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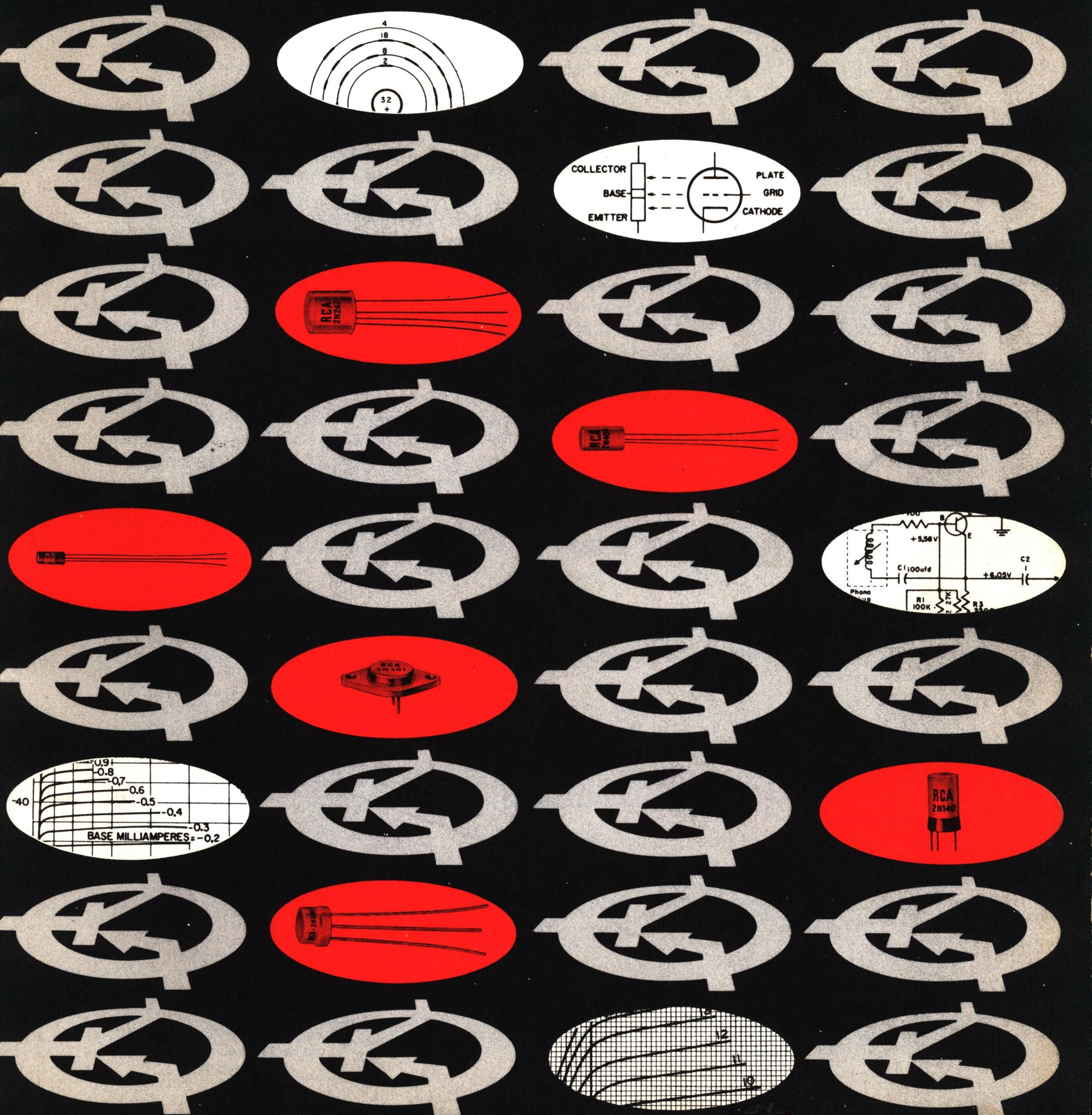
TRANSISTOR FUNDAMENTALS & APPLICATIONS



TRANSISTOR FUNDAMENTALS AND APPLICATIONS

by

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Contents

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TRANSISTOR FUNDAMENTALS

2-1 Introduction

The development of many new inventions in the field of electronics is perhaps not startling to us. One new invention after another has led us to believe that this is the normal way of advancement of the Electronics Industry. We have accepted these inventions and proved to ourselves how they operate by applying our knowledge of basic theory. However, transistors are an entirely new concept and require more than just basic electronics to understand their operation. The invention of the transistor in 1948 was not accepted as just a routine development but an achievement destined to make electronics history and leave a lasting impression on the future development of the Electronics Industry.

The transistor has many superiorities when compared to the vacuum tube. Transistors are generally housed in tiny cylinders less than an inch long. They weigh just a fraction of an ounce, have no filaments, consume very little power, have long operating lives, are solid in construction, extremely rugged and free from microphonics. In addition, transistors have no warm up period. They can be made impervious to the weather and in special applications can even operate under water. Their associated circuitry is greatly simplified. They have the ability to oscillate or amplify, serve as an electronic switch, mixer and modulator as well as a detector.

Engineers are designing new products to make use of the advantages offered by transistors. Although there are many types of transistors offered by the leaders of the Electronic Industry, a few of the more popular types are illustrated in Figure 2-1. It is the intent of this lesson to familiarize you with the theory of operation and characteristics of transistors.

2-2 Transistor Physics

The study of the transistor can best begin by reviewing the structure of matter. Everything about us is composed of matter. Matter may appear in various states such as liquid or solid. We can best describe matter as that substance of which any physical object is composed.

Take water for example. If we were to repeatedly divide a given quantity of water until we had the smallest amount of water and still not change its *chemical characteristics*, we would have one molecule of water. A *molecule* is, therefore, the smallest amount of a given substance. The single molecule of

