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CHAPTER 2

TRANSISTORS

LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

1. Define the term *transistor* and give a brief description of its construction and operation.
2. Explain how the transistor can be used to amplify a signal.
3. Name the four classes of amplifiers and give an explanation for each.
4. List the three different transistor circuit configurations and explain their operation.
5. Identify the different types of transistors by their symbology and alphanumeric designations.
6. List the precautions to be taken when working with transistors and describe ways to test them.
7. Explain the meaning of the expression "integrated circuits."
8. Give a brief description on how integrated circuits are constructed and the advantages they offer over conventional transistor circuits.
9. Name the two types of circuit boards.
10. State the purpose and function of modular circuitry.

INTRODUCTION TO TRANSISTORS

The discovery of the first transistor in 1948 by a team of physicists at the Bell Telephone Laboratories sparked an interest in solid-state research that spread rapidly. The transistor, which began as a simple laboratory oddity, was rapidly developed into a semiconductor device of major importance. The transistor demonstrated for the first time in history that amplification in solids was possible. Before the transistor, amplification was achieved only with electron tubes. Transistors now perform numerous electronic tasks with new and improved transistor designs being continually put on the market. In many cases, transistors are more desirable than tubes because they are small, rugged, require no filament power, and operate at low voltages with comparatively high efficiency. The development of a family of transistors has even made possible the miniaturization of electronic circuits. Figure 2-1 shows a sample of the many different types of transistors you may encounter when working with electronic equipment.

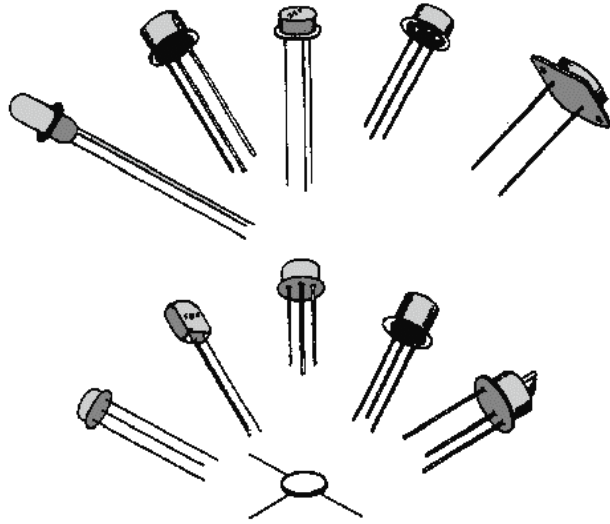


Figure 2-1.—An assortment of different types of transistors.

Transistors have infiltrated virtually every area of science and industry, from the family car to satellites. Even the military depends heavily on transistors. The ever increasing uses for transistors have created an urgent need for sound and basic information regarding their operation.

From your study of the PN-junction diode in the preceding chapter, you now have the basic knowledge to grasp the principles of transistor operation. In this chapter you will first become acquainted with the basic types of transistors, their construction, and their theory of operation. You will also find out just how and why transistors amplify. Once this basic information is understood, transistor terminology, capabilities, limitations, and identification will be discussed. Last, we will talk about transistor maintenance, integrated circuits, circuit boards, and modular circuitry.

TRANSISTOR FUNDAMENTALS

The first solid-state device discussed was the two-element semiconductor diode. The next device on our list is even more unique. It not only has one more element than the diode but it can amplify as well. Semiconductor devices that have three or more elements are called TRANSISTORS. The term transistor was derived from the words TRANSfer and resISTOR. This term was adopted because it best describes the operation of the transistor - the transfer of an input signal current from a low-resistance circuit to a high-resistance circuit. Basically, the transistor is a solid-state device that amplifies by controlling the flow of current carriers through its semiconductor materials.

There are many different types of transistors, but their basic theory of operation is all the same. As a matter of fact, the theory we will be using to explain the operation of a transistor is the same theory used earlier with the PN-junction diode except that now two such junctions are required to form the three elements of a transistor. The three elements of the two-junction transistor are (1) the EMITTER, which gives off, or emits, "current carriers (electrons or holes); (2) the BASE, which controls the flow of current carriers; and (3) the COLLECTOR, which collects the current carriers.

CLASSIFICATION

Transistors are classified as either NPN or PNP according to the arrangement of their N and P materials. Their basic construction and chemical treatment is implied by their names, "NPN" or "PNP." That

is, an NPN transistor is formed by introducing a thin region of P-type material between two regions of N-type material. On the other hand, a PNP transistor is formed by introducing a thin region of N-type material between two regions of P-type material. Transistors constructed in this manner have two PN junctions, as shown in figure 2-2. One PN junction is between the emitter and the base; the other PN junction is between the collector and the base. The two junctions share one section of semiconductor material so that the transistor actually consists of three elements.

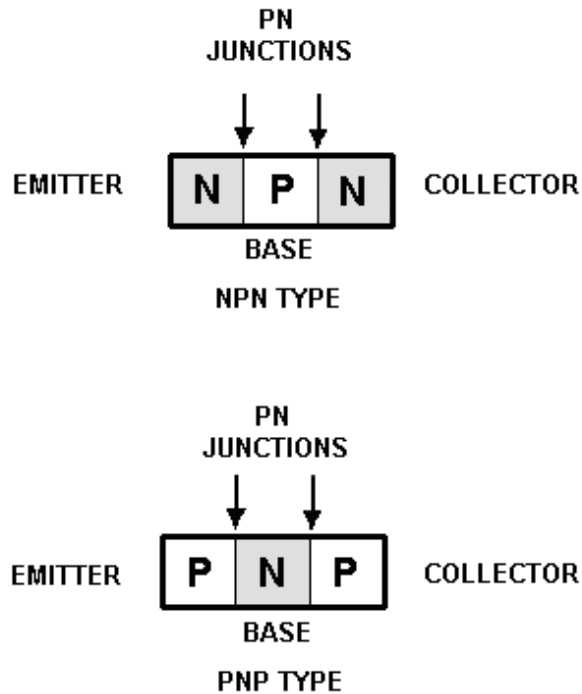


Figure 2-2.—Transistor block diagrams.

Since the majority and minority current carriers are different for N and P materials, it stands to reason that the internal operation of the NPN and PNP transistors will also be different. The theory of operation of the NPN and PNP transistors will be discussed separately in the next few paragraphs. Any additional information about the PN junction will be given as the theory of transistor operation is developed.

To prepare you for the forthcoming information, the two basic types of transistors along with their circuit symbols are shown in figure 2-3. It should be noted that the two symbols are different. The horizontal line represents the base, the angular line with the arrow on it represents the emitter, and the other angular line represents the collector. The direction of the arrow on the emitter distinguishes the NPN from the PNP transistor. If the arrow points in, (Points iN) the transistor is a PNP. On the other hand if the arrow points out, the transistor is an NPN (Not Pointing iN).

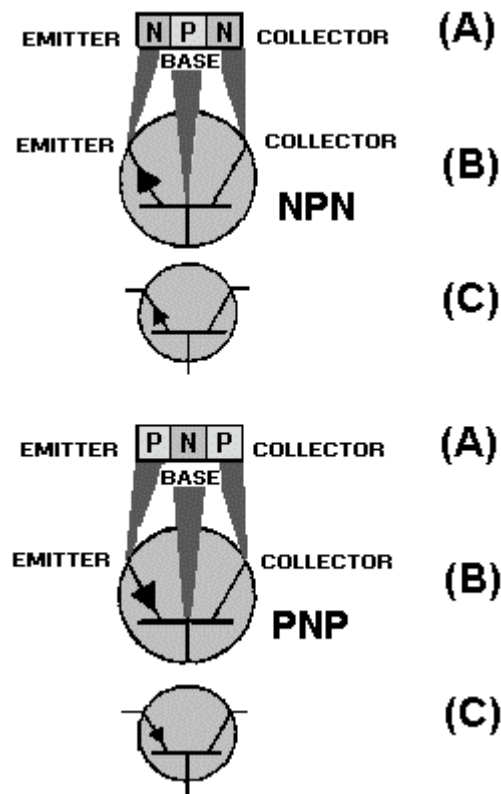
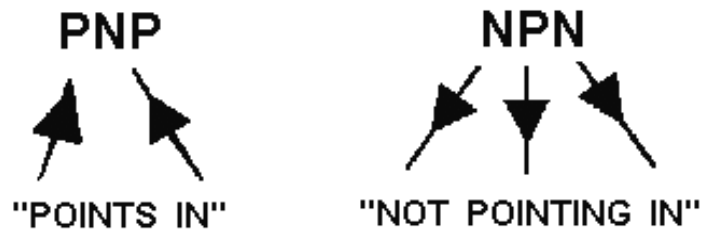


Figure 2-3.—Transistor representations.

Another point you should keep in mind is that the arrow always points in the direction of hole flow, or from the P to N sections, no matter whether the P section is the emitter or base. On the other hand, electron flow is always toward or against the arrow, just like in the junction diode.

CONSTRUCTION

The very first transistors were known as point-contact transistors. Their construction is similar to the construction of the point-contact diode covered in chapter 1. The difference, of course, is that the point-contact transistor has two P or N regions formed instead of one. Each of the two regions constitutes an electrode (element) of the transistor. One is named the emitter and the other is named the collector, as shown in figure 2-4, view A.

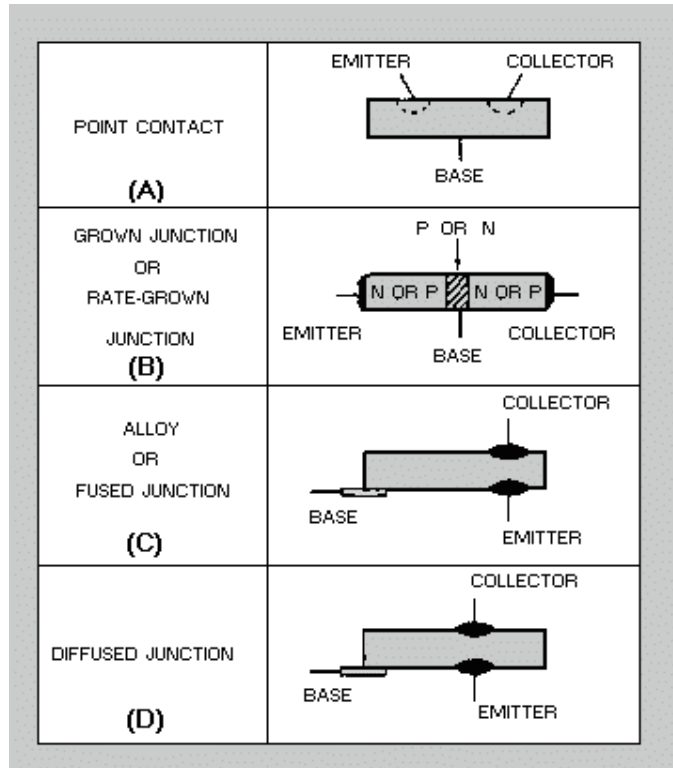


Figure 2-4.—Transistor constructions.

Point-contact transistors are now practically obsolete. They have been replaced by junction transistors, which are superior to point-contact transistors in nearly all respects. The junction transistor generates less noise, handles more power, provides higher current and voltage gains, and can be mass-produced more cheaply than the point-contact transistor. Junction transistors are manufactured in much the same manner as the PN junction diode discussed earlier. However, when the PNP or NPN material is grown (view B), the impurity mixing process must be reversed twice to obtain the two junctions required in a transistor. Likewise, when the alloy-junction (view C) or the diffused-junction (view D) process is used, two junctions must also be created within the crystal.

Although there are numerous ways to manufacture transistors, one of the most important parts of any manufacturing process is quality control. Without good quality control, many transistors would prove unreliable because the construction and processing of a transistor govern its thermal ratings, stability, and electrical characteristics. Even though there are many variations in the transistor manufacturing processes, certain structural techniques, which yield good reliability and long life, are common to all processes: (1) Wire leads are connected to each semiconductor electrode; (2) the crystal is specially mounted to protect it against mechanical damage; and (3) the unit is sealed to prevent harmful contamination of the crystal.

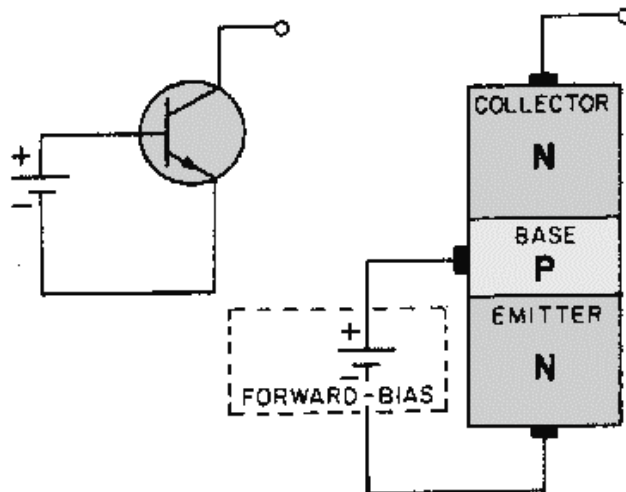
- Q1. *What is the name given to the semiconductor device that has three or more elements?*
- Q2. *What electronic function made the transistor famous?*
- Q3. *In which direction does the arrow point on an NPN transistor?*
- Q4. *What was the name of the very first transistor?*
- Q5. *What is one of the most important parts of any transistor manufacturing process?*

TRANSISTOR THEORY

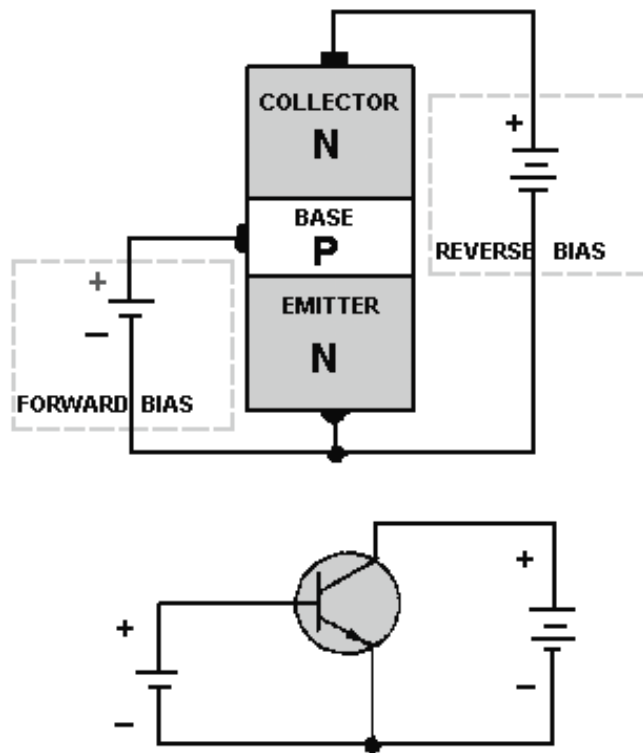
You should recall from an earlier discussion that a forward-biased PN junction is comparable to a low-resistance circuit element because it passes a high current for a given voltage. In turn, a reverse-biased PN junction is comparable to a high-resistance circuit element. By using the Ohm's law formula for power ($P = I^2R$) and assuming current is held constant, you can conclude that the power developed across a high resistance is greater than that developed across a low resistance. Thus, if a crystal were to contain two PN junctions (one forward-biased and the other reverse-biased), a low-power signal could be injected into the forward-biased junction and produce a high-power signal at the reverse-biased junction. In this manner, a power gain would be obtained across the crystal. This concept, which is merely an extension of the material covered in chapter 1, is the basic theory behind how the transistor amplifies. With this information fresh in your mind, let's proceed directly to the NPN transistor.

NPN Transistor Operation

Just as in the case of the PN junction diode, the N material comprising the two end sections of the NPN transistor contains a number of free electrons, while the center P section contains an excess number of holes. The action at each junction between these sections is the same as that previously described for the diode; that is, depletion regions develop and the junction barrier appears. To use the transistor as an amplifier, each of these junctions must be modified by some external bias voltage. For the transistor to function in this capacity, the first PN junction (emitter-base junction) is biased in the forward, or low-resistance, direction. At the same time the second PN junction (base-collector junction) is biased in the reverse, or high-resistance, direction. A simple way to remember how to properly bias a transistor is to observe the NPN or PNP elements that make up the transistor. The letters of these elements indicate what polarity voltage to use for correct bias. For instance, notice the NPN transistor below:



1. The emitter, which is the first letter in the NPN sequence, is connected to the negative side of the battery while the base, which is the second letter (NPN), is connected to the positive side.
2. However, since the second PN junction is required to be reverse biased for proper transistor operation, the collector must be connected to an opposite polarity voltage (positive) than that indicated by its letter designation(NPN). The voltage on the collector must also be more positive than the base, as shown below:



We now have a properly biased NPN transistor.

