic where binary 1 or 0 is irrelevant and only highs and lows are important.

(1) Let's say we have a circuit from which we obtain a high when any input is low, and the high output is used to activate another circuit or light a lamp.

(2) We probably would select a NOR gate with circles on the input rather than the NAND symbol with a circle at the output even though they perform the same function. The reason is that we usually select symbols that show the active output - in this case the high we need to activate a circuit or light a lamp.

A	B	OUT
L	L	H
L	H	L
H	L	L
H	H	L

Figure 2-1

A	B	OUT
L	L	H
L	H	H
H	L	H
H	H	L

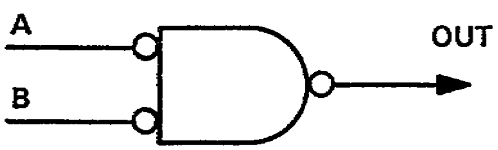
Figure 2-3

A	B	C	OUT
L	L	L	L
L	L	H	H
L	H	L	H
L	H	H	H
H	L	L	H
H	L	H	H
H	H	L	H
H	H	H	H

Figure 3-4, Part B

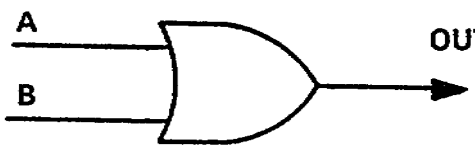
A	B	C	OUT
L	L	L	L
L	L	H	L
L	H	L	L
L	H	H	L
H	L	L	L
H	L	H	L
H	H	L	L
H	H	H	H

Figure 3-8, Part B



A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	H

Figure 3-13



A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	H

Figure 3-14

Figure 3-17. Solutions to truth table exercises

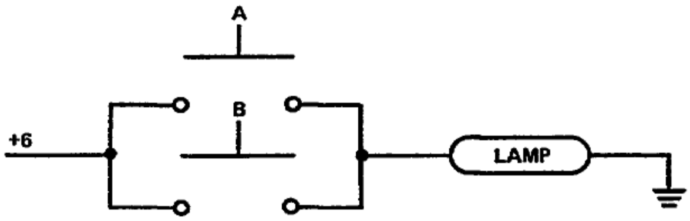
LESSON 3
PRACTICE EXERCISE

1. How many input connections can an OR gate have?

   a. Any number
   b. 10
   c. 8
   d. 6

2. What is the name of the switch below (fig 3-1)?

   a. OR gate
   b. NOR gate
   c. NAND gate
   d. AND gate



3. When input A is low and input B is high, diode CR1 in Figure 3-6A is?

   a. Reverse bias
   b. Forward bias
   c. Both a and b
   d. Neither a or b

4. On a three-input OR gate what inputs are needed to result in a low out (fig 3-4)?

   a. All highs
   b. All lows
   c. Two highs
   d. Two lows

5. On a three-input AND gate what inputs are needed to result in a high out (fig 3-8)?

   a. All highs
   b. All lows
   c. Two highs
   d. Two lows

ANSWERS TO PRACTICE EXERCISES

Lesson 1

1.	c	LE 4	para 1	pg 4
2.	c	LE 4	para 1	pg 5
3.	d	LE 4	para 7	pg 7
4.	a	LE 4	para 7	pg 8
5.	c	LE 2	para 6	pg 3
6.	a	LE 2	para 3a	pg 3

LESSON 2

1.	a	LE 1	para 1	pg 11
2.	b	LE 2	para 1	pg 12
3.	a	LE 2	para 3	pg 12
4.	b	LE 3	para 1	pg 13
5.	c	LE 4	para 4b	pg 15

LESSON 3

1.	a	LE 1	para 3	pg 18
2.	a	LE 1	para 1	pg 17
3.	b	LE 2	para 3(2)	pg 24
4.	b	LE 1	para 13 fig 3-4	pg 22
5.	a	LE 2	para 5 fig 3-8	pg 25