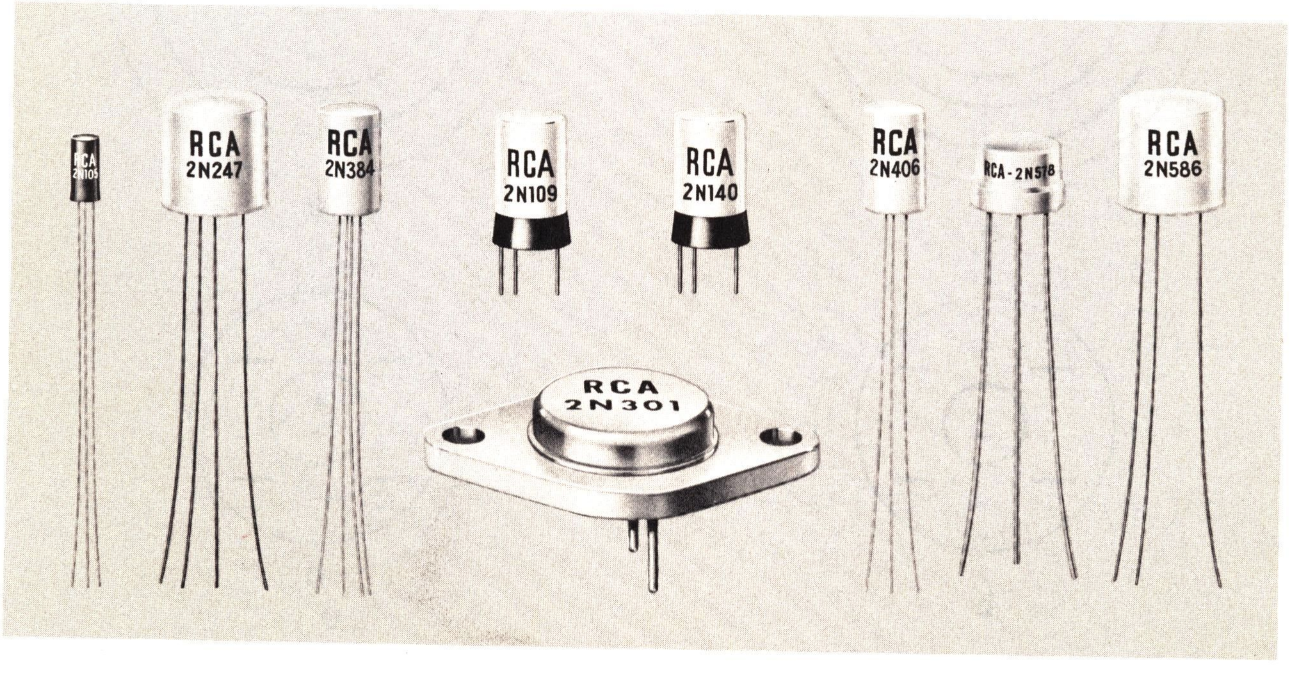


FIGURE 2-1

water can be further divided into *elements* of oxygen and hydrogen. The smallest subdivision of an element is called an *atom;* therefore, the molecule of water can be split into two atoms of Hydrogen and one atom of Oxygen. In the study of transistors we will be dealing with atoms of germanium, silicon, antimony, arsenic, aluminum and gallium. It will be necessary for us to consider the atomic structure of these atoms.

The Germanium Atom—Germanium is one of the elements most commonly used in the manufacture of transistors. A germanium atom is graphically illustrated in Figure 2-2 (a). It consists of a *nucleus* in the center and tightly bound *electrons* surrounding it. Upon closer examination it can be seen that the nucleus is composed of 32 *protons* which constitute the principal part of its mass. These protons exhibit a positive charge of electricity.

The nucleus is surrounded by 32 electrons which rotate in fixed orbits. The four electrons in the outer ring are not as tightly bound to the nucleus as those electrons in the inner rings. The electrons in this outer ring are called *valence electrons.* We are mainly concerned with the valence electrons and therefore, we can simplify the diagram of the germanium atom as shown in Figure 2-2 (b). Here we show a net charge of (+) four in the nucleus which is the total number of protons in the nucleus, minus the tightly bound electrons.

The Silicon Atom—Silicon is another element used in the construction of transistors. In Figure 2-3 (a) a silicon atom is illustrated. There are 14 protons in its nucleus and 10 tightly bound electrons surrounding it. The valence electrons are shown in the outer ring and as in the germanium atom, there are four.

The simplified diagram of a silicon atom is illustrated in Figure 2-3 (b) showing only the net charge on the core and the valence electrons. You will notice it looks exactly like the germanium atom. In fact, germanium or silicon can be used equally well in the making of transistors.

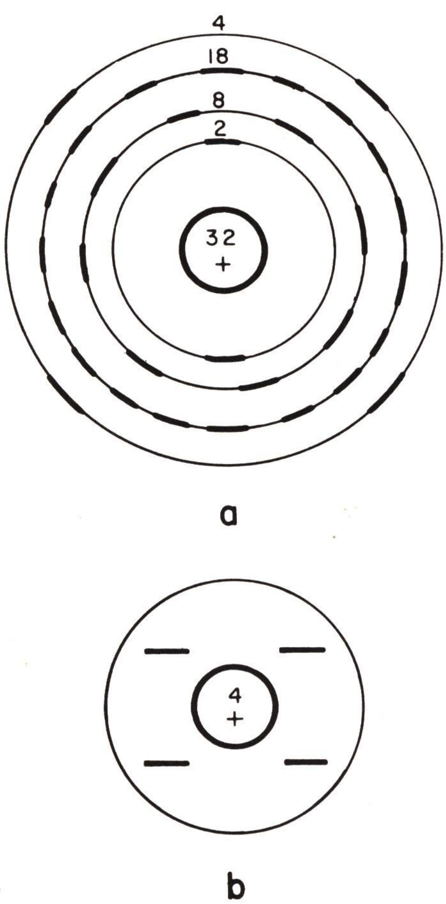


FIGURE 2-2

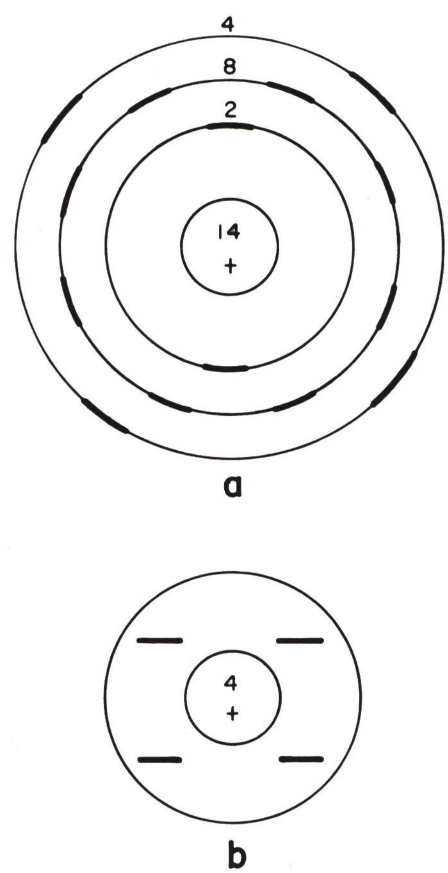


FIGURE 2-3

Atoms of Several Substances

We mentioned earlier that antimony and arsenic, in addition to germanium and silicon, can be used in the making of transistors. In Figure 2-4 (a) are the simplified diagrams of these elements. Note that there are 5 valence electrons for these elements and a net charge of 5 protons. It is important at this time to realize that the number of valence electrons may differ for various elements.

The final two elements with which we shall deal are aluminum and gallium. In Figure 2-4 (b) we can see that there are 3 valence electrons and a net charge of 3 protons in the nucleus. We shall see shortly how these atoms of various valences are put to use in the making of transistors.

Crystal Structures—Certain substances have the ability to take on a very stable crystalline form. The most popular crystalline substance is the diamond. In this crystalline form valence rings of adjacent atoms interlock with each other. This action of binding the valence rings together is known as the formation of *covalent bonds*. Germanium also has the ability to form covalent bonds. Figure 2-5 shows the plan by which a pure germanium crystal is formed. Upon examination of the structure you can see that electrons of neighboring atoms interlock with one another.