In summary, the base of the NPN transistor must be positive with respect to the emitter, and the collector must be more positive than the base.

NPN FORWARD-BIASED JUNCTION.—An important point to bring out at this time, which was not necessarily mentioned during the explanation of the diode, is the fact that the N material on one side of the forward-biased junction is more heavily doped than the P material. This results in more current being carried across the junction by the majority carrier electrons from the N material than the majority carrier holes from the P material. Therefore, conduction through the forward-biased junction, as shown in figure 2-5, is mainly by majority carrier electrons from the N material (emitter).

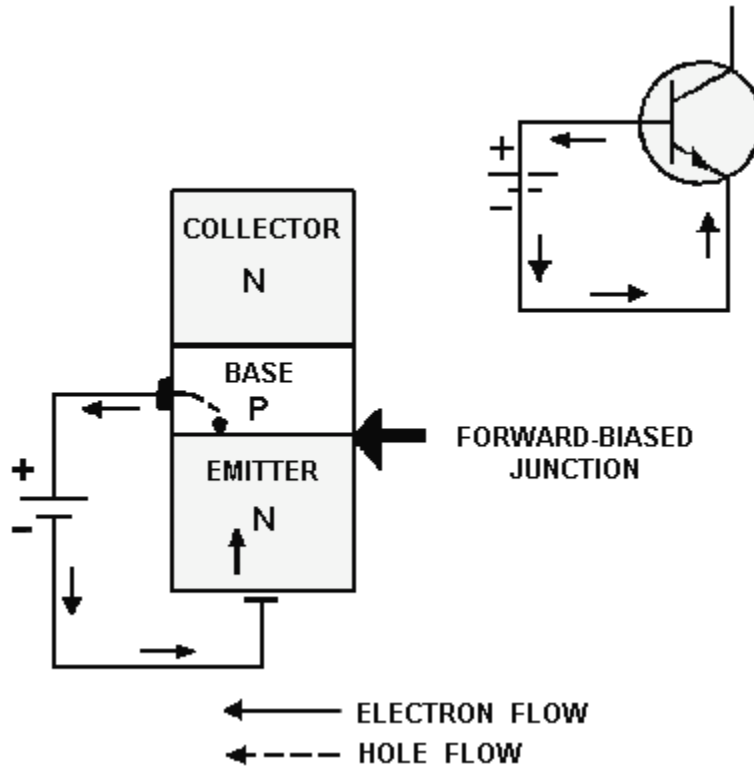


Figure 2-5.—The forward-biased junction in an NPN transistor.

With the emitter-to-base junction in the figure biased in the forward direction, electrons leave the negative terminal of the battery and enter the N material (emitter). Since electrons are majority current carriers in the N material, they pass easily through the emitter, cross over the junction, and combine with holes in the P material (base). For each electron that fills a hole in the P material, another electron will leave the P material (creating a new hole) and enter the positive terminal of the battery.

NPN REVERSE-BIASED JUNCTION.—The second PN junction (base-to-collector), or reverse-biased junction as it is called (fig. 2-6), blocks the majority current carriers from crossing the junction. However, there is a very small current, mentioned earlier, that does pass through this junction. This current is called minority current, or reverse current. As you recall, this current was produced by the electron-hole pairs. The minority carriers for the reverse-biased PN junction are the electrons in the P material and the holes in the N material. These minority carriers actually conduct the current for the reverse-biased junction when electrons from the P material enter the N material, and the holes from the N material enter the P material. However, the minority current electrons (as you will see later) play the most important part in the operation of the NPN transistor.

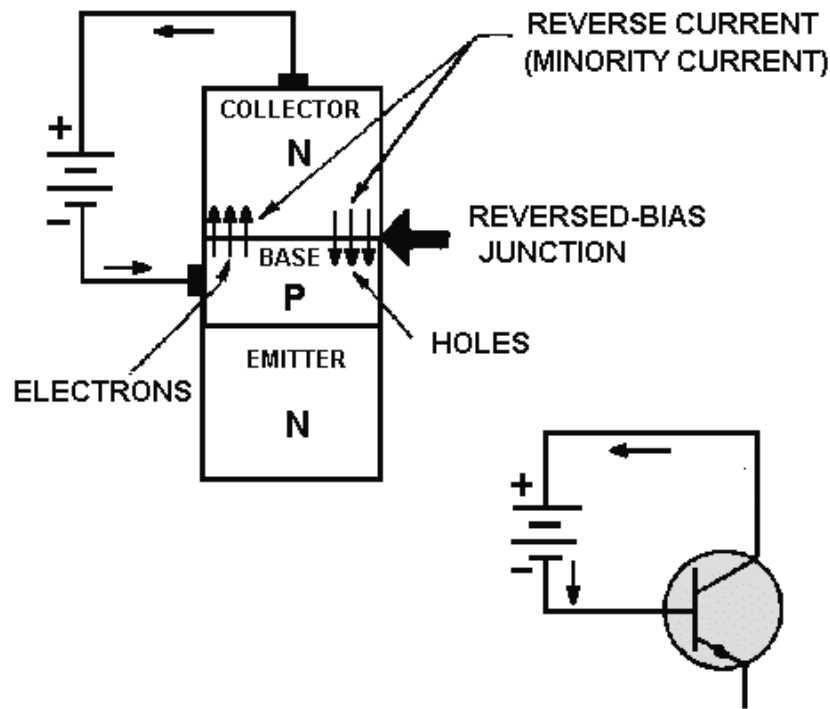


Figure 2-6.—The reverse-biased junction in an NPN transistor.

At this point you may wonder why the second PN junction (base-to-collector) is not forward biased like the first PN junction (emitter-to-base). If both junctions were forward biased, the electrons would have a tendency to flow from each end section of the N P N transistor (emitter and collector) to the center P section (base). In essence, we would have two junction diodes possessing a common base, thus eliminating any amplification and defeating the purpose of the transistor. A word of caution is in order at this time. If you should mistakenly bias the second PN junction in the forward direction, the excessive current could develop enough heat to destroy the junctions, making the transistor useless. Therefore, be sure your bias voltage polarities are correct before making any electrical connections.

NPN JUNCTION INTERACTION.—We are now ready to see what happens when we place the two junctions of the NPN transistor in operation at the same time. For a better understanding of just how the two junctions work together, refer to figure 2-7 during the discussion.

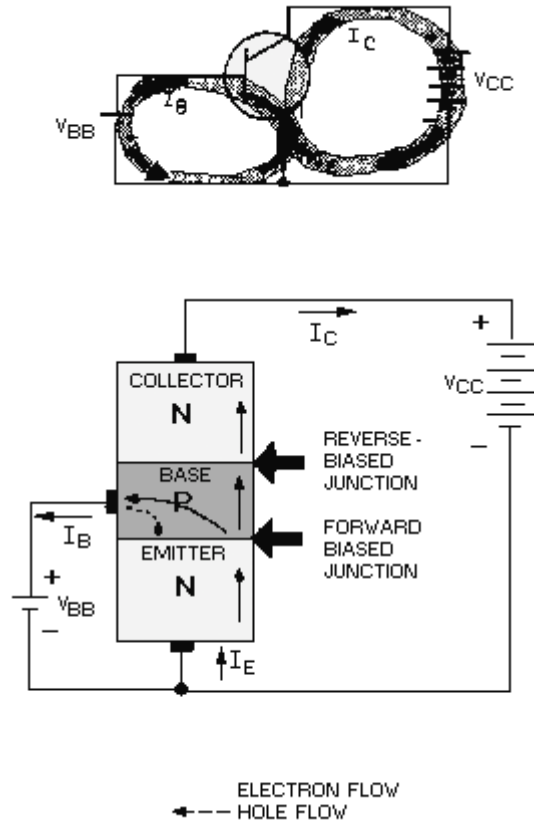


Figure 2-7.—NPN transistor operation.

The bias batteries in this figure have been labeled V_{CC} for the collector voltage supply, and V_{BB} for the base voltage supply. Also notice the base supply battery is quite small, as indicated by the number of cells in the battery, usually 1 volt or less. However, the collector supply is generally much higher than the base supply, normally around 6 volts. As you will see later, this difference in supply voltages is necessary to have current flow from the emitter to the collector.

As stated earlier, the current flow in the external circuit is always due to the movement of free electrons. Therefore, electrons flow from the negative terminals of the supply batteries to the N-type emitter. This combined movement of electrons is known as emitter current (I_E). Since electrons are the majority carriers in the N material, they will move through the N material emitter to the emitter-base junction. With this junction forward biased, electrons continue on into the base region. Once the electrons are in the base, which is a P-type material, they become minority carriers. Some of the electrons that move into the base recombine with available holes. For each electron that recombines, another electron moves out through the base lead as base current I_B (creating a new hole for eventual combination) and returns to the base supply battery V_{BB} . The electrons that recombine are lost as far as the collector is concerned. Therefore, to make the transistor more efficient, the base region is made very thin and lightly doped. This reduces the opportunity for an electron to recombine with a hole and be lost. Thus, most of the electrons that move into the base region come under the influence of the large collector reverse bias. This bias acts as forward bias for the minority carriers (electrons) in the base and, as such, accelerates them through the base-collector junction and on into the collector region. Since the collector is made of an N-type material, the electrons that reach the collector again become majority current carriers. Once in the collector, the electrons move easily through the N material and return to the positive terminal of the collector supply battery V_{CC} as collector current (I_C).

To further improve on the efficiency of the transistor, the collector is made physically larger than the base for two reasons: (1) to increase the chance of collecting carriers that diffuse to the side as well as directly across the base region, and (2) to enable the collector to handle more heat without damage.

In summary, total current flow in the NPN transistor is through the emitter lead. Therefore, in terms of percentage, I_E is 100 percent. On the other hand, since the base is very thin and lightly doped, a smaller percentage of the total current (emitter current) will flow in the base circuit than in the collector circuit. Usually no more than 2 to 5 percent of the total current is base current (I_B) while the remaining 95 to 98 percent is collector current (I_C). A very basic relationship exists between these two currents:

$$I_E = I_B + I_C$$

In simple terms this means that the emitter current is separated into base and collector current. Since the amount of current leaving the emitter is solely a function of the emitter-base bias, and because the collector receives most of this current, a small change in emitter-base bias will have a far greater effect on the magnitude of collector current than it will have on base current. In conclusion, the relatively small emitter-base bias controls the relatively large emitter-to-collector current.

- Q6. To properly bias an NPN transistor, what polarity voltage is applied to the collector, and what is its relationship to the base voltage?*
- Q7. Why is conduction through the forward-biased junction of an NPN transistor primarily in one direction, namely from the emitter to base?*
- Q8. In the NPN transistor, what section is made very thin compared with the other two sections?*
- Q9. What percentage of current in an NPN transistor reaches the collector?*

PNP Transistor Operation

The PNP transistor works essentially the same as the NPN transistor. However, since the emitter, base, and collector in the PNP transistor are made of materials that are different from those used in the NPN transistor, different current carriers flow in the PNP unit. The majority current carriers in the PNP transistor are holes. This is in contrast to the NPN transistor where the majority current carriers are electrons. To support this different type of current (hole flow), the bias batteries are reversed for the PNP transistor. A typical bias setup for the PNP transistor is shown in figure 2-8. Notice that the procedure used earlier to properly bias the NPN transistor also applies here to the PNP transistor. The first letter (P) in the PNP sequence indicates the polarity of the voltage required for the emitter (positive), and the second letter (N) indicates the polarity of the base voltage (negative). Since the base-collector junction is always reverse biased, then the opposite polarity voltage (negative) must be used for the collector. Thus, the base of the PNP transistor must be negative with respect to the emitter, and the collector must be more negative than the base. Remember, just as in the case of the NPN transistor, this difference in supply voltage is necessary to have current flow (hole flow in the case of the PNP transistor) from the emitter to the collector. Although hole flow is the predominant type of current flow in the PNP transistor, hole flow only takes place within the transistor itself, while electrons flow in the external circuit. However, it is the internal hole flow that leads to electron flow in the external wires connected to the transistor.

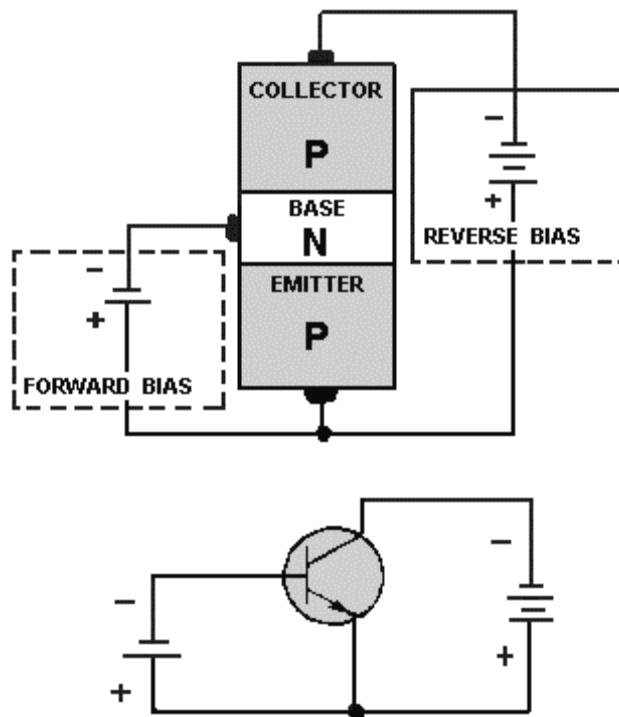


Figure 2-8.—A properly biased PNP transistor.

PNP FORWARD-BIASED JUNCTION.—Now let us consider what happens when the emitter-base junction in figure 2-9 is forward biased. With the bias setup shown, the positive terminal of the battery repels the emitter holes toward the base, while the negative terminal drives the base electrons toward the emitter. When an emitter hole and a base electron meet, they combine. For each electron that combines with a hole, another electron leaves the negative terminal of the battery, and enters the base. At the same time, an electron leaves the emitter, creating a new hole, and enters the positive terminal of the battery. This movement of electrons into the base and out of the emitter constitutes base current flow (I_B), and the path these electrons take is referred to as the emitter-base circuit.

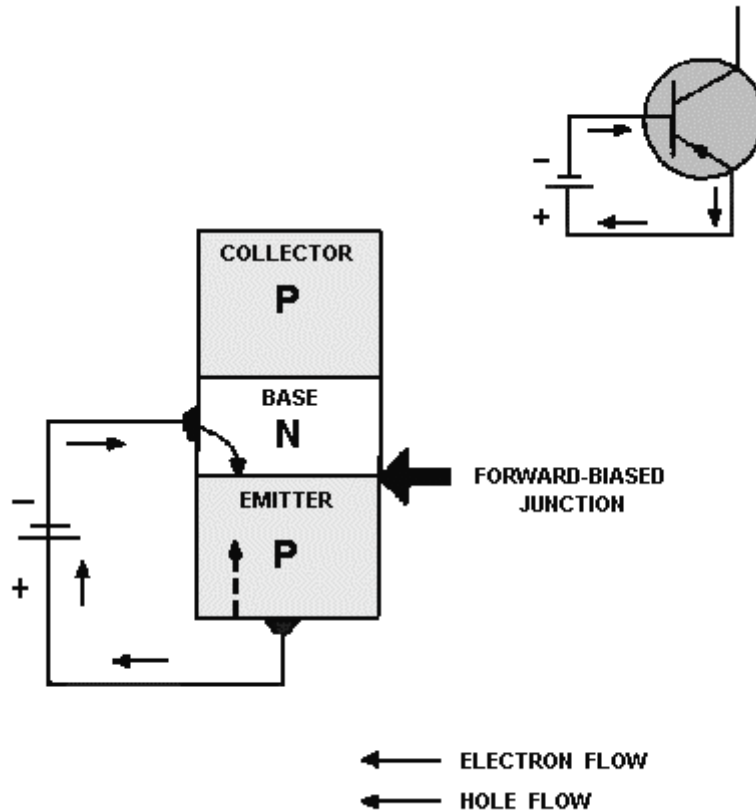


Figure 2-9.—The forward-biased junction in a PNP transistor.

PNP REVERSE-BIASED JUNCTION.—In the reverse-biased junction (fig. 2-10), the negative voltage on the collector and the positive voltage on the base block the majority current carriers from crossing the junction. However, this same negative collector voltage acts as forward bias for the minority current holes in the base, which cross the junction and enter the collector. The minority current electrons in the collector also sense forward bias—the positive base voltage—and move into the base. The holes in the collector are filled by electrons that flow from the negative terminal of the battery. At the same time the electrons leave the negative terminal of the battery, other electrons in the base break their covalent bonds and enter the positive terminal of the battery. Although there is only minority current flow in the reverse-biased junction, it is still very small because of the limited number of minority current carriers.

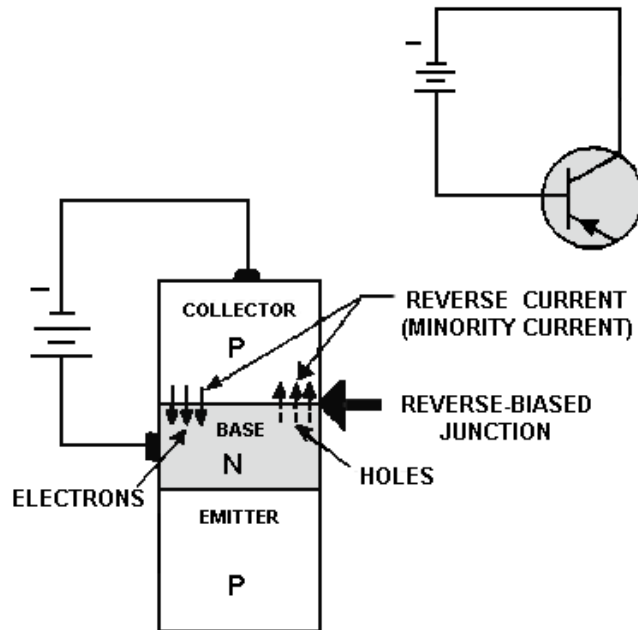


Figure 2-10.—The reverse-biased junction in a PNP transistor.

PNP JUNCTION INTERACTION.—The interaction between the forward- and reverse-biased junctions in a PNP transistor is very similar to that in an NPN transistor, except that in the PNP transistor, the majority current carriers are holes. In the PNP transistor shown in figure 2-11, the positive voltage on the emitter repels the holes toward the base. Once in the base, the holes combine with base electrons. But again, remember that the base region is made very thin to prevent the recombination of holes with electrons. Therefore, well over 90 percent of the holes that enter the base become attracted to the large negative collector voltage and pass right through the base. However, for each electron and hole that combine in the base region, another electron leaves the negative terminal of the base battery (V_{BB}) and enters the base as base current (I_B). At the same time an electron leaves the negative terminal of the battery, another electron leaves the emitter as I_E (creating a new hole) and enters the positive terminal of V_{BB} . Meanwhile, in the collector circuit, electrons from the collector battery (V_{CC}) enter the collector as I_C and combine with the excess holes from the base. For each hole that is neutralized in the collector by an electron, another electron leaves the emitter and starts its way back to the positive terminal of V_{CC} .

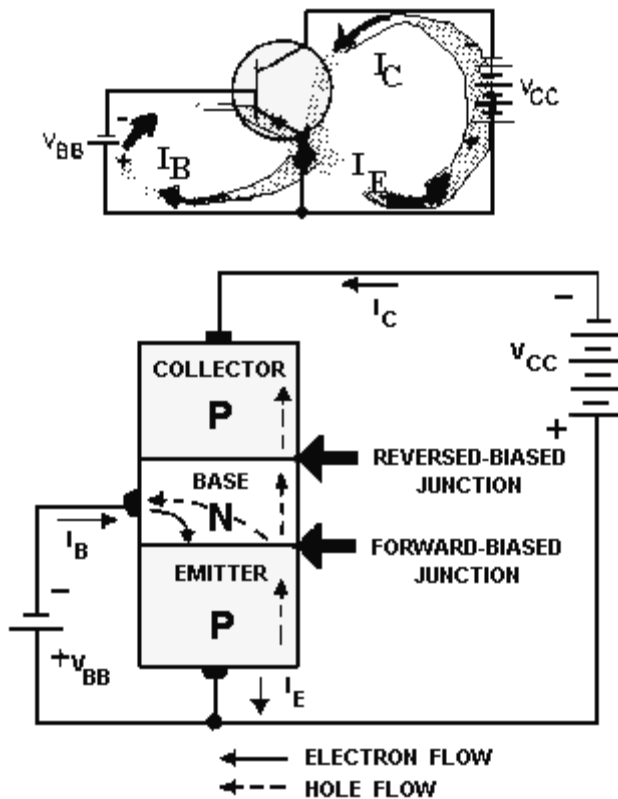


Figure 2-11.—PNP transistor operation.

Although current flow in the external circuit of the PNP transistor is opposite in direction to that of the NPN transistor, the majority carriers always flow from the emitter to the collector. This flow of majority carriers also results in the formation of two individual current loops within each transistor. One loop is the base-current path, and the other loop is the collector-current path. The combination of the current in both of these loops ($I_B + I_C$) results in total transistor current (I_E). The most important thing to remember about the two different types of transistors is that the emitter-base voltage of the PNP transistor has the same controlling effect on collector current as that of the NPN transistor. In simple terms, increasing the forward-bias voltage of a transistor reduces the emitter-base junction barrier. This action allows more carriers to reach the collector, causing an increase in current flow from the emitter to the collector and through the external circuit. Conversely, a decrease in the forward-bias voltage reduces collector current.

- Q10. What are the majority current carriers in a PNP transistor?
- Q11. What is the relationship between the polarity of the voltage applied to the PNP transistor and that applied to the NPN transistor?
- Q12. What is the letter designation for base current?
- Q13. Name the two current loops in a transistor.

THE BASIC TRANSISTOR AMPLIFIER

In the preceding pages we explained the internal workings of the transistor and introduced new terms, such as emitter, base, and collector. Since you should be familiar by now with all of the new terms

mentioned earlier and with the internal operation of the transistor, we will move on to the basic transistor amplifier.

To understand the overall operation of the transistor amplifier, you must only consider the current in and out of the transistor and through the various components in the circuit. Therefore, from this point on, only the schematic symbol for the transistor will be used in the illustrations, and rather than thinking about majority and minority carriers, we will now start thinking in terms of emitter, base, and collector current.

Before going into the basic transistor amplifier, there are two terms you should be familiar with: AMPLIFICATION and AMPLIFIER. Amplification is the process of increasing the strength of a SIGNAL. A signal is just a general term used to refer to any particular current, voltage, or power in a circuit. An amplifier is the device that provides amplification (the increase in current, voltage, or power of a signal) without appreciably altering the original signal.

Transistors are frequently used as amplifiers. Some transistor circuits are CURRENT amplifiers, with a small load resistance; other circuits are designed for VOLTAGE amplification and have a high load resistance; others amplify POWER.

Now take a look at the NPN version of the basic transistor amplifier in figure 2-12 and let's see just how it works.

So far in this discussion, a separate battery has been used to provide the necessary forward-bias voltage. Although a separate battery has been used in the past for convenience, it is not practical to use a battery for emitter-base bias. For instance, it would take a battery slightly over .2 volts to properly forward bias a germanium transistor, while a similar silicon transistor would require a voltage slightly over .6 volts. However, common batteries do not have such voltage values. Also, since bias voltages are quite critical and must be held within a few tenths of one volt, it is easier to work with bias currents flowing through resistors of high ohmic values than with batteries.

By inserting one or more resistors in a circuit, different methods of biasing may be achieved and the emitter-base battery eliminated. In addition to eliminating the battery, some of these biasing methods compensate for slight variations in transistor characteristics and changes in transistor conduction resulting from temperature irregularities. Notice in figure 2-12 that the emitter-base battery has been eliminated and the bias resistor R_B has been inserted between the collector and the base. Resistor R_B provides the necessary forward bias for the emitter-base junction. Current flows in the emitter-base bias circuit from ground to the emitter, out the base lead, and through R_B to V_{CC} . Since the current in the base circuit is very small (a few hundred microamperes) and the forward resistance of the transistor is low, only a few tenths of a volt of positive bias will be felt on the base of the transistor. However, this is enough voltage on the base, along with ground on the emitter and the large positive voltage on the collector, to properly bias the transistor.

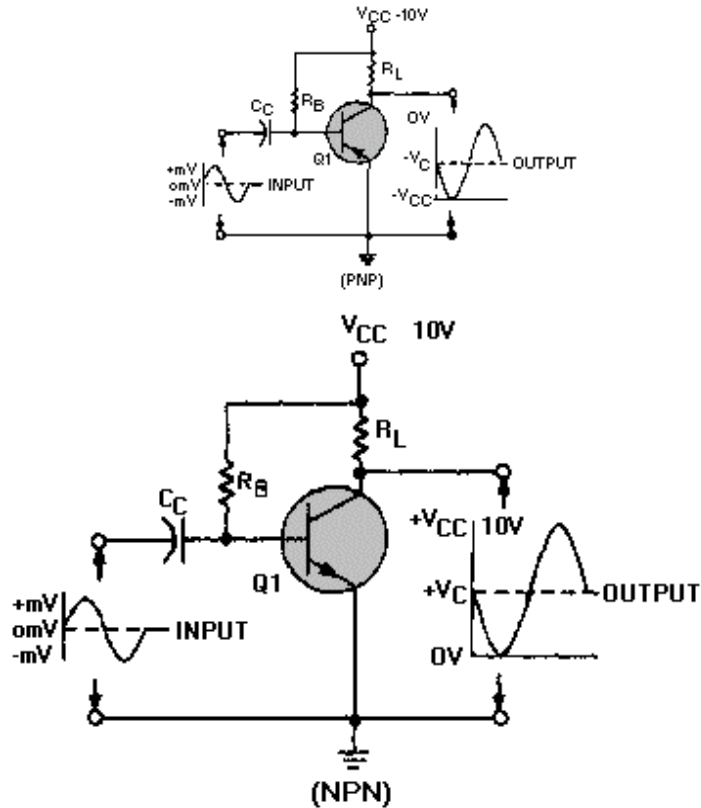


Figure 2-12.—The basic transistor amplifier.

With Q1 properly biased, direct current flows continuously, with or without an input signal, throughout the entire circuit. The direct current flowing through the circuit develops more than just base bias; it also develops the collector voltage (V_C) as it flows through Q1 and R_L . Notice the collector voltage on the output graph. Since it is present in the circuit without an input signal, the output signal starts at the V_C level and either increases or decreases. These dc voltages and currents that exist in the circuit before the application of a signal are known as QUIESCENT voltages and currents (the quiescent state of the circuit).

Resistor R_L , the collector load resistor, is placed in the circuit to keep the full effect of the collector supply voltage off the collector. This permits the collector voltage (V_C) to change with an input signal, which in turn allows the transistor to amplify voltage. Without R_L in the circuit, the voltage on the collector would always be equal to V_{CC} .

The coupling capacitor (C_C) is another new addition to the transistor circuit. It is used to pass the ac input signal and block the dc voltage from the preceding circuit. This prevents dc in the circuitry on the left of the coupling capacitor from affecting the bias on Q1. The coupling capacitor also blocks the bias of Q1 from reaching the input signal source.

The input to the amplifier is a sine wave that varies a few millivolts above and below zero. It is introduced into the circuit by the coupling capacitor and is applied between the base and emitter. As the input signal goes positive, the voltage across the emitter-base junction becomes more positive. This in effect increases forward bias, which causes base current to increase at the same rate as that of the input sine wave. Emitter and collector currents also increase but much more than the base current. With an increase in collector current, more voltage is developed across R_L . Since the voltage across R_L and the voltage across Q1 (collector to emitter) must add up to V_{CC} , an increase in voltage across R_L results in an equal decrease in

voltage across Q1. Therefore, the output voltage from the amplifier, taken at the collector of Q1 with respect to the emitter, is a negative alternation of voltage that is larger than the input, but has the same sine wave characteristics.

During the negative alternation of the input, the input signal opposes the forward bias. This action decreases base current, which results in a decrease in both emitter and collector currents. The decrease in current through R_L decreases its voltage drop and causes the voltage across the transistor to rise along with the output voltage. Therefore, the output for the negative alternation of the input is a positive alternation of voltage that is larger than the input but has the same sine wave characteristics.

By examining both input and output signals for one complete alternation of the input, we can see that the output of the amplifier is an exact reproduction of the input except for the reversal in polarity and the increased amplitude (a few millivolts as compared to a few volts).

The PNP version of this amplifier is shown in the upper part of the figure. The primary difference between the NPN and PNP amplifier is the polarity of the source voltage. With a negative V_{CC} , the PNP base voltage is slightly negative with respect to ground, which provides the necessary forward bias condition between the emitter and base.

When the PNP input signal goes positive, it opposes the forward bias of the transistor. This action cancels some of the negative voltage across the emitter-base junction, which reduces the current through the transistor. Therefore, the voltage across the load resistor decreases, and the voltage across the transistor increases. Since V_{CC} is negative, the voltage on the collector (V_C) goes in a negative direction (as shown on the output graph) toward $-V_{CC}$ (for example, from -5 volts to -7 volts). Thus, the output is a negative alternation of voltage that varies at the same rate as the sine wave input, but it is opposite in polarity and has a much larger amplitude.

During the negative alternation of the input signal, the transistor current increases because the input voltage aids the forward bias. Therefore, the voltage across R_L increases, and consequently, the voltage across the transistor decreases or goes in a positive direction (for example: from -5 volts to -3 volts). This action results in a positive output voltage, which has the same characteristics as the input except that it has been amplified and the polarity is reversed.

In summary, the input signals in the preceding circuits were amplified because the small change in base current caused a large change in collector current. And, by placing resistor R_L in series with the collector, voltage amplification was achieved.

Q14. What is the name of the device that provides an increase in current, voltage, or power of a signal without appreciably altering the original signal?

Q15. Besides eliminating the emitter-base battery, what other advantages can different biasing methods offer?

Q16. In the basic transistor amplifier discussed earlier, what is the relationship between the polarity of the input and output signals?

Q17. What is the primary difference between the NPN and PNP amplifiers?

TYPES OF BIAS

One of the basic problems with transistor amplifiers is establishing and maintaining the proper values of quiescent current and voltage in the circuit. This is accomplished by selecting the proper circuit-biasing conditions and ensuring these conditions are maintained despite variations in ambient (surrounding)

temperature, which cause changes in amplification and even distortion (an unwanted change in a signal). Thus a need arises for a method to properly bias the transistor amplifier and at the same time stabilize its dc operating point (the no signal values of collector voltage and collector current). As mentioned earlier, various biasing methods can be used to accomplish both of these functions. Although there are numerous biasing methods, only three basic types will be considered.

Base-Current Bias (Fixed Bias)

The first biasing method, called BASE CURRENT BIAS or sometimes FIXED BIAS, was used in figure 2-12. As you recall, it consisted basically of a resistor (R_B) connected between the collector supply voltage and the base. Unfortunately, this simple arrangement is quite thermally unstable. If the temperature of the transistor rises for any reason (due to a rise in ambient temperature or due to current flow through it), collector current will increase. This increase in current also causes the dc operating point, sometimes called the quiescent or static point, to move away from its desired position (level). This reaction to temperature is undesirable because it affects amplifier gain (the number of times of amplification) and could result in distortion, as you will see later in this discussion.

Self-Bias

A better method of biasing is obtained by inserting the bias resistor directly between the base and collector, as shown in figure 2-13. By tying the collector to the base in this manner, feedback voltage can be fed from the collector to the base to develop forward bias. This arrangement is called SELF-BIAS. Now, if an increase of temperature causes an increase in collector current, the collector voltage (V_C) will fall because of the increase of voltage produced across the load resistor (R_L). This drop in V_C will be fed back to the base and will result in a decrease in the base current. The decrease in base current will oppose the original increase in collector current and tend to stabilize it. The exact opposite effect is produced when the collector current decreases.