Keeping in mind the structure of the atom, specifically the valence electrons, we can say whether a particular element is classified as a conductor or insulator by the degree of difficulty with which the electrons can be dislodged from the outer ring. Those elements in which the electrons can not be dislodged easily are called *insulators*. Contrary to this, those elements in which the electrons can be dislodged easily are good conductors. An element which falls somewhere between is a *semi-conductor*. Semi-conductors are the basic materials of which transistors are made.

Semi-Conductors—Two semi-conductors often used for transistors are germanium and silicon. For transistor action, however, it is necessary to control the electrical properties of the semi-conductor material. This control is achieved by the addition of minute quantities of impurities. The impurity can be any of several elements such as antimony, arsenic, aluminum or gallium. The ratio of impurity to germanium need be only 1 part to 10 million. Depending on the type of impurity used, two types of

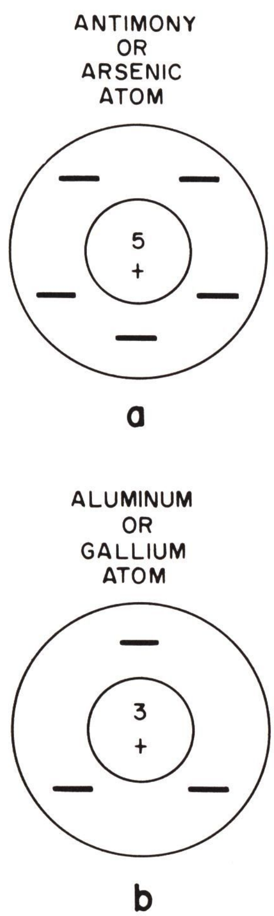


FIGURE 2-4

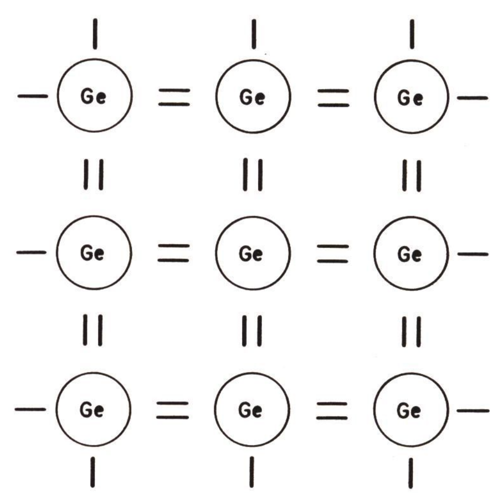


FIGURE 2-5

semi-conductors will result; namely N-type or P-type.

N-Type Germanium (donors)—Impurities such as arsenic or antimony, having five electrons in their valence ring, may be added to germanium. Four valence electrons of the impurity atoms form covalent bonds with their neighboring germanium atoms.

The fifth electron is free to drift through the crystal structure. The effect of adding arsenic or antimony to the germanium or silicon crystal is illustrated in Figure 2-6. Impurities that have a valence of five are called *pentavalent-type* impurities or *donors* because they donate electrons to the semi-conductor crystal.

If we were to connect a battery across this type of semi-conductor, conduction takes place. The free electron in the semi-conductor is attracted by the positive potential and enters the positive terminal of the battery as shown in Figure 2-7. Simultaneously, an electron leaves the negative terminal of the battery and enters the semi-conductor. Thus, a continuous flow of electrons is maintained from the negative to positive terminal as long as the battery potential remains. This type of semi-conductor is called N-type.

P-Type Germanium (acceptors)—A second method of modifying a semi-conductor is by the addition of aluminum or gallium to germanium. In our discussion of elements we noticed that the aluminum and gallium atoms had a valence of three. Remember that the aluminum or gallium atom has one less valence electron than does the germanium or silicon atom. Therefore, one covalent bond is incomplete, resulting in a deficiency of an electron or the presence of a "hole." This is illustrated in Figure 2-8. Impurities that create a hole in germanium or silicon are *trivalent*, meaning a valence of three and are called *acceptors* because they take electrons from the germanium crystal. This type of semi-conductor with acceptor impurities is termed *P-type* germanium.

Let us examine how conduction takes place in a P-type semi-conductor. Figure 2-9 (a) illustrates a piece of P-type semi-conductor. The hole is shown near the center of the semi-conductor. In reality it may be located any place in the semi-conductor, but for simplicity let us have it exist in the center. A battery is