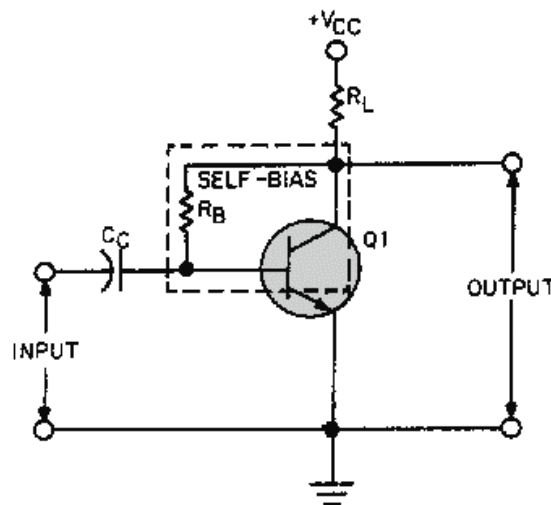


Figure 2-13.—A basic transistor amplifier with self-bias.

Self-bias has two small drawbacks: (1) It is only partially effective and, therefore, is only used where moderate changes in ambient temperature are expected; (2) it reduces amplification since the signal on the collector also affects the base voltage. This is because the collector and base signals for this particular amplifier configuration are 180 degrees out of phase (opposite in polarity) and the part of the collector signal that is fed back to the base cancels some of the input signal. This process of returning a part of the output back to its input is known as DEGENERATION or NEGATIVE FEEDBACK. Sometimes degeneration is

desired to prevent amplitude distortion (an output signal that fails to follow the input exactly) and self-bias may be used for this purpose.

Combination Bias

A combination of fixed and self-bias can be used to improve stability and at the same time overcome some of the disadvantages of the other two biasing methods. One of the most widely used combination-bias systems is the voltage-divider type shown in figure 2-14. Fixed bias is provided in this circuit by the voltage-divider network consisting of R_1 , R_2 , and the collector supply voltage (V_{CC}). The dc current flowing through the voltage-divider network biases the base positive with respect to the emitter. Resistor R_3 , which is connected in series with the emitter, provides the emitter with self-bias. Should I_E increase, the voltage drop across R_3 would also increase, reducing V_C . This reaction to an increase in I_E by R_3 is another form of degeneration, which results in less output from the amplifier. However, to provide long-term or dc thermal stability, and at the same time, allow minimal ac signal degeneration, the bypass capacitor (C_{bp}) is placed across R_3 . If C_{bp} is large enough, rapid signal variations will not change its charge materially and no degeneration of the signal will occur.

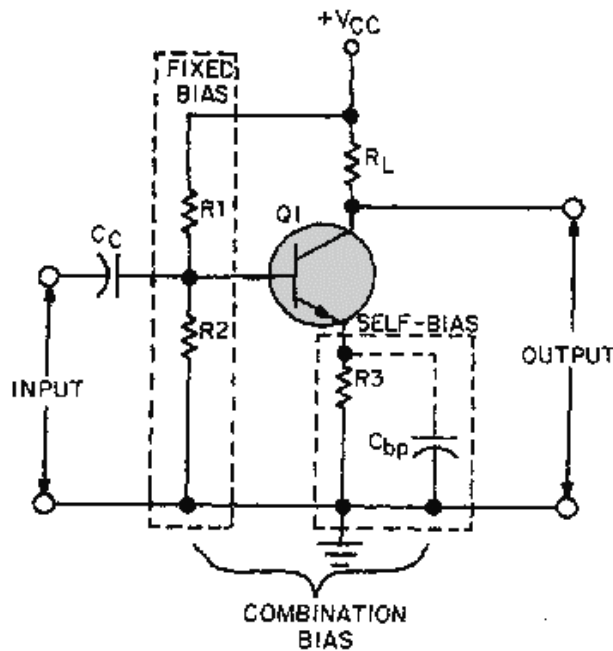


Figure 2-14.—A basic transistor amplifier with combination bias.

In summary, the fixed-bias resistors, R_1 and R_2 , tend to keep the base bias constant while the emitter bias changes with emitter conduction. This action greatly improves thermal stability and at the same time maintains the correct operating point for the transistor.

- Q18. Which biasing method is the most unstable?
- Q19. What type of bias is used where only moderate changes in ambient temperature are expected?
- Q20. When is degeneration tolerable in an amplifier?
- Q21. What is the most widely used combination-bias system?

AMPLIFIER CLASSES OF OPERATION

In the previous discussions, we assumed that for every portion of the input signal there was an output from the amplifier. This is not always the case with amplifiers. It may be desirable to have the transistor conducting for only a portion of the input signal. The portion of the input for which there is an output determines the class of operation of the amplifier. There are four classes of amplifier operations. They are class A, class AB, class B, and class C.

Class A Amplifier Operation

Class A amplifiers are biased so that variations in input signal polarities occur within the limits of CUTOFF and SATURATION. In a PNP transistor, for example, if the base becomes positive with respect to the emitter, holes will be repelled at the PN junction and no current can flow in the collector circuit. This condition is known as cutoff. Saturation occurs when the base becomes so negative with respect to the emitter that changes in the signal are not reflected in collector-current flow.

Biasing an amplifier in this manner places the dc operating point between cutoff and saturation and allows collector current to flow during the complete cycle (360 degrees) of the input signal, thus providing an output which is a replica of the input. Figure 2-12 is an example of a class A amplifier. Although the output from this amplifier is 180 degrees out of phase with the input, the output current still flows for the complete duration of the input.

The class A operated amplifier is used as an audio- and radio-frequency amplifier in radio, radar, and sound systems, just to mention a few examples.

For a comparison of output signals for the different amplifier classes of operation, refer to figure 2-15 during the following discussion.

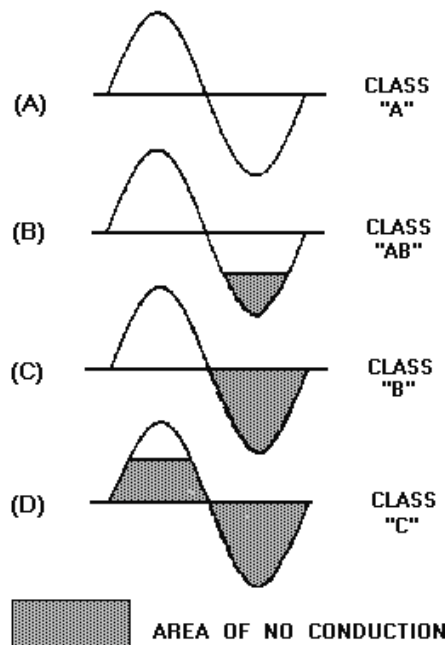


Figure 2-15.—A comparison of output signals for the different amplifier classes of operation.

Class AB Amplifier Operation

Amplifiers designed for class AB operation are biased so that collector current is zero (cutoff) for a portion of one alternation of the input signal. This is accomplished by making the forward-bias voltage less than the peak value of the input signal. By doing this, the base-emitter junction will be reverse biased during one alternation for the amount of time that the input signal voltage opposes and exceeds the value of forward-bias voltage. Therefore, collector current will flow for more than 180 degrees but less than 360 degrees of the input signal, as shown in figure 2-15 view B. As compared to the class A amplifier, the dc operating point for the class AB amplifier is closer to cutoff.

The class AB operated amplifier is commonly used as a push-pull amplifier to overcome a side effect of class B operation called crossover distortion.

Class B Amplifier Operation

Amplifiers biased so that collector current is cut off during one-half of the input signal are classified class B. The dc operating point for this class of amplifier is set up so that base current is zero with no input signal. When a signal is applied, one half cycle will forward bias the base-emitter junction and I_C will flow. The other half cycle will reverse bias the base-emitter junction and I_C will be cut off. Thus, for class B operation, collector current will flow for approximately 180 degrees (half) of the input signal, as shown in figure 2-15 view C.

The class B operated amplifier is used extensively for audio amplifiers that require high-power outputs. It is also used as the driver- and power-amplifier stages of transmitters.

Class C Amplifier Operation

In class C operation, collector current flows for less than one half cycle of the input signal, as shown in figure 2-15 view D. The class C operation is achieved by reverse biasing the emitter-base junction, which sets the dc operating point below cutoff and allows only the portion of the input signal that overcomes the reverse bias to cause collector current flow.

The class C operated amplifier is used as a radio-frequency amplifier in transmitters.

From the previous discussion, you can conclude that two primary items determine the class of operation of an amplifier — (1) the amount of bias and (2) the amplitude of the input signal. With a given input signal and bias level, you can change the operation of an amplifier from class A to class B just by removing forward bias. Also, a class A amplifier can be changed to class AB by increasing the input signal amplitude. However, if an input signal amplitude is increased to the point that the transistor goes into saturation and cutoff, it is then called an OVERDRIVEN amplifier.

You should be familiar with two terms used in conjunction with amplifiers — FIDELITY and EFFICIENCY. Fidelity is the faithful reproduction of a signal. In other words, if the output of an amplifier is just like the input except in amplitude, the amplifier has a high degree of fidelity. The opposite of fidelity is a term we mentioned earlier — distortion. Therefore, a circuit that has high fidelity has low distortion. In conclusion, a class A amplifier has a high degree of fidelity. A class AB amplifier has less fidelity, and class B and class C amplifiers have low or "poor" fidelity.

The efficiency of an amplifier refers to the ratio of output-signal power compared to the total input power. An amplifier has two input power sources: one from the signal, and one from the power supply. Since every device takes power to operate, an amplifier that operates for 360 degrees of the input signal uses more power than if operated for 180 degrees of the input signal. By using more power, an amplifier has less power available for the output signal; thus the efficiency of the amplifier is low. This is the case

with the class A amplifier. It operates for 360 degrees of the input signal and requires a relatively large input from the power supply. Even with no input signal, the class A amplifier still uses power from the power supply. Therefore, the output from the class A amplifier is relatively small compared to the total input power. This results in low efficiency, which is acceptable in class A amplifiers because they are used where efficiency is not as important as fidelity.

Class AB amplifiers are biased so that collector current is cut off for a portion of one alternation of the input, which results in less total input power than the class A amplifier. This leads to better efficiency.

Class B amplifiers are biased with little or no collector current at the dc operating point. With no input signal, there is little wasted power. Therefore, the efficiency of class B amplifiers is higher still.

The efficiency of class C is the highest of the four classes of amplifier operations.

Q22. What amplifier class of operation allows collector current to flow during the complete cycle of the input?

Q23. What is the name of the term used to describe the condition in a transistor when the emitter-base junction has zero bias or is reverse biased and there is no collector current?

Q24. What two primary items determine the class of operation of an amplifier?

Q25. What amplifier class of operation is the most inefficient but has the least distortion?

TRANSISTOR CONFIGURATIONS

A transistor may be connected in any one of three basic configurations (fig. 2-16): common emitter (CE), common base (CB), and common collector (CC). The term common is used to denote the element that is common to both input and output circuits. Because the common element is often grounded, these configurations are frequently referred to as grounded emitter, grounded base, and grounded collector.

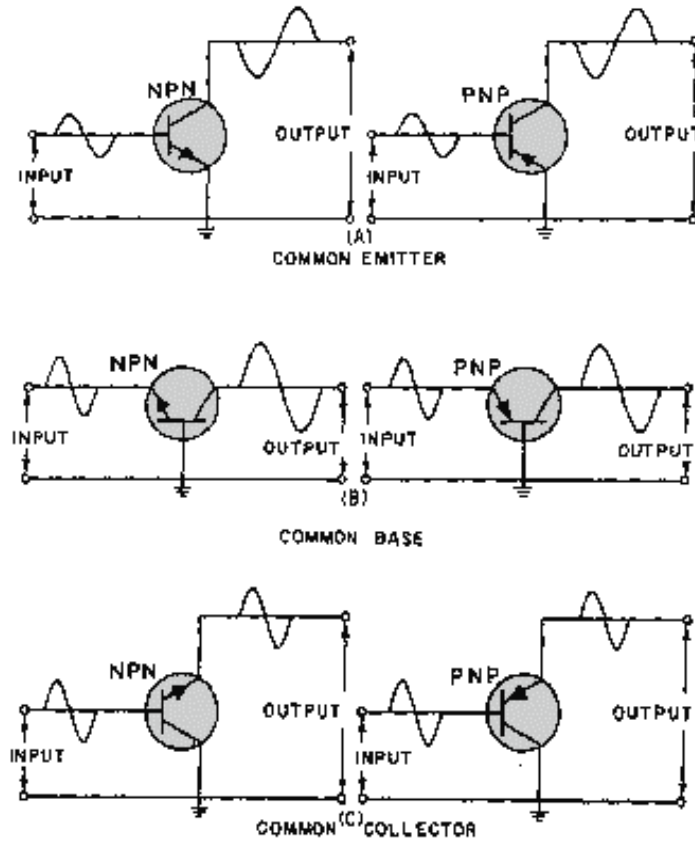


Figure 2-16.—Transistor configurations.

Each configuration, as you will see later, has particular characteristics that make it suitable for specific applications. An easy way to identify a specific transistor configuration is to follow three simple steps:

1. Identify the element (emitter, base, or collector) to which the input signal is applied.
2. Identify the element (emitter, base, or collector) from which the output signal is taken.
3. The remaining element is the common element, and gives the configuration its name.

Therefore, by applying these three simple steps to the circuit in figure 2-12, we can conclude that this circuit is more than just a basic transistor amplifier. It is a common-emitter amplifier.

Common Emitter

The common-emitter configuration (CE) shown in figure 2-16 view A is the arrangement most frequently used in practical amplifier circuits, since it provides good voltage, current, and power gain. The common emitter also has a somewhat low input resistance (500 ohms-1500 ohms), because the input is applied to the forward-biased junction, and a moderately high output resistance (30 kilohms-50 kilohms or more), because the output is taken off the reverse-biased junction. Since the input signal is applied to the base-emitter circuit and the output is taken from the collector-emitter circuit, the emitter is the element common to both input and output.

Since you have already covered what you now know to be a common-emitter amplifier (fig. 2-12), let's take a few minutes and review its operation, using the PNP common-emitter configuration shown in figure 2-16 view A.

When a transistor is connected in a common-emitter configuration, the input signal is injected between the base and emitter, which is a low resistance, low-current circuit. As the input signal swings positive, it also causes the base to swing positive with respect to the emitter. This action decreases forward bias which reduces collector current (I_C) and increases collector voltage (making V_C more negative). During the negative alternation of the input signal, the base is driven more negative with respect to the emitter. This increases forward bias and allows more current carriers to be released from the emitter, which results in an increase in collector current and a decrease in collector voltage (making V_C less negative or swing in a positive direction). The collector current that flows through the high resistance reverse-biased junction also flows through a high resistance load (not shown), resulting in a high level of amplification.

Since the input signal to the common emitter goes positive when the output goes negative, the two signals (input and output) are 180 degrees out of phase. The common-emitter circuit is the only configuration that provides a phase reversal.

The common-emitter is the most popular of the three transistor configurations because it has the best combination of current and voltage gain. The term *GAIN* is used to describe the amplification capabilities of the amplifier. It is basically a ratio of output versus input. Each transistor configuration gives a different value of gain even though the same transistor is used. The transistor configuration used is a matter of design consideration. However, as a technician you will become interested in this output versus input ratio (gain) to determine whether or not the transistor is working properly in the circuit.

The current gain in the common-emitter circuit is called BETA (β). Beta is the relationship of collector current (output current) to base current (input current). To calculate beta, use the following formula:

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

(Δ is the Greek letter delta, it is used to indicate a small change)

For example, if the input current (I_B) in a common emitter changes from 75 μ A to 100 μ A and the output current (I_C) changes from 1.5 mA to 2.6 mA, the current gain (β) will be 44.

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{11 \times 10^{-3}}{25 \times 10^{-6}} = 44$$

This simply means that a change in base current produces a change in collector current which is 44 times as large.

You may also see the term h_{fe} used in place of β . The terms h_{fe} and β are equivalent and may be used interchangeably. This is because "h_{fe}" means:

h = hybrid (meaning mixture)

f = forward current transfer ratio

e = common emitter configuration

The resistance gain of the common emitter can be found in a method similar to the one used for finding beta:

$$R = \frac{R_{out}}{R_{in}}$$

Once the resistance gain is known, the voltage gain is easy to calculate since it is equal to the current gain (β) multiplied by the resistance gain ($E = \beta R$). And, the power gain is equal to the voltage gain multiplied by the current gain β ($P = \beta E$).

Common Base

The common-base configuration (CB) shown in figure 2-16, view B is mainly used for impedance matching, since it has a low input resistance (30 ohms-160 ohms) and a high output resistance (250 kilohms-550 kilohms). However, two factors limit its usefulness in some circuit applications: (1) its low input resistance and (2) its current gain of less than 1. Since the CB configuration will give voltage amplification, there are some additional applications, which require both a low-input resistance and voltage amplification, that could use a circuit configuration of this type; for example, some microphone amplifiers.

In the common-base configuration, the input signal is applied to the emitter, the output is taken from the collector, and the base is the element common to both input and output. Since the input is applied to the emitter, it causes the emitter-base junction to react in the same manner as it did in the common-emitter circuit. For example, an input that aids the bias will increase transistor current, and one that opposes the bias will decrease transistor current.

Unlike the common-emitter circuit, the input and output signals in the common-base circuit are in phase. To illustrate this point, assume the input to the PNP version of the common-base circuit in figure 2-16 view B is positive. The signal adds to the forward bias, since it is applied to the emitter, causing the collector current to increase. This increase in I_C results in a greater voltage drop across the load resistor R_L (not shown), thus lowering the collector voltage V_C . The collector voltage, in becoming less negative, is swinging in a positive direction, and is therefore in phase with the incoming positive signal.

The current gain in the common-base circuit is calculated in a method similar to that of the common emitter except that the input current is I_E not I_B and the term ALPHA (α) is used in place of beta for gain. Alpha is the relationship of collector current (output current) to emitter current (input current). Alpha is calculated using the formula:

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

For example, if the input current (I_E) in a common base changes from 1 mA to 3 mA and the output current (I_C) changes from 1 mA to 2.8 mA, the current gain (α) will be 0.90 or:

$$\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{18 \times 10^{-3}}{2 \times 10^{-3}} = 0.90$$

This is a current gain of less than 1.

Since part of the emitter current flows into the base and does not appear as collector current, collector current will always be less than the emitter current that causes it. (Remember, $I_E = I_B + I_C$) Therefore, ALPHA is ALWAYS LESS THAN ONE FOR A COMMON-BASE CONFIGURATION.

Another term for " α " is h_f . These terms (and h_f) are equivalent and may be used interchangeably. The meaning for the term h_f is derived in the same manner as the term h_{fe} mentioned earlier, except that the last letter "e" has been replaced with "b" to stand for common-base configuration.

Many transistor manuals and data sheets only list transistor current gain characteristics in terms of β or h_{fe} . To find alpha (α) when given beta (β), use the following formula to convert β to α for use with the common-base configuration:

$$\alpha = \frac{\beta}{\beta + 1}$$

To calculate the other gains (voltage and power) in the common-base configuration when the current gain (α) is known, follow the procedures described earlier under the common-emitter section.

Common Collector

The common-collector configuration (CC) shown in figure 2-16 view C is used mostly for impedance matching. It is also used as a current driver, because of its substantial current gain. It is particularly useful in switching circuitry, since it has the ability to pass signals in either direction (bilateral operation).

In the common-collector circuit, the input signal is applied to the base, the output is taken from the emitter, and the collector is the element common to both input and output. The common collector is equivalent to our old friend the electron-tube cathode follower. Both have high input and low output resistance. The input resistance for the common collector ranges from 2 kilohms to 500 kilohms, and the output resistance varies from 50 ohms to 1500 ohms. The current gain is higher than that in the common emitter, but it has a lower power gain than either the common base or common emitter. Like the common base, the output signal from the common collector is in phase with the input signal. The common collector is also referred to as an emitter-follower because the output developed on the emitter follows the input signal applied to the base.

Transistor action in the common collector is similar to the operation explained for the common base, except that the current gain is not based on the emitter-to-collector current ratio, alpha (α). Instead, it is based on the emitter-to-base current ratio called GAMMA (γ), because the output is taken off the emitter. Since a small change in base current controls a large change in emitter current, it is still possible to obtain high current gain in the common collector. However, since the emitter current gain is offset by the low output resistance, the voltage gain is always less than 1 (unity), exactly as in the electron-tube cathode follower

The common-collector current gain, gamma (γ), is defined as

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

and is related to collector-to-base current gain, beta (β), of the common-emitter circuit by the formula:

$$\gamma = \beta + 1$$

Since a given transistor may be connected in any of three basic configurations, there is a definite relationship, as pointed out earlier, between alpha (α), beta (β), and gamma (γ). These relationships are listed again for your convenience:

$$\alpha = \frac{\beta}{\beta + 1} \quad \beta = \frac{\alpha}{1 - \alpha} \quad \gamma = \beta + 1$$

Take, for example, a transistor that is listed on a manufacturer's data sheet as having an alpha of 0.90. We wish to use it in a common emitter configuration. This means we must find beta. The calculations are:

$$\beta = \frac{\alpha}{1 - \alpha} = \frac{0.90}{1 - 0.90} = \frac{0.90}{0.1} = 9$$

Therefore, a change in base current in this transistor will produce a change in collector current that will be 9 times as large.

If we wish to use this same transistor in a common collector, we can find gamma (γ) by:

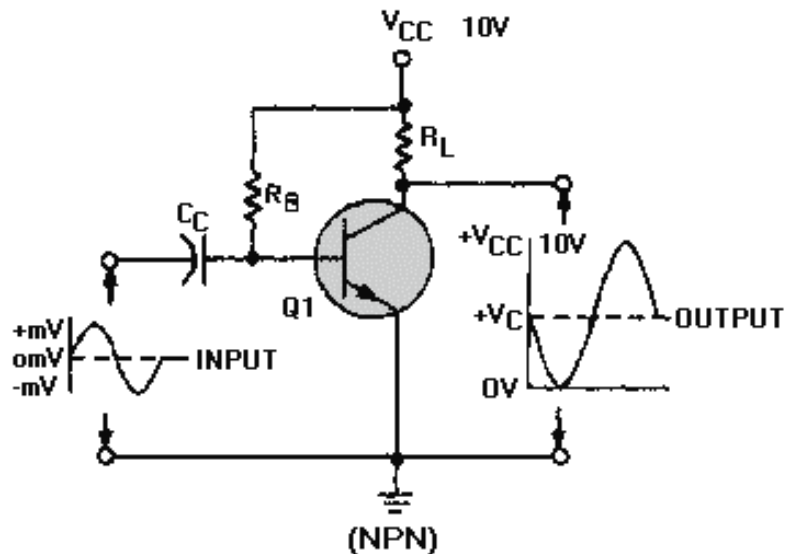
$$\gamma = \beta + 1 = 9 + 1 = 10$$

To summarize the properties of the three transistor configurations, a comparison chart is provided in table 2-1 for your convenience.

Table 2-1.—Transistor Configuration Comparison Chart

AMPLIFIER TYPE	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
INPUT/OUTPUT PHASE RELATIONSHIP	0°	180°	0°
VOLTAGE GAIN	HIGH	MEDIUM	LOW
CURRENT GAIN	LOW(α)	MEDIUM(β)	HIGH(γ)
POWER GAIN	LOW	HIGH	MEDIUM
INPUT RESISTANCE	LOW	MEDIUM	HIGH
OUTPUT RESISTANCE	HIGH	MEDIUM	LOW

Now that we have analyzed the basic transistor amplifier in terms of bias, class of operation, and circuit configuration, let's apply what has been covered to figure 2-12. A reproduction of figure 2-12 is shown below for your convenience.



This illustration is not just the basic transistor amplifier shown earlier in figure 2-12 but a class A amplifier configured as a common emitter using fixed bias. From this, you should be able to conclude the following:

- Because of its fixed bias, the amplifier is thermally unstable.
- Because of its class A operation, the amplifier has low efficiency but good fidelity.
- Because it is configured as a common emitter, the amplifier has good voltage, current, and power gain.

In conclusion, the type of bias, class of operation, and circuit configuration are all clues to the function and possible application of the amplifier.

- Q26. *What are the three transistor configurations?*
- Q27. *Which transistor configuration provides a phase reversal between the input and output signals?*
- Q28. *What is the input current in the common-emitter circuit?*
- Q29. *What is the current gain in a common-base circuit called?*
- Q30. *Which transistor configuration has a current gain of less than 1?*
- Q31. *What is the output current in the common-collector circuit?*
- Q32. *Which transistor configuration has the highest input resistance?*
- Q33. *What is the formula for GAMMA (γ)?*

TRANSISTOR SPECIFICATIONS

Transistors are available in a large variety of shapes and sizes, each with its own unique characteristics. The characteristics for each of these transistors are usually presented on SPECIFICATION SHEETS or they may be included in transistor manuals. Although many properties of a transistor could be specified on these sheets, manufacturers list only some of them. The specifications listed vary with different manufacturers, the type of transistor, and the application of the transistor. The specifications usually cover the following items.

1. A general description of the transistor that includes the following information:
 - a. The kind of transistor. This covers the material used, such as germanium or silicon; the type of transistor (NPN or PNP); and the construction of the transistor (whether alloy-junction, grown, or diffused junction, etc.).
 - b. Some of the common applications for the transistor, such as audio amplifier, oscillator, rf amplifier, etc.
 - c. General sales features, such as size and packaging mechanical data).
2. The "Absolute Maximum Ratings" of the transistor are the direct voltage and current values that if exceeded in operation may result in transistor failure. Maximum ratings usually include collector-to-base voltage, emitter-to-base voltage, collector current, emitter current, and collector power dissipation.
3. The typical operating values of the transistor. These values are presented only as a guide. The values vary widely, are dependent upon operating voltages, and also upon which element is common in the circuit. The values listed may include collector-emitter voltage, collector current, input resistance, load resistance, current-transfer ratio (another name for alpha or beta), and collector cutoff current, which is leakage current from collector to base when no emitter current is applied. Transistor characteristic curves may also be included in this section. A transistor characteristic curve is a graph plotting the relationship between currents and voltages in a circuit. More than one curve on a graph is called a "family of curves."
4. Additional information for engineering-design purposes.

So far, many letter symbols, abbreviations, and terms have been introduced, some frequently used and others only rarely used. For a complete list of all semiconductor letter symbols and terms, refer to EIMB series 000-0140, Section III.

TRANSISTOR IDENTIFICATION

Transistors can be identified by a Joint Army-Navy (JAN) designation printed directly on the case of the transistor. The marking scheme explained earlier for diodes is also used for transistor identification. The first number indicates the number of junctions. The letter "N" following the first number tells us that the component is a semiconductor. And, the 2- or 3-digit number following the N is the manufacturer's identification number. If the last number is followed by a letter, it indicates a later, improved version of the device. For example, a semiconductor designated as type 2N130A signifies a three-element transistor of semiconductor material that is an improved version of type 130:

NUMBER OF JUNCTIONS (TRANSISTOR)	SEMI- CONDUCTOR	IDENTIFICATION NUMBER	FIRST MODIFICATION
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You may also find other markings on transistors that do not relate to the JAN marking system. These markings are manufacturers' identifications and may not conform to a standardized system. If in doubt, always replace a transistor with one having identical markings. To ensure that an identical replacement or a correct substitute is used, consult an equipment or transistor manual for specifications on the transistor.

TRANSISTOR MAINTENANCE

Transistors are very rugged and are expected to be relatively trouble free. Encapsulation and conformal coating techniques now in use promise extremely long life expectancies. In theory, a transistor should last indefinitely. However, if transistors are subjected to current overloads, the junctions will be damaged or even destroyed. In addition, the application of excessively high operating voltages can damage or destroy the junctions through arc-over or excessive reverse currents. One of the greatest dangers to the transistor is heat, which will cause excessive current flow and eventual destruction of the transistor.

To determine if a transistor is good or bad, you can check it with an ohmmeter or a transistor tester. In many cases, you can substitute a transistor known to be good for one that is questionable and thus determine the condition of a suspected transistor. This method of testing is highly accurate and sometimes the quickest, but it should be used only after you make certain that there are no circuit defects that might damage the replacement transistor. If more than one defective transistor is present in the equipment where the trouble has been localized, this testing method becomes cumbersome, as several transistors may have to be replaced before the trouble is corrected. To determine which stages failed and which transistors are not defective, all the removed transistors must be tested. This test can be made by using a standard Navy ohmmeter, transistor tester, or by observing whether the equipment operates correctly as each of the removed transistors is reinserted into the equipment. A word of caution-indiscriminate substitution of transistors in critical circuits should be avoided.

When transistors are soldered into equipment, substitution is not practicable; it is generally desirable to test these transistors in their circuits.

- Q34. List three items of information normally included in the general description section of a specification sheet for a transistor.*
- Q35. What does the number "2" (before the letter "N") indicate in the JAN marking scheme?*
- Q36. What is the greatest danger to a transistor?*
- Q37. What method for checking transistors is cumbersome when more than one transistor is bad in a circuit?*

PRECAUTIONS

Transistors, although generally more rugged mechanically than electron tubes, are susceptible to damage by electrical overloads, heat, humidity, and radiation. Damage of this nature often occurs during transistor servicing by applying the incorrect polarity voltage to the collector circuit or excessive voltage to the input circuit. Careless soldering techniques that overheat the transistor have also been known to cause considerable damage. One of the most frequent causes of damage to a transistor is the electrostatic

discharge from the human body when the device is handled. You may avoid such damage before starting repairs by discharging the static electricity from your body to the chassis containing the transistor. You can do this by simply touching the chassis. Thus, the electricity will be transferred from your body to the chassis before you handle the transistor.

To prevent transistor damage and avoid electrical shock, you should observe the following precautions when you are working with transistorized equipment:

1. Test equipment and soldering irons should be checked to make certain there is no leakage current from the power source. If leakage current is detected, isolation transformers should be used.
2. Always connect a ground between test equipment and circuit before attempting to inject or monitor a signal.
3. Ensure test voltages do not exceed maximum allowable voltage for circuit components and transistors. Also, never connect test equipment outputs directly to a transistor circuit.
4. Ohmmeter ranges that require a current of more than one milliamperere in the test circuit should not be used for testing transistors.
5. Battery eliminators should not be used to furnish power for transistor equipment because they have poor voltage regulation and, possibly, high-ripple voltage.
6. The heat applied to a transistor, when soldered connections are required, should be kept to a minimum by using a low-wattage soldering iron and heat shunts, such as long-nose pliers, on the transistor leads.
7. When it becomes necessary to replace transistors, never pry transistors to loosen them from printed circuit boards.
8. All circuits should be checked for defects before replacing a transistor.
9. The power must be removed from the equipment before replacing a transistor.
10. Using conventional test probes on equipment with closely spaced parts often causes accidental shorts between adjacent terminals. These shorts rarely cause damage to an electron tube but may ruin a transistor. To prevent these shorts, the probes can be covered with insulation, except for a very short length of the tips.

LEAD IDENTIFICATION

Transistor lead identification plays an important part in transistor maintenance; because, before a transistor can be tested or replaced, its leads or terminals must be identified. Since there is no standard method of identifying transistor leads, it is quite possible to mistake one lead for another. Therefore, when you are replacing a transistor, you should pay close attention to how the transistor is mounted, particularly to those transistors that are soldered in, so that you do not make a mistake when you are installing the new transistor. When you are testing or replacing a transistor, if you have any doubts about which lead is which, consult the equipment manual or a transistor manual that shows the specifications for the transistor being used.

There are, however, some typical lead identification schemes that will be very helpful in transistor troubleshooting. These schemes are shown in figure 2-17. In the case of the oval-shaped transistor shown in view A, the collector lead is identified by a wide space between it and the base lead. The lead farthest from the collector, in line, is the emitter lead. When the leads are evenly spaced and in line, as shown in

view B, a colored dot, usually red, indicates the collector. If the transistor is round, as in view C, a red line indicates the collector, and the emitter lead is the shortest lead. In view D the leads are in a triangular arrangement that is offset from the center of the transistor. The lead opposite the blank quadrant in this scheme is the base lead. When viewed from the bottom, the collector is the first lead clockwise from the base. The leads in view E are arranged in the same manner as those in view D except that a tap is used to identify the leads. When viewed from the bottom in a clockwise direction, the first lead following the tab is the emitter, followed by the base and collector.