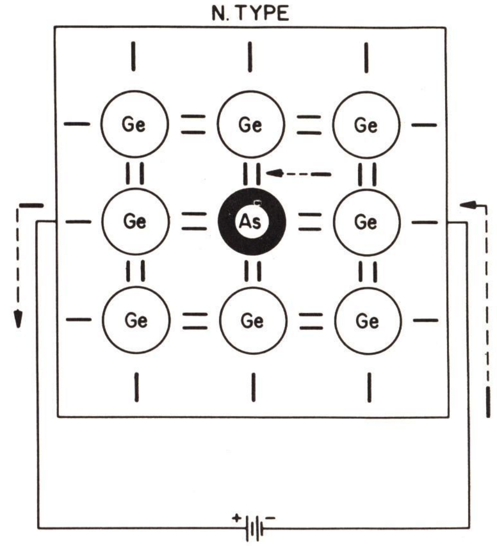


FIGURE 2-7

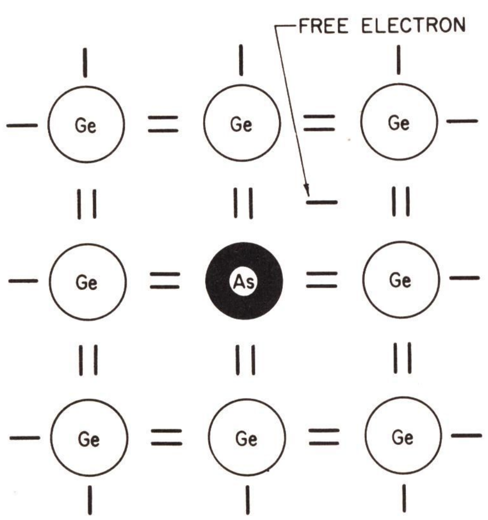


FIGURE 2-6

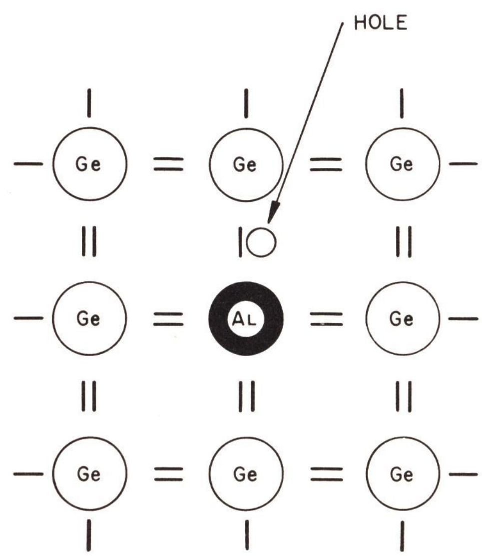


FIGURE 2-8

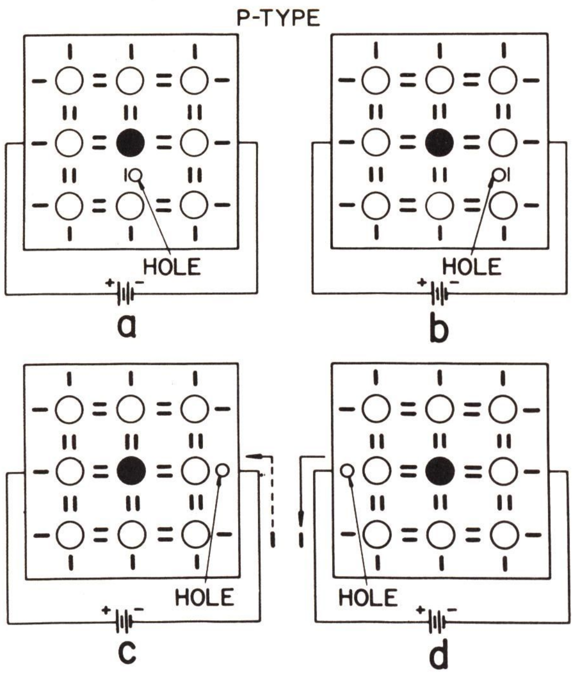


FIGURE 2-9

also shown. The instant the battery is connected, an electron from an adjacent covalent bond moves from its present position and fills the hole. This action is illustrated in Figure 2-9 (b). The movement of this valence electron creates a vacancy in the covalent bond it just left. Once again an electron from a covalent bond nearer the negative terminal moves out of the bond and fills the hole. This action is illustrated in Figure 2-9 (c). The hole is now located on the extreme end of the semi-conductor. In this position there is room for an electron from the supply (negative terminal) to enter the semi-conductor and fill the hole. The instant an electron enters the semi-conductor from the battery an electron from a covalent bond nearest the positive terminal of the battery leaves the semi-conductor and enters the positive terminal of the battery. The removal of this electron from a covalent bond results in the formation of a hole. An electron must leave the semi-conductor in order to maintain the *original characteristic*. That is to have a deficiency of one electron. This action is illustrated in Figure 2-9 (d). It is possible for conduction to take place within the P-type semi-conductor because by the application of an external supply (battery), valence electrons are made to move into the hole made by the preceding movement of the valence electrons from an adjacent covalent bond. This process is in effect as though the hole was moving toward the negative battery potential. Actually it is the valence electrons that are moving, however, for ease of explanation we will consider hole movement in preference to electron movement in P-type semi-conductors.

Now we have two types of semi-conductors, the N-type and the P-type. The N-type is formed by a donor when arsenic or antimony joins the crystal structure in which electrons are the principal current carriers. The P-type semi-conductor is formed when an acceptor such as aluminum or gallium joins the crystal structure. In this instance holes are the principal current carriers.

Intrinsic Germanium—Absolutely pure germanium or germanium having an equal number of donor and acceptor atoms, has an intrinsic characteristic. Conduction in this type of semi-conductor can only take place if the covalent bonds are broken down by external energy in the form of heat or light. Very pure germanium exhibits some intrinsic conductivity at normal room temperature.

2-3 The PN Junction

The electrons or holes in semi-conductors of either N or P type are constantly on the move or drifting about in an irregular manner. This intrinsic activity takes place without the presence of an external potential. As we mentioned in discussing the manufacture of N-type semi-conductors, the impurity atom is of the pentavalent type. Keep in mind that the nucleus of the impurity atom is +5 and there are a total of 5 electrons surrounding the impurity atom. This is equal in number to the nucleus and, consequently, the impurity atom exhibits no charge. But this is not always the condition since the excess electron is always on the move.

Now consider the excess electron having moved from its present association with the impurity atom. This time the charge of +5 in the nucleus cannot be equaled by the 4 valence electrons surrounding it. Therefore, the impurity atom takes on a charge of +1. It can be seen then, that as long as the electron is associated with the impurity atom, the atom exhibits no charge and as soon as the electron moves away, the impurity atom takes on a +1 charge.

In the P-type semi-conductor there is a similar activity going on. The introduction of impurity atoms of the trivalent type into germanium results in a deficiency of an electron or the formation of a hole. Once again this hole is not fixed in the crystal structure but *effectively* moves about. In considering the trivalent impurity atom, we know it has a charge of +3 in its nucleus. But because of its thieving nature it takes an electron from a neighboring valence bond to add to its own 3 valence electrons; as a result there is one more electron than necessary to satisfy the +3 charge on the nucleus. The end result is that the impurity atom takes a —1 charge. As long as the hole is associated with the impurity atom, the atom exhibits no charge and as soon as the hole is filled, the impurity atom takes on a —1 charge.

Although this activity is going on within the semi-conductor without an applied potential, the total mass of the N or P type semi-conductors *do not* exhibit a charge. That is, we cannot measure a plus or minus charge on either type.

Keeping this in mind, let us form a piece of germanium with P-type semi-conductor on one end and N-type on the other. This is illustrated in Figure 2-10 and shows the free holes in the P-region and free electrons in the N-region. The area in the center is designated as the P-N Junction. It might appear at first that some of the free electrons would inadvertently diffuse across the junction, but because of the negative charge exhibited by the fixed impurity atoms in the P-region, they are repelled as illustrated in Figure 2-11. This is caused by the simple fact that unlike charges attract and like charges repel. The free holes in the P-region remain there for the same reason. That is, the fixed donor atoms in the N-region exhibit a positive charge, thus repelling the holes. The potential which exists at the junction because of the unlike charges on either

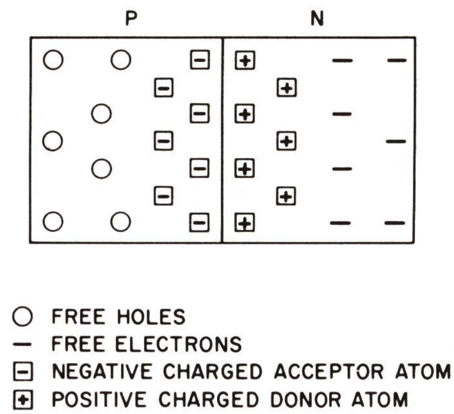


FIGURE 2-11

side is commonly called the *potential gradient* or *potential energy* barrier.

Current Flow—Let's connect a battery across a P-N junction as illustrated in Figure 2-12, and examine the effects. The holes will move to the left toward the negative potential of the battery. Simultaneously, the electrons will move to the right toward the positive terminal of the battery as illustrated in Figure 2-12. This movement of holes and electrons effectively increases the potential barrier at the junction and there is less chance for electron flow through the P-N junction. We can, therefore, conclude that the resistance to current flow has been increased. The battery connected in this manner is sometimes referred to as *reverse bias.*

Now let us take the same P-N junction and reverse the external battery connections. That is, connect the positive potential to the P-region and the negative potential to the N-region. This is illustrated in Figure 2-13. This method of connection effectively decreases the potential barrier at the junction and decreases the resistance to current flow.