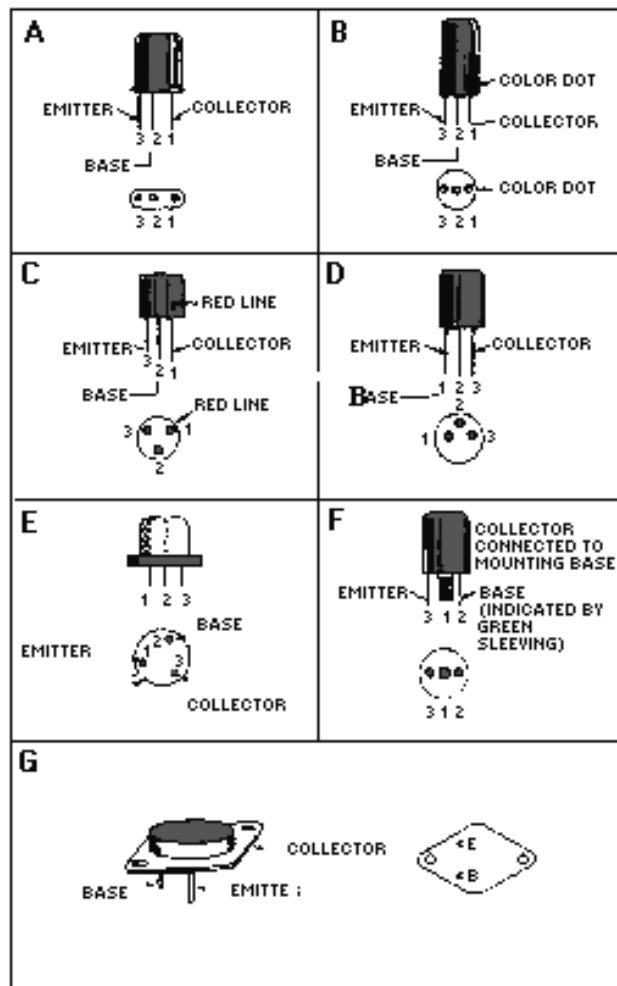


Figure 2-17.—Transistor lead identification.

In a conventional power transistor as shown in views F and G, the collector lead is usually connected to the mounting base. For further identification, the base lead in view F is covered with green sleeving. While the leads in view G are identified by viewing the transistor from the bottom in a clockwise direction (with mounting holes occupying 3 o'clock and 9 o'clock positions), the emitter lead will be either at the 5 o'clock or 11 o'clock position. The other lead is the base lead.

TRANSISTOR TESTING

There are several different ways of testing transistors. They can be tested while in the circuit, by the substitution method mentioned, or with a transistor tester or ohmmeter.

Transistor testers are nothing more than the solid-state equivalent of electron-tube testers (although they do not operate on the same principle). With most transistor testers, it is possible to test the transistor in or out of the circuit.

There are four basic tests required for transistors in practical troubleshooting: gain, leakage, breakdown, and switching time. For maintenance and repair, however, a check of two or three parameters is usually sufficient to determine whether a transistor needs to be replaced.

Since it is impractical to cover all the different types of transistor testers and since each tester comes with its own operator's manual, we will move on to something you will use more frequently for testing transistors—the ohmmeter.

Testing Transistors with an Ohmmeter

Two tests that can be done with an ohmmeter are gain, and junction resistance. Tests of a transistor's junction resistance will reveal leakage, shorts, and opens.

TRANSISTOR GAIN TEST.—A basic transistor gain test can be made using an ohmmeter and a simple test circuit. The test circuit can be made with just a couple of resistors and a switch, as shown in figure 2-18. The principle behind the test lies in the fact that little or no current will flow in a transistor between emitter and collector until the emitter-base junction is forward biased. The only precaution you should observe is with the ohmmeter. Any internal battery may be used in the meter provided that it does not exceed the maximum collector-emitter breakdown voltage.

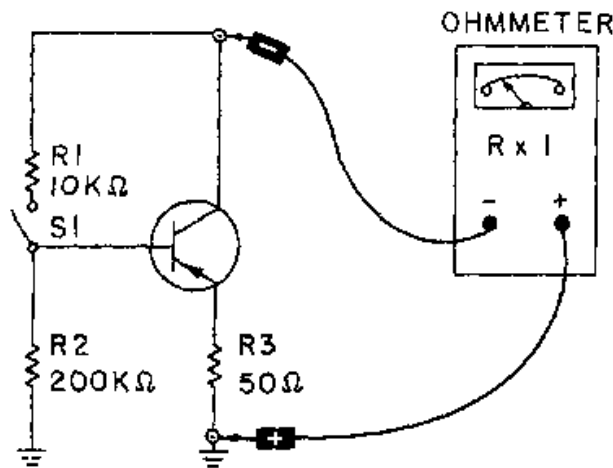


Figure 2-18.—Testing a transistor's gain with an ohmmeter.

With the switch in figure 2-18 in the open position as shown, no voltage is applied to the PNP transistor's base, and the emitter-base junction is not forward biased. Therefore, the ohmmeter should read a high resistance, as indicated on the meter. When the switch is closed, the emitter-base circuit is forward biased by the voltage across R1 and R2. Current now flows in the emitter-collector circuit, which causes a lower resistance reading on the ohmmeter. A 10-to-1 resistance ratio in this test between meter readings indicates a normal gain for an audio-frequency transistor.

To test an NPN transistor using this circuit, simply reverse the ohmmeter leads and carry out the procedure described earlier.

TRANSISTOR JUNCTION RESISTANCE TEST.—An ohmmeter can be used to test a transistor for leakage (an undesirable flow of current) by measuring the base-emitter, base-collector, and collector-emitter forward and reverse resistances.

For simplicity, consider the transistor under test in each view of figure 2-19 (view A, view B and view C) as two diodes connected back to back. Therefore, each diode will have a low forward resistance and a high reverse resistance. By measuring these resistances with an ohmmeter as shown in the figure, you can determine if the transistor is leaking current through its junctions. When making these measurements, avoid using the R1 scale on the meter or a meter with a high internal battery voltage. Either of these conditions can damage a low-power transistor.

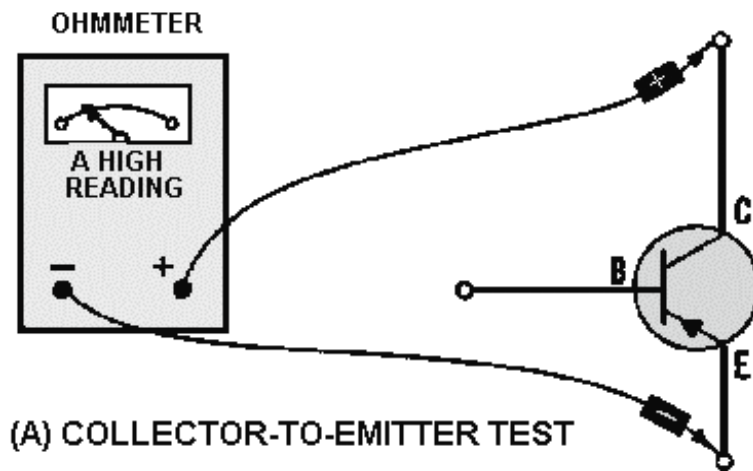


Figure 2-19A.—Testing a transistor's leakage with an ohmmeter. COLLECTOR-TO-EMITTER TEST

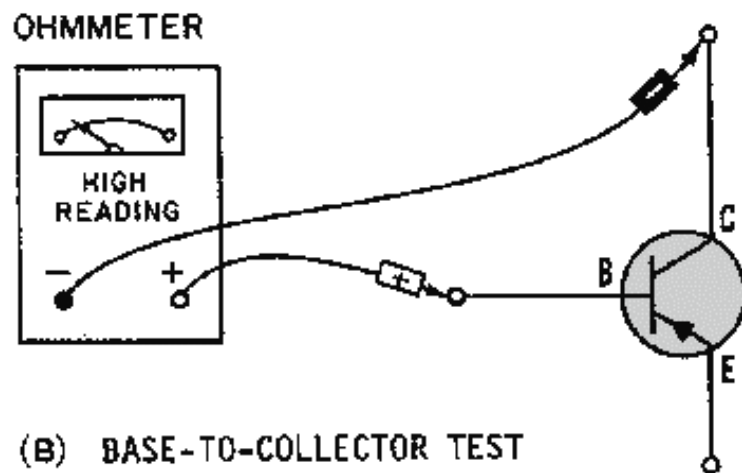
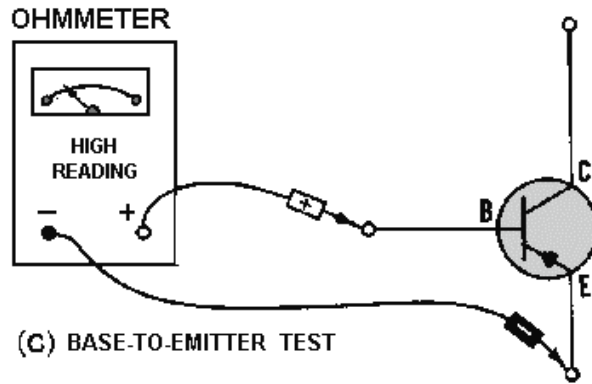


Figure 2-19B.—Testing a transistor's leakage with an ohmmeter. BASE-TO-COLLECTOR TEST



NOTE: Reversing the meter leads will give a low reading.

Figure 2-19C.—Testing a transistor's leakage with an ohmmeter. BASE-TO-EMITTER TEST

Now consider the possible transistor problems that could exist if the indicated readings in figure 2-19 are not obtained. A list of these problems is provided in table 2-2.

Table 2-2.—Possible Transistor Problems from Ohmmeter Readings

RESISTANCE READINGS		PROBLEMS
FORWARD	REVERSE	The transistor is:
LOW (NOT SHORTED)	LOW (NOT SHORTED)	LEAKING
LOW (SHORTED)	LOW (SHORTED)	SHORTED
HIGH	HIGH	OPEN*
*Except collector-to-emitter test.		

By now, you should recognize that the transistor used in figure 2-19 (view A, view B and view C) is a PNP transistor. If you wish to test an NPN transistor for leakage, the procedure is identical to that used for testing the PNP except the readings obtained are reversed.

When testing transistors (PNP or NPN), you should remember that the actual resistance values depend on the ohmmeter scale and the battery voltage. Typical forward and reverse resistances are insignificant. The best indicator for showing whether a transistor is good or bad is the ratio of forward-to-reverse resistance. If the transistor you are testing shows a ratio of at least 30 to 1, it is probably good. Many transistors show ratios of 100 to 1 or greater.

- Q38. *What safety precaution must be taken before replacing a transistor?*
- Q39. *How is the collector lead identified on an oval-shaped transistor?*
- Q40. *What are two transistor tests that can be done with an ohmmeter?*
- Q41. *When you are testing the gain of an audio-frequency transistor with an ohmmeter, what is indicated by a 10-to-1 resistance ratio?*

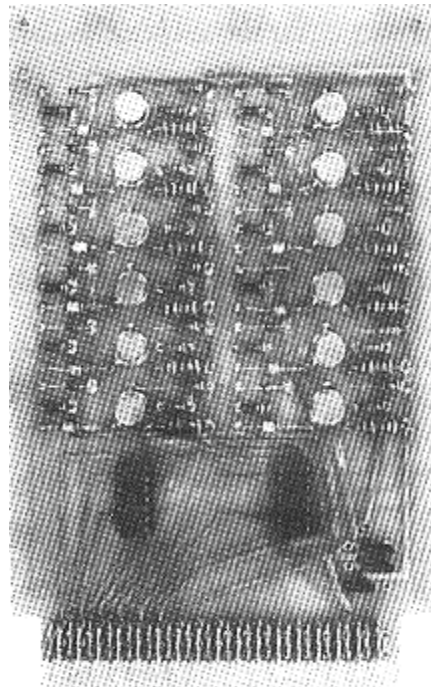
Q42. When you are using an ohmmeter to test a transistor for leakage, what is indicated by a low, but not shorted, reverse resistance reading?

MICROELECTRONICS

Up to now the various semiconductors, resistors, capacitors, etc., in our discussions have been considered as separately packaged components, called DISCRETE COMPONENTS. In this section we will introduce some of the more complex devices that contain complete circuits packaged as a single component. These devices are referred to as INTEGRATED CIRCUITS and the broad term used to describe the use of these devices to miniaturize electronic equipment is called MICROELECTRONICS.

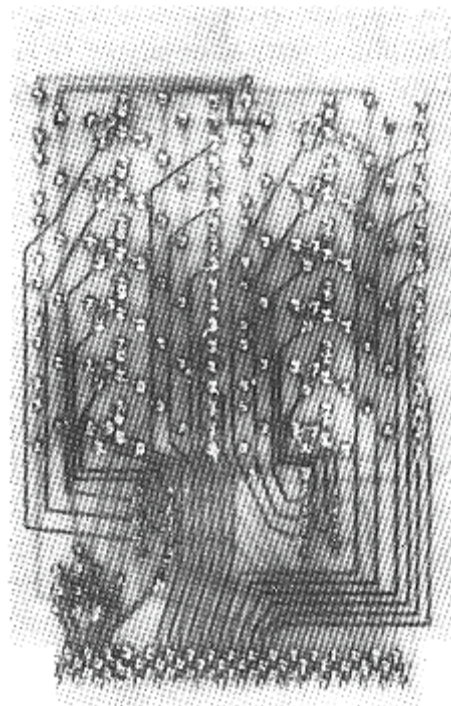
With the advent of the transistor and the demand by the military for smaller equipment, design engineers set out to miniaturize electronic equipment. In the beginning, their efforts were frustrated because most of the other components in a circuit such as resistors, capacitors, and coils were larger than the transistor. Soon these other circuit components were miniaturized, thereby pushing ahead the development of smaller electronic equipment. Along with miniature resistors, capacitors, and other circuit elements, the production of components that were actually smaller than the space required for the interconnecting wiring and cabling became possible. The next step in the research process was to eliminate these bulky wiring components. This was accomplished with the PRINTED CIRCUIT BOARD (PCB).

A printed circuit board is a flat insulating surface upon which printed wiring and miniaturized components are connected in a predetermined design, and attached to a common base. Figure 2-20 (view A and view B) shows a typical printed circuit board. Notice that various components are connected to the board and the printed wiring is on the reverse side. With this technique, all interconnecting wiring in a piece of equipment, except for the highest power leads and cabling, is reduced to lines of conducting material (copper, silver, gold, etc.) deposited directly on the surface of an insulating "circuit board." Since printed circuit boards are readily adapted as plug-in units, the elimination of terminal boards, fittings and tie points, not to mention wires, results in a substantial reduction in the overall size of electronic equipment.



(A) FRONT SIDE

Figure 2-20A.—A typical printed circuit board (PCB). FRONT SIDE



(B) REVERSE SIDE

Figure 2-20B.—A typical printed circuit board (PCB). REVERSE SIDE

After the printed circuit boards were perfected, efforts to miniaturize electronic equipment were then shifted to assembly techniques, which led to MODULAR CIRCUITRY. In this technique, printed circuit boards are stacked and connected together to form a module. This increases the packaging density of circuit components and results in a considerable reduction in the size of electronic equipment. Since the module can be designed to perform any electronic function, it is also a very versatile unit.

However, the drawback to this approach was that the modules required a considerable number of connections that took up too much space and increased costs. In addition, tests showed the reliability was adversely affected by the increase in the number of connections.

A new technique was required to improve reliability and further increase packaging density. The solution was INTEGRATED CIRCUITS.

An integrated circuit is a device that integrates (combines) both active components (transistors, diodes, etc.) and passive components (resistors, capacitors, etc.) of a complete electronic circuit in a single chip (a tiny slice or wafer of semiconductor crystal or insulator).

Integrated circuits (ICs) have almost eliminated the use of individual electronic components (resistors, capacitors, transistors, etc.) as the building blocks of electronic circuits. Instead, tiny CHIPS have been developed whose functions are not that of a single part, but of dozens of transistors, resistors, capacitors, and other electronic elements, all interconnected to perform the task of a complex circuit. Often these comprise a number of complete conventional circuit stages, such as a multistage amplifier (in one extremely small component). These chips are frequently mounted on a printed circuit board, as shown in figure 2-21, which plugs into an electronic unit.

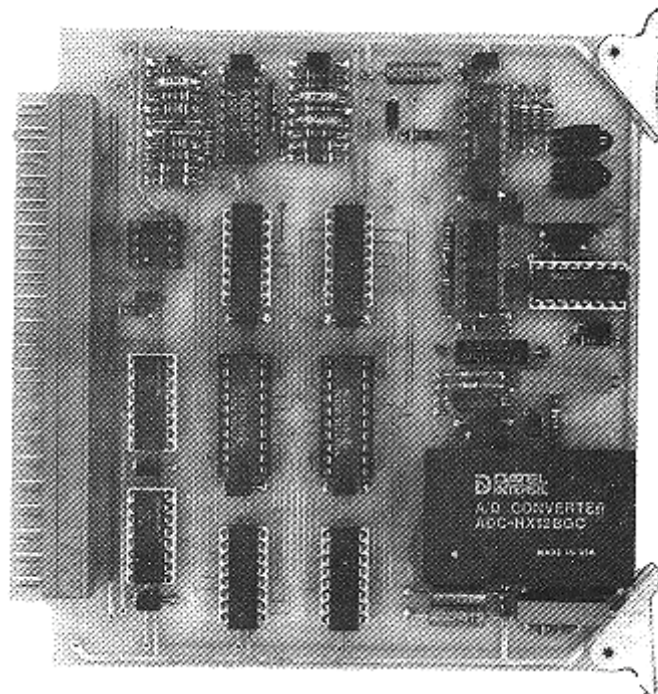


Figure 2-21.—ICs on a printed circuit board.

Integrated circuits have several advantages over conventional wired circuits of discrete components. These advantages include (1) a drastic reduction in size and weight, (2) a large increase in reliability, (3) lower cost, and (4) possible improvement in circuit performance. However, integrated circuits are

composed of parts so closely associated with one another that repair becomes almost impossible. In case of trouble, the entire circuit is replaced as a single component.

Basically, there are two general classifications of integrated circuits: HYBRID and MONOLITHIC. In the monolithic integrated circuit, all elements (resistors, transistors, etc.) associated with the circuit are fabricated inseparably within a continuous piece of material (called the SUBSTRATE), usually silicon. The monolithic integrated circuit is made very much like a single transistor. While one part of the crystal is being doped to form a transistor, other parts of the crystal are being acted upon to form the associated resistors and capacitors. Thus, all the elements of the complete circuit are created in the crystal by the same processes and in the same time required to make a single transistor. This produces a considerable cost savings over the same circuit made with discrete components by lowering assembly costs.

Hybrid integrated circuits are constructed somewhat differently from the monolithic devices. The PASSIVE components (resistors, capacitors) are deposited onto a substrate (foundation) made of glass, ceramic, or other insulating material. Then the ACTIVE components (diodes, transistors) are attached to the substrate and connected to the passive circuit components on the substrate using very fine (.001 inch) wire. The term hybrid refers to the fact that different processes are used to form the passive and active components of the device.

Hybrid circuits are of two general types: (1) thin film and (2) thick film. "Thin" and "thick" film refer to the relative thickness of the deposited material used to form the resistors and other passive components. Thick film devices are capable of dissipating more power, but are somewhat more bulky.

Integrated circuits are being used in an ever increasing variety of applications. Small size and weight and high reliability make them ideally suited for use in airborne equipment, missile systems, computers, spacecraft, and portable equipment. They are often easily recognized because of the unusual packages that contain the integrated circuit. A typical packaging sequence is shown in figure 2-22. These tiny packages protect and help dissipate heat generated in the device. One of these packages may contain one or several stages, often having several hundred components. Some of the most common package styles are shown in figure 2-23.

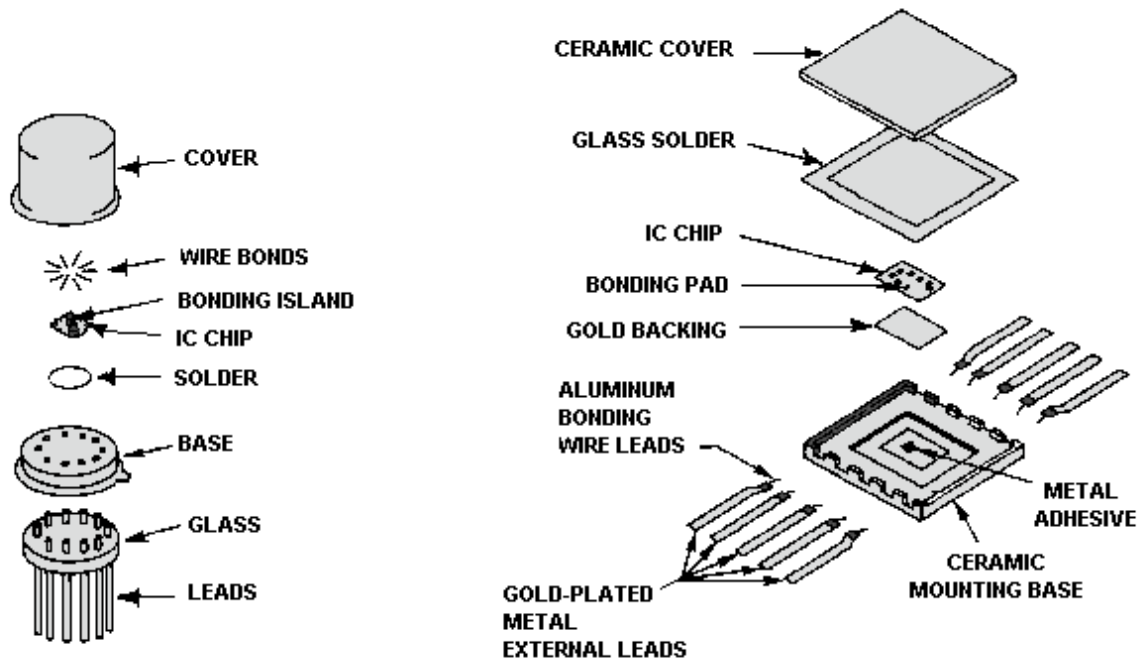


Figure 2-22.—A typical integrated circuit packaging sequence.

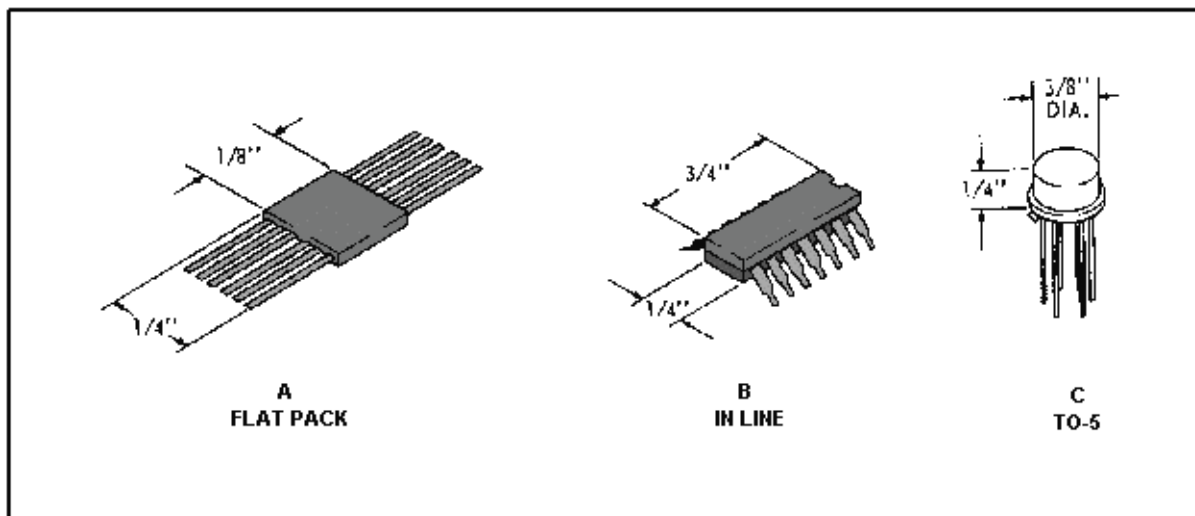


Figure 2-23.—Common IC packaging styles.

The preceding information was presented to give you a brief introduction into integrated circuits. If you wish to pursue this subject further, additional information is available in your ship's or station's library.

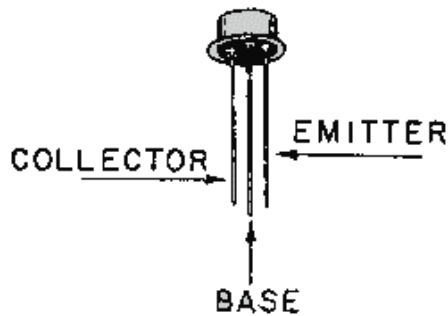
SUMMARY

Now that you have completed this chapter, a short review of the more important points covered in the chapter will follow. This review should refresh your memory of transistors, their theory of operation, and how they are tested with an ohmmeter.

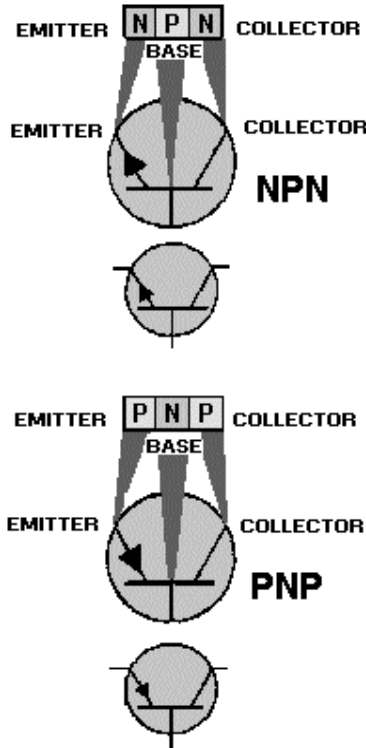
A **TRANSISTOR** is a three or more element solid-state device that amplifies by controlling the flow of current carriers through its semiconductor materials.



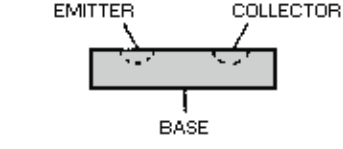
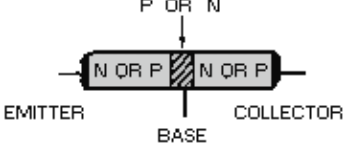
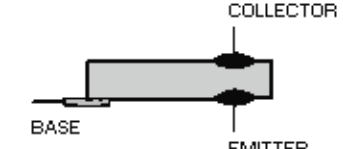
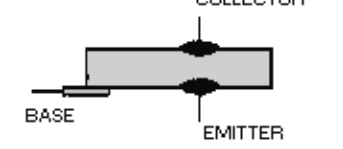
The **THREE ELEMENTS OF A TRANSISTOR** are (1) the **EMITTER**, which gives off current carriers, (2) the **BASE**, which controls the carriers, and (3) the **COLLECTOR**, which collects the carriers.



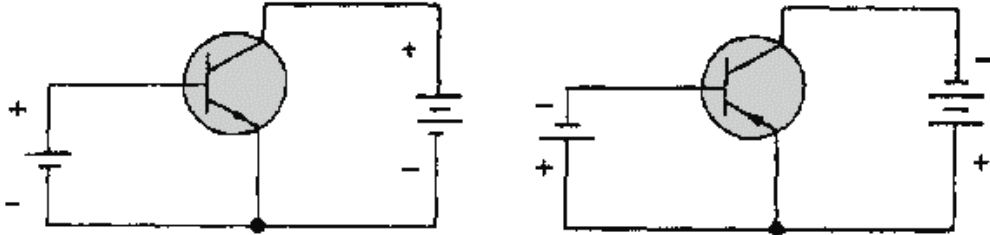
The two **BASIC TYPES OF TRANSISTORS** are the NPN and PNP. The only difference in symbology between the two transistors is the direction of the arrow on the emitter. If the arrow points in, it is a PNP transistor and if it points outward, it is an NPN transistor.



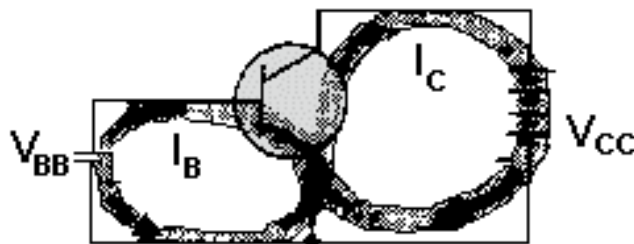
The four **TRANSISTOR MANUFACTURING PROCESSES** are the (1) point contact, (2) grown or rate-grown junction, (3) alloy or fused junction, and (4) diffused junction.

POINT CONTACT (A)	
GROWN JUNCTION OR RATE-GROWN JUNCTION (B)	
ALLOY OR FUSED JUNCTION (C)	
DIFFUSED JUNCTION (D)	

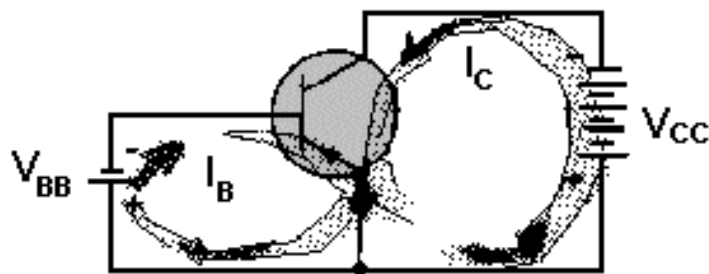
The **PROPER BIASING OF A TRANSISTOR** enables the transistor to be used as an amplifier. To function in this capacity, the emitter-to-base junction of the transistor is forward biased, while the base-to-collector junction is reverse biased.



NPN TRANSISTOR OPERATION is basically the action of a relatively small emitter-base bias voltage controlling a relatively large emitter-to-collector current.



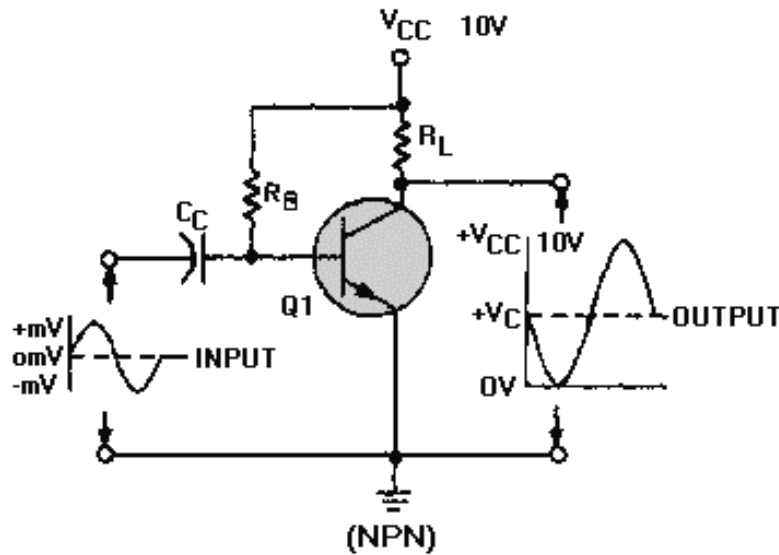
PNP TRANSISTOR OPERATION is essentially the same as the NPN operation except the majority current carriers are holes and the bias batteries are reversed.



AMPLIFICATION is the process of increasing the strength of a signal.

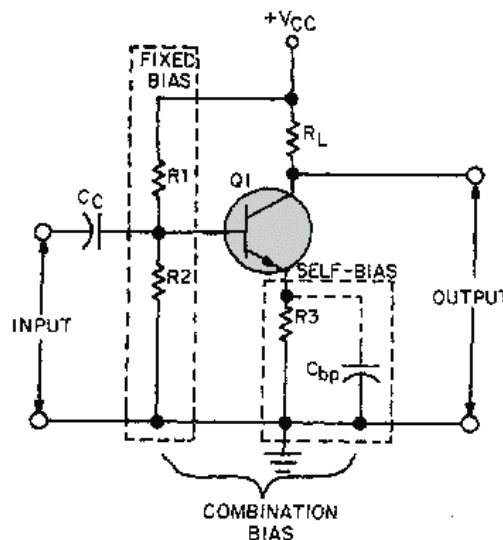
An **AMPLIFIER** is the device that provides amplification without appreciably altering the original signal.

The **BASIC TRANSISTOR AMPLIFIER** amplifies by producing a large change in collector current for a small change in base current. This action results in voltage amplification because the load resistor placed in series with the collector reacts to these large changes in collector current which, in turn, results in large variations in the output voltage.