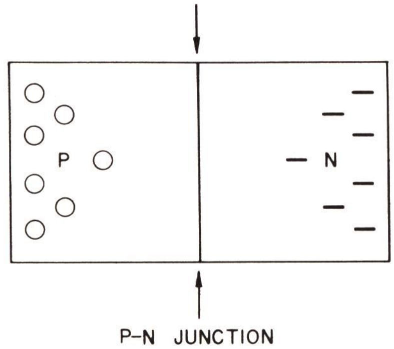


FIGURE 2-10

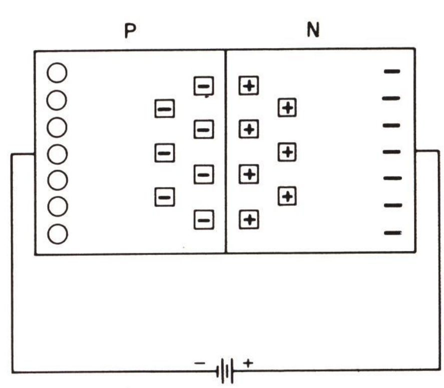


FIGURE 2-12

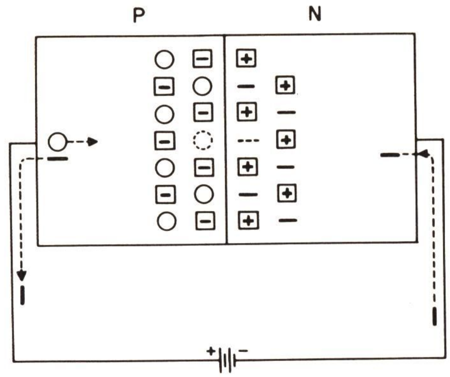


FIGURE 2-13

The electrons present in the N-region move toward the junction due to the negative potential of the battery. Some of the electrons are forced across the junction and enter the P-region where they combine with existing holes. For each combination, a covalent bond in the P-region nearest the positive terminal of the battery breaks down and the liberated electron enters the positive battery terminal. This action creates a new hole which moves toward the junction. Simultaneously, for each electron that combines with a hole in the P-region, another electron enters the N-region from the negative terminal of the battery and moves toward the junction. The total current flowing through the semi-conductor material is composed of electron flow in the N-region and hole flow in the P-region. The battery connected in this manner is sometimes referred to as *forward bias.*

It is obvious now that the junction formed by the N and P type semi-conductors is capable of rectification. If an A/C signal were applied across the P-N junction, as illustrated in Figure 2-14, current would flow during the positive half cycle and there would be little or no current flow during the negative half cycle. Therefore, the junction formed by the combination of N and P type semi-conductors is an effective rectifying device and is commonly referred to as a *junction diode.*

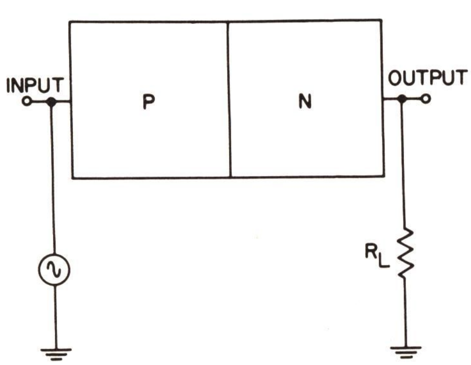


FIGURE 2-14

2-4 The PNP and NPN Junction Transistor

Although there are many variations of a junction transistor, we can easily understand their operation if we consider them being assembled as a sandwich. The outside layers are relatively thick as compared to the very thin center layer. The important fact being that the semiconductor material is used alternately, such as NPN or PNP. These types are represented by the illustrations in Figure 2-15. The leads are identified as the emitter, collector and base.

NPN Transistor Action—The transistor illustrated in Figure 2-16 is of the NPN type. It is impossible for either holes or electrons to overcome the potential barriers formed at the two junctions. Consequently, no current flow is possible without the application of an external voltage source.

Now let us take the NPN transistor and connect the external voltage sources as illustrated in Figure 2-17. After studying the P-N junction we know that battery A connected as shown, will in effect, reduce the potential barrier between the emitter and base regions. Also, we know that battery B, connected as shown, will in effect increase the potential barrier between the base and collector regions. This battery arrangement will permit electrons to flow from the emitter into the base region. But because the base region is so very thin, most of the electrons will not combine

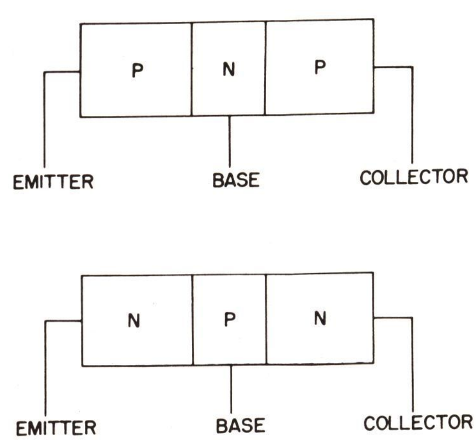


FIGURE 2-15

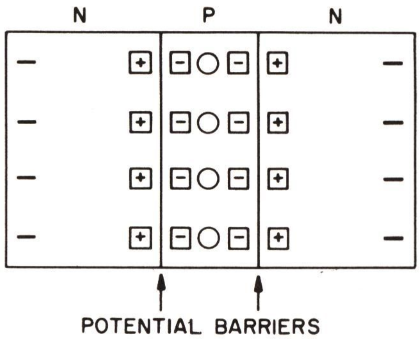


FIGURE 2-16

with the holes in this region but will pass into the collector region. This electron passage is possible due to the fact that voltage source B, connected across the second P-N junction, is of such polarity that it favors the entrance of electrons from the base to the collector. Once in the collector (N-region), the electrons are attracted to the positive collector electrode, thereby completing their passage through the transistor.

Now let's see what takes place when an A/C signal is applied to the emitter as shown in Figure 2-18. When the signal swings positive, the potential barrier increases, thereby reducing electron flow through the emitter. When the negative half cycle of the signal is present at the emitter it tends to reduce the potential barrier, increasing electron flow through the emitter. Again because the base region is so very thin most electrons will pass through without combining with the holes and find entrance to the collector.

PNP Transistor Action—A junction transistor of the PNP type is illustrated in Figure 2-19. It consists of P and N semi-conductors

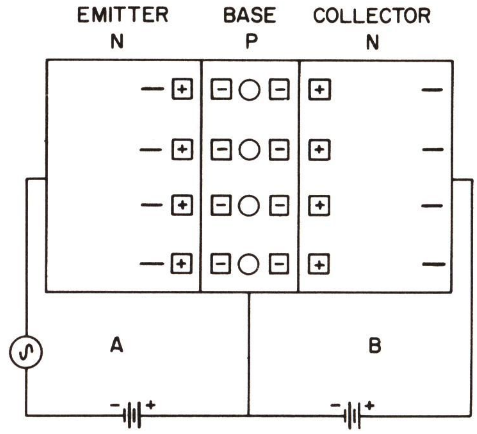


FIGURE 2-18

used alternately. In order to have conduction in such a transistor, it is necessary that the battery polarity to the emitter and collector be opposite to that used by the NPN transistor. With this connection the holes in the emitter region are repelled by the positive potential of the battery toward the PN junction. Since this reduces the potential barrier existing between the emitter and base, the majority of the holes pass through the relatively thin base area (N-region) into the collector region. A small number of holes are lost by combination with electrons in the base region. As each of the remaining holes enters the collector it is filled by an electron emitted by the negative terminal of the battery.

For each hole lost by combination within the base or collector region, an electron from one of the covalent bonds near the emitter electrode enters the positive terminal of the battery, resulting in the formation of a new hole. The new hole moves toward the junction

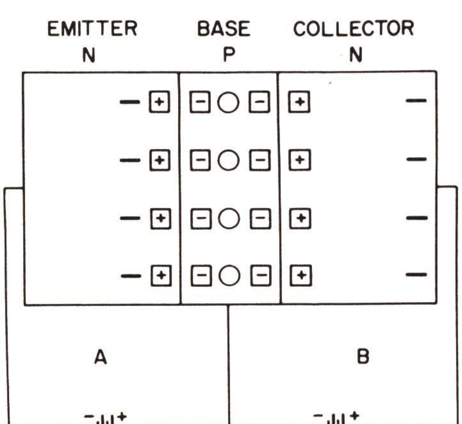


FIGURE 2-17

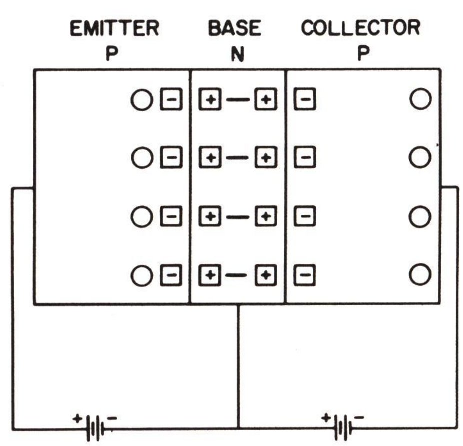


FIGURE 2-19

area, thus maintaining a continuous flow of holes from emitter to collector.

Amplification in a Junction Transistor—Further investigation of conduction in a junction transistor will show that the emitter current is greater than the collector current. For example, let us consider a case where 1 ma of current flows in the emitter circuit as illustrated in Figure 2-20. The base current under this condition will be proportional to the number of hole and electron combinations that take place in the base region; also, this base current will be affected by the amount of voltage applied between the base and collector. Under normal operating conditions the voltages are adjusted so that 5% of the total emitter current will flow in the base circuit, the remaining 95% of the emitter current flows in the collector circuit. From this it can be seen that the collector current will be less than unity as compared to the emitter current. The chart in Figure 2-21 shows the relationship between the collector voltage and current. As indicated by letter A, there will be no flow of current in the collector circuit when the collector voltage is zero. As we increase the collector voltage the collector current will increase linearly until a point of saturation is reached as indicated by the letter B in Figure 2-21. If we further increase the collector voltage the collector current will remain nearly constant. This response curve is very similar to that of the Ip Ep curve of a pentode vacuum tube. Thus, it can be seen that current flow within the collector region is independent of the collector voltage after the point of current saturation has been reached. Therefore, it is desirable to operate the collector circuit at a voltage indicated by the letter C in Figure 2-21.

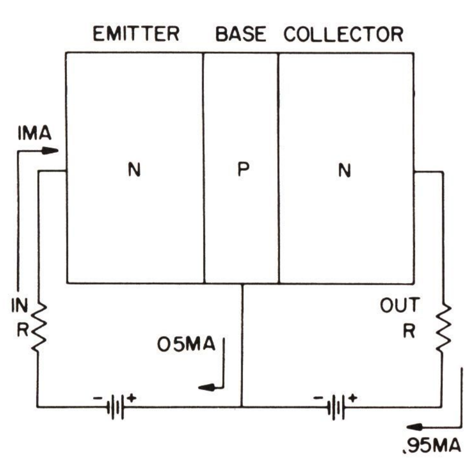


FIGURE 2-20

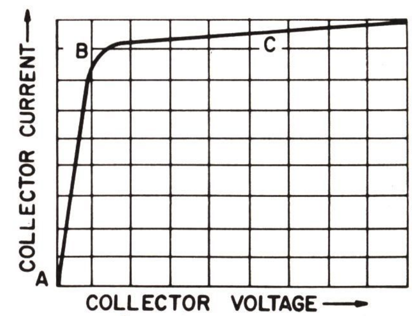


FIGURE 2-21

In order to understand how amplification can take place within a transistor, we must investigate the input and output resistance characteristics of the junction transistor. The battery in Figure 2-20 is connected between the emitter and base with its polarity such that the potential barrier between the emitter and base is greatly reduced. Current readily flows through this junction, thereby reducing the input resistance to the emitter.

The battery connected between the collector and base is of such polarity that the potential barrier between the base and collector is greatly increased. Thus. the output resistance of the collector circuit is very high. Since we have a low input resistance and a high output resistance, voltage amplification can be effected by a junction transistor. Due to this resistance difference, a small voltage change in the emitter circuit will cause a relatively large voltage change in the collector output circuit. This is due to the fact that a small voltage change at the input will cause a large current change within the emitter. The current change in the collector circuit is directly proportional to the current change in the emitter circuit. Since the output resistance of the collector circuit is relatively high, a change in collector current will produce a relatively large voltage change across this output resistance. This action can be closely related to a pentode vacuum tube circuit, where small grid voltage changes produce relatively large plate voltage changes. From the foregoing it can be seen that if we apply a small A/C signal to the input of the transistor, this signal will be amplified in the collector circuit.

Another factor must be taken into consideration. that is, the peak to peak voltage swing at the input of the transistor must not exceed the battery potential connected between the emitter and base; also the peak to peak voltage swing in the collector circuit must not exceed the battery potential between the collector and base. If the A/C swing should exceed either of these battery potentials, the signal will be greatly distorted.

Both NPN and PNP type transistors may be used as amplifiers. The only basic difference is that the battery potentials are reversed when comparing these two types of transistors in their circuit applications. The applications of these transistors will be discussed later.

2-5 The Point Contact Transistor

The point contact transistor is the result of early experimentation with the germanium crystal. The construction of the point contact transistor is illustrated in Figure 2-22. It consists of a piece of N-type semi-conductor to which are attached leads known as the emitter, base and collector. An important fact in the construction of the point contact transistor is the method in which the leads are attached to the piece of semi-conductor material. The base lead as illustrated in Figure 2-23 is a low resistance connection, whereas the emitter and collector leads make contact by the sharp pointed ends of the leads. The emitter and collector leads are high resistance connections.

To understand transistor action in the point contact transistor let us begin by analyzing the emitter portion as illustrated in Figure 2-24. We learned from a previous section that N-type semi-conductor material has an excess of free electrons, and by the application of a potential across the semi-conductor, electrons will flow through the semi-conductor to complete the circuit. Figure 2-24 (a) illustrates a negative potential applied to the emitter and a positive potential applied to the base. Under these conditions electron flow will take place.