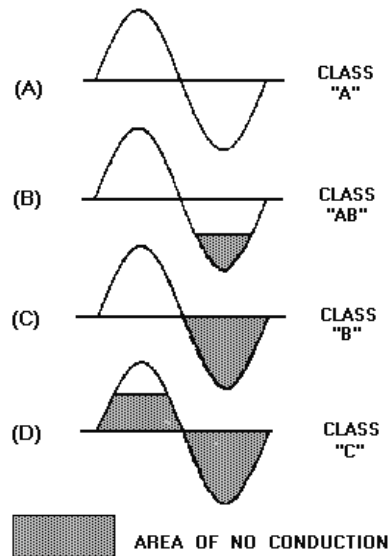
The three types of BIAS used to properly bias a transistor are base-current bias (fixed bias), self-bias, and combination bias.

Combination bias is the one most widely used because it improves circuit stability and at the same time overcomes some of the disadvantages of base-current bias and self-bias.



THE CLASS OF AMPLIFIER OPERATION is determined by the portion of the input signal for which there is an output.

There are four classes of amplifier operations: class A, class AB, class B, and class C.

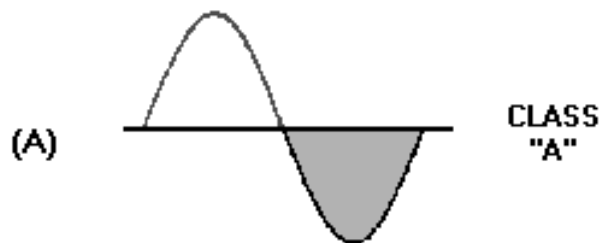


CUTOFF occurs when the base-to-emitter bias prevents current from flowing in the emitter circuit. For example, in the PNP transistor, if the base becomes positive with respect to the emitter, holes are repelled at the emitter-base junction. This prevents current from flowing in the collector circuit.

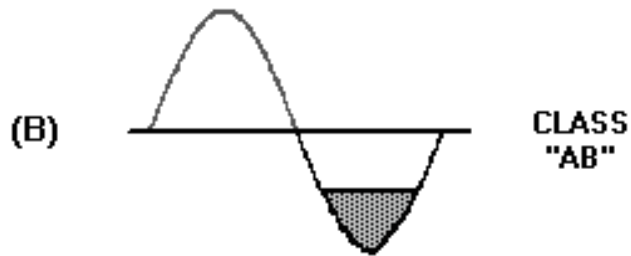
SATURATION occurs in a PNP transistor when the base becomes so negative, with respect to the emitter, that changes in the signal are not reflected in collector-current flow.

CLASS A AMPLIFIERS are biased so that variations in input signal polarities occur within the limits of cutoff and saturation. Biasing an amplifier in this manner allows collector current to flow during the complete cycle (360 degrees) of the input signal, thus providing an output which is a replica of the input but 180 degrees out of phase.

Class A operated amplifiers are used as audio- and radio-frequency amplifiers in radio, radar, and sound systems.

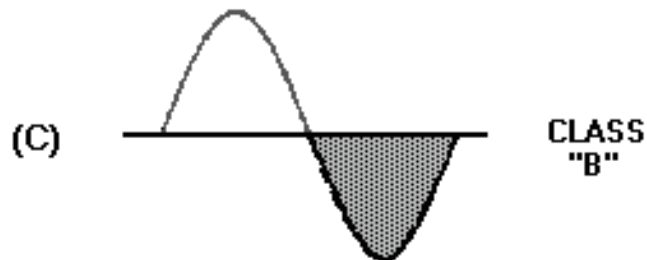


CLASS AB AMPLIFIERS are biased so that collector current is zero (cutoff) for a portion of one alternation of the input signal. Therefore, collector current will flow for more than 180 degrees but less than 360 degrees of the input signal. The class AB amplifier is commonly used as a push-pull amplifier to overcome a side effect of class B operations.



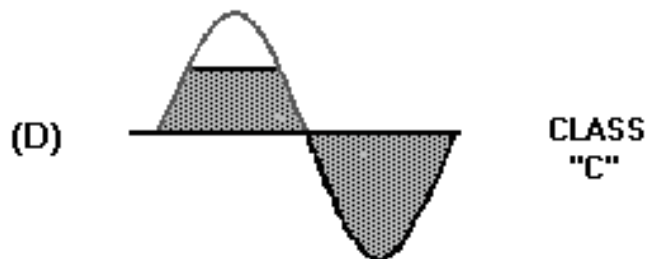
CLASS B AMPLIFIERS are biased so that collector current is cut off during one-half of the input signal. Thus, for a class B operation, collector current will flow for approximately 180 degrees (half) of the input signal.

The class B operated amplifier is used as an audio amplifier and sometimes as the driver- and power-amplifier stage of transmitters.



CLASS C AMPLIFIERS are biased so that collector current flows for less than one-half cycle of the input signal.

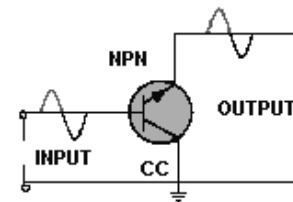
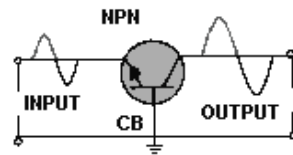
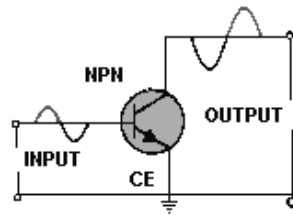
The class C operated amplifier is used as a radio-frequency amplifier in transmitters.



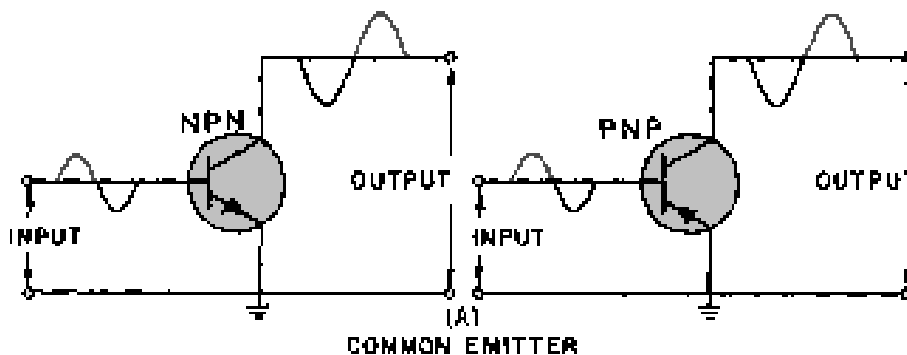
FIDELITY and **EFFICIENCY** are two terms used in conjunction with amplifiers. Fidelity is the faithful reproduction of a signal, while efficiency is the ratio of output signal power compared to the total input power.

The class A amplifier has the highest degree of fidelity, but the class C amplifier has the highest efficiency.

A **TRANSISTOR CONFIGURATION** is the particular way a transistor is connected in a circuit. A transistor may be connected in any one of three different configurations: common emitter (CE), common base (CB), and common collector (CC).

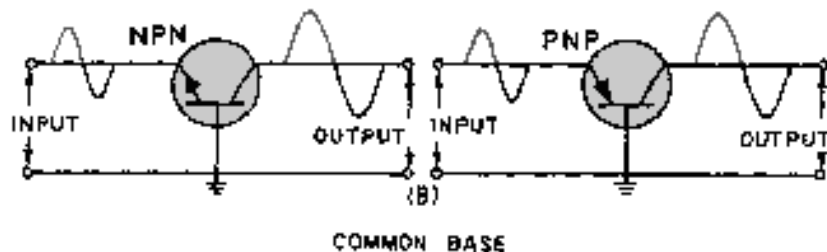


The **COMMON-EMITTER CONFIGURATION (CE)** is the most frequently used configuration in practical amplifier circuits, since it provides good voltage, current, and power gain. The input to the CE is applied to the base-emitter circuit and the output is taken from the collector-emitter circuit, making the emitter the element "common" to both input and output. The CE is set apart from the other configurations, because it is the only configuration that provides a phase reversal between input and output signals.



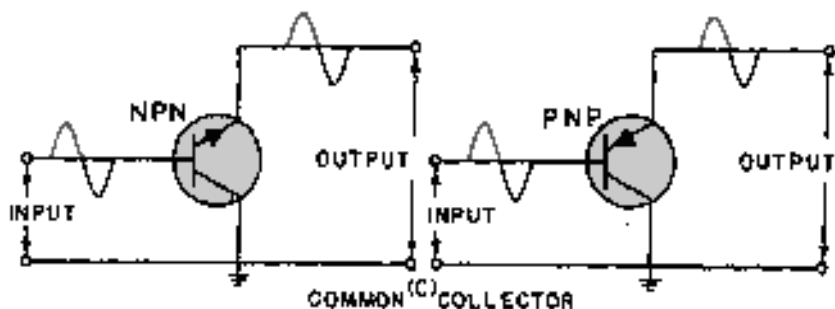
The **COMMON-BASE CONFIGURATION (CB)** is mainly used for impedance matching, since it has a low input resistance and a high output resistance. It also has a current gain of less than 1.

In the CB, the input is applied to the emitter, the output is taken from the collector, and the base is the element common to both input and output.



The **COMMON-COLLECTOR CONFIGURATION (CC)** is used as a current driver for impedance matching and is particularly useful in switching circuits. The CC is also referred to as an emitter-follower and is equivalent to the electron-tube cathode follower. Both have high input impedance and low output impedance.

In the CC, the input is applied to the base, the output is taken from the emitter, and the collector is the element common to both input and output.



GAIN is a term used to describe the amplification capabilities of an amplifier. It is basically a ratio of output to input. The current gain for the three transistor configurations (CB, CE, and CC) are ALPHA (α), BETA (β), and GAMMA (γ), respectively.

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

The **TRANSISTOR CONFIGURATION COMPARISON CHART** gives a rundown of the different properties of the three configurations.

AMPLIFIER TYPE	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
INPUT/OUTPUT PHASE RELATIONSHIP	0°	180°	0°
VOLTAGE GAIN	HIGH	MEDIUM	LOW
CURRENT GAIN	LOW(α)	MEDIUM(β)	HIGH(γ)
POWER GAIN	LOW	HIGH	MEDIUM
INPUT RESISTANCE	LOW	MEDIUM	HIGH
OUTPUT RESISTANCE	HIGH	MEDIUM	LOW

TRANSISTOR CHARACTERISTICS are usually presented on specification sheets. These sheets usually cover the following items:

1. The kind of transistor.
2. The absolute maximum ratings of the transistor.
3. The typical operating values of the transistor.
4. Additional engineering/design information.

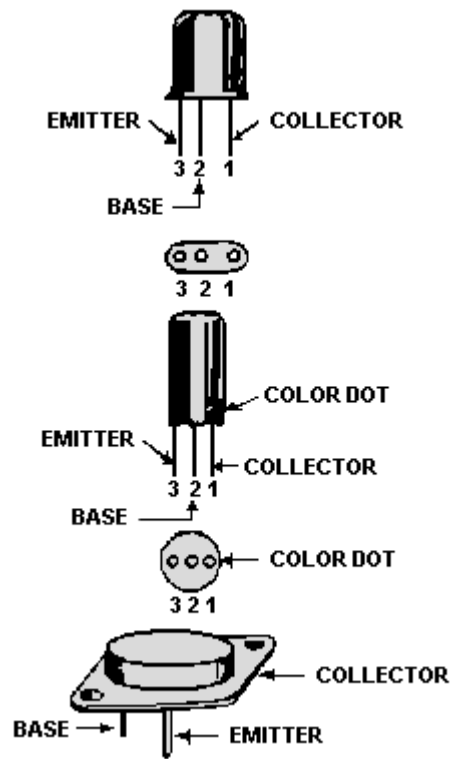
TRANSISTORS ARE IDENTIFIED by a Joint Army-Navy (JAN) designation printed directly on the case of the transistor. If in doubt about a transistor's markings, always replace a transistor with one having identical markings, or consult an equipment or transistor manual to ensure that an identical replacement or substitute is used.

2	N	130	A
NUMBER OF JUNCTIONS (TRANSISTOR)	SEMI-CONDUCTOR	IDENTIFICATION NUMBER	FIRST MODIFICATION

TESTING A TRANSISTOR to determine if it is good or bad can be done with an ohmmeter or transistor tester or by the substitution method.

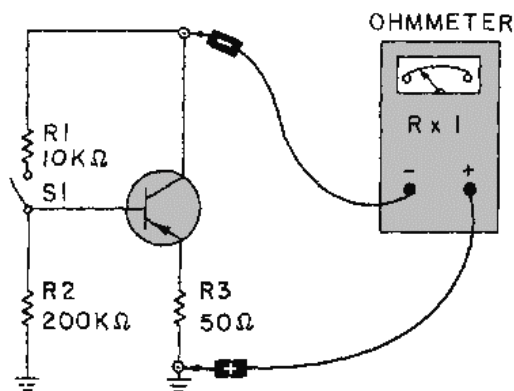
PRECAUTIONS should be taken when working with transistors since they are susceptible to damage by electrical overloads, heat, humidity, and radiation.

TRANSISTOR LEAD IDENTIFICATION plays an important part in transistor maintenance because before a transistor can be tested or replaced, its leads must be identified. Since there is NO standard method of identifying transistor leads, check some typical lead identification schemes or a transistor manual before attempting to replace a transistor.

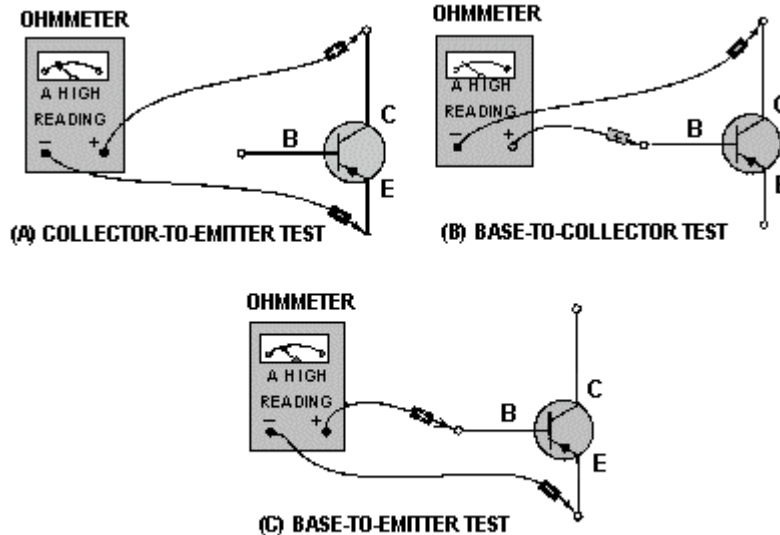


A **TRANSISTOR GAIN TEST** can be made using an ohmmeter and a simple test circuit. The principle behind this test lies in the fact that little or no current will flow in a transistor between emitter and collector until the emitter-base junction is forward biased.

A 10-to-1 resistance ratio in the test between meter readings indicates normal gain.



TRANSISTOR JUNCTION RESISTANCE TEST can also be made using an ohmmeter by measuring the base-emitter, base-collector, and collector-emitter forward and reverse resistances.



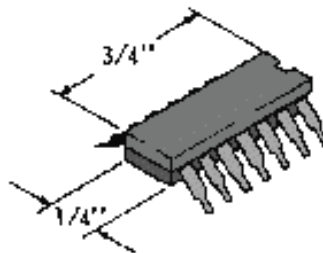
NOTE: Reversing the meter leads will give a low reading.

MICROELECTRONICS is a broad term used to describe the use of integrated circuits to miniaturize electronic equipment.

A **PRINTED CIRCUIT BOARD (PCB)** is a flat, insulating surface upon which printed wiring and miniaturized components are connected in a predetermined design and attached to a common base.

MODULAR CIRCUITRY is an assembly technique in which printed circuit boards are stacked and connected together to form a module. This technique increases the packaging density of circuit components and results in a considerable reduction in the size of electronic equipment.

An **INTEGRATED CIRCUIT** is a device that integrates (combines) both active components (transistors, diodes, etc.) and passive components (resistors, capacitors, etc.) of a complete electronic circuit in a single chip.



The two basic types of ICs are the **HYBRID** and the **MONOLITHIC**.

In the **MONOLITHIC IC**, all elements (resistors, transistors, etc.) associated with the circuit are fabricated inseparably with a continuous piece of material (called the substrate).

In the **HYBRID IC**, the passive components (resistors, capacitors) are deposited onto a substrate (foundation) made of glass, ceramic, or other insulating material. Then the active components (diodes, transistors) are attached to the substrate and connected to the passive components using fine wire.