Let us change the polarity of the supply battery so that the emitter contact is now positive and the base is negative as illustrated in Figure 2-24 (b). Now the *positive* potential is applied to a small point, rather than being distributed evenly along the entire base area as in Figure 2-24 (a). The emitter now being positive in polarity results in the attraction of free electrons from the N-type semi-conductor. Thus, electron flow takes place. However, because of the *intense concentration of energy* in the vicinity of the emitter, it not only attracts the free electrons present in the semi-conductor but also withdraws valence electrons from the covalent bond structure in the immediate area. This action of removing valence electrons results in the formation of holes. These holes diffuse toward the base which discharges additional electrons to fill them with the result of *increased electron flow.* It can then be seen that as long as the emitter

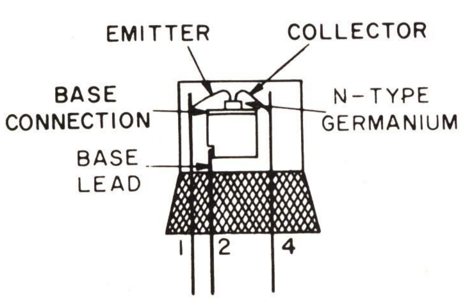


FIGURE 2-22

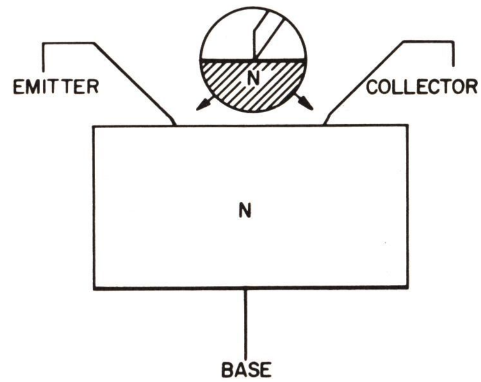


FIGURE 2-23

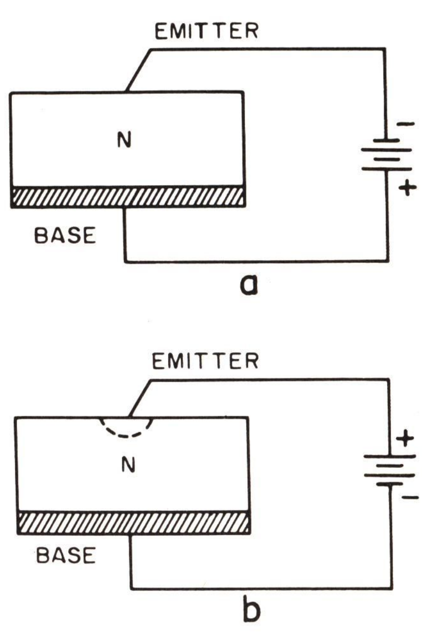


FIGURE 2-24

is negative in polarity there is relatively little electron flow. However, if the emitter is made positive there is the formation of holes due to the *concentration of energy* present at the point contact, which results in an *increase of electron flow*. Rectification, therefore, is possible.

A simplified diagram of a point contact transistor is illustrated in Figure 2-25. Consider the emitter and base as constituting one rectifier and the collector and base another rectifier. Battery A, provides a positive potential to the emitter which effectively biases the emitter in the direction that results in the *greatest* electron flow. The battery B provides a negative potential to the collector which biases the collector in the direction of *least* electron flow. Let us consider what takes place in the point contact transistor with the emitter and collector biased in this manner. Figure 2-26 illustrates the emitter creating holes in its immediate area and in effect creates a space charge consisting of holes. Since the holes were created by virtually pulling an electron from a covalent bond, it is understandable why adjoining electrons want to fill the hole. Since the closest supply of electrons is present at the collector (negative) the holes tend to move toward the negative potential. During their movement toward the collector some holes are filled by electrons, but because of the very close spacing of the emitter and collector a majority of the holes reach the collector. Keep in mind that the collector is biased negatively and consequently, very little electron flow takes place between the collector and base. However, with the presence of the holes in the vicinity of the collector many more electrons can leave the negative terminal of the battery and enter the collector region and fill the holes. Thus, the presence of the holes in the vicinity of the collector causes a marked reduction in the resistance of the collector region which results in an increase in electron flow.

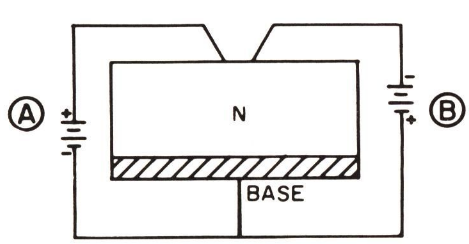


FIGURE 2-25

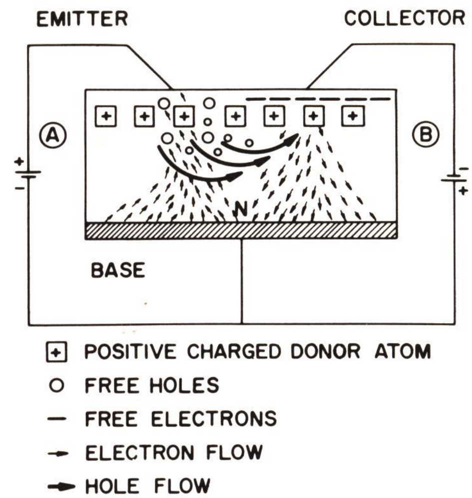


FIGURE 2-26

From the above theory it can be seen how a signal varying in polarity can be fed to the emitter circuit with the result of corresponding holes being formed in the emitter area. These holes in turn control the resistance of the collector region and result in a corresponding change in electron flow in the collector circuit. Because it takes just a small variation in the electron flow in the emitter circuit to *produce* and *control* a greater electron flow in the collector circuit, amplification takes place.

In average point contact transistors, an increase in emitter electron flow of one milliampere will cause an increase in collector electron flow of 2.5 milliamperes. The current gain factor of 2.5 is typical of point contact transistors. This figure may seem low when compared with the amplification factor of a vacuum tube. However, another factor, the input and the output resistance of the transistor plays an important part. The input resistance is approximately 300 ohms, while the output resistance is approximately 20,000 ohms. It can be seen that there is another gain characteristic, namely the resistance gain. The transistor voltage gain equals the current gain times the resistance gain. Therefore, the voltage gain obtainable is comparable to a Hi-Mu vacuum tube.

2-6 Transistor Characteristics

Symbol and Lead Identification—The symbols used for transistors are illustrated in Figure 2-27. The symbol in Figure 2-27 (a) is of the conventional type presently in widespread use. The heavy horizontal line represents the base and the two angular lines repre-

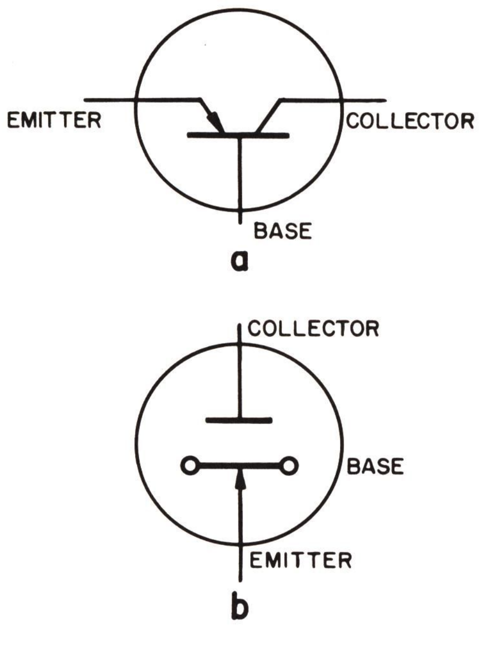


FIGURE 2-27

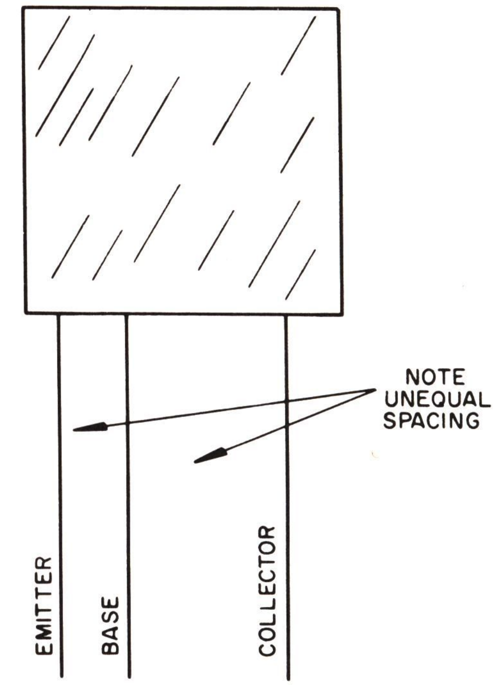


FIGURE 2-28

sent the emitter and collector. The arrow head, drawn on the emitter indicates the direction of *current* flow. This provides an aid in identifying the type of transistor. In the case of a junction transistor of the PNP type, the arrow is drawn pointing toward the base. An NPN type is drawn with the arrow in the opposite direction.

Another symbol used to represent a transistor is illustrated in Figure 2-27 (b). This is perhaps more representative of the actual transistor construction and relationship of the elements in comparison to the vacuum tube symbol. The arrow also shows the direction of current flow in the emitter.

The leads on an actual transistor are readily identified by the position and spacing of the leads. A "standard" transistor is illustrated in Figure 2-28. The base lead is the center lead. The emitter and collector leads are on either side of the base lead. The collector lead can be identified by the larger space existing between it and the base lead.

Methods of Operation—In general, the transistor can be compared to a vacuum tube. The illustration in Figure 2-29 shows the similarities. The base is similar to the grid of the vacuum tube in that they both serve to control electron flow through the unit. The emitter and cathode supply the source of electron flow. The collector of the transistor and the plate of the vacuum tube are similar in that they both are normally part of the output circuit.

The transistor's input and output impedance can be varied by the method in which it is connected in a circuit. Figure 2-30 illustrates the various methods of operating a transistor. A comparable connection of a vacuum tube is shown below each method. In each instance one electrode is common to both the input and output circuits. The common base type is illustrated in Figure 2-30 (a). This type of operation is similar to a vacuum tube used as a grounded grid amplifier. The advantage of using a transistor in this manner is that it has a low input impedance and a high output impedance.

The common collector type is illustrated in Figure 2-30 (b). This is similar to a vacuum tube used as a cathode follower. With a common collector, the impedance characteristics

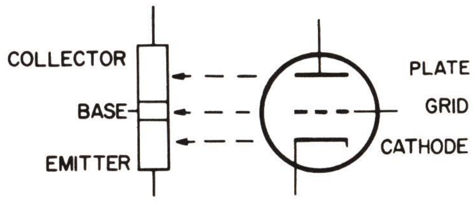


FIGURE 2-29

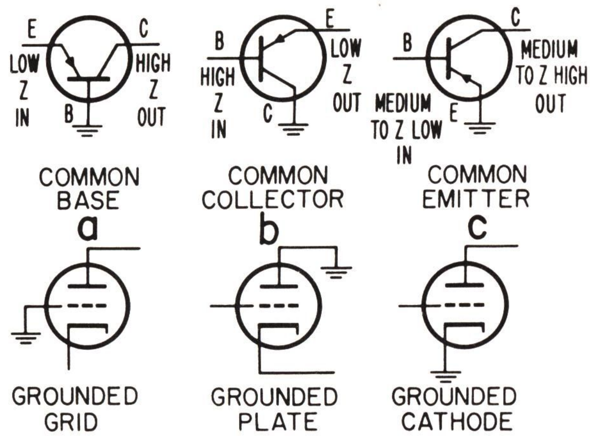


FIGURE 2-30

of the transistor are such that the input now possesses a high impedance and the output a low impedance.

The final method of operation is the common emitter type and is illustrated in Figure 2-30 (c). This is similar to a grounded cathode vacuum tube circuit. The input impedance is medium to low and the output impedance is medium to high. The grounded emitter is generally employed in conventional circuit applications. For use in special circuits the correct impedance match can be made by choosing the proper method of connection. Thus, almost any impedance ratio can be inserted to satisfy the circuit requirements.

Electrical Characteristics — The manufacturer of transistors generally supplies the mechanical and electrical characteristics in the form of a specification sheet. Let us examine the specifications pertaining to an RCA type 2N109 junction transistor.

The manufacturer tabulates the specifications of transistor units in the following categories; general data, maximum rating, typical operating characteristics and characteristic curves.

General data includes the following:

Electrical:

Maximum DC Collector Current for dc collector-to-base voltage of —25 volts with emitter open, and at ambient temperature of 25°C. . .	—10 μ amp
Maximum DC Emitter Current for dc emitter-to-base voltage of —25 volts with collector open, and at ambient temperature of 25°C.	—10 μ amp

Mechanical:

Mounting Position.	any
Maximum Overall Length.	0.697″
Maximum Seated Length.	0.495″
Maximum Diameter.	0.260″
Case.	Metal, Insulated
Envelope Seals.	Hermetic
Base.	Small-Round Linotetrar 3-Pin (JETEC No. E3-25)

Maximum ratings are those values of voltage, current and temperatures that must not be exceeded when operating the units. The values given are important not only to the electronic engineer but also to the service technician. The maximum ratings for the RCA type 2N109 transistor are as follows:

Maximum Ratings:

Peak Collector-to-Base Voltage.	—25 max. volts
DC Collector-to-Base Voltage (for inductive load).	—12 max. volts
Peak Collector Current. .	—70 max. ma
Average Collector Current	—35 max. ma
Peak Emitter Current. . .	70 max. ma
Average Emitter Current	35 max. ma
Collector Dissipation. . . .	50 max. mw
Ambient Temperature (during operation). . . .	50 max. °C
Storage-Temperature Range.	—55 to +85°C

Characteristics:

DC Collector-to-Emitter Voltage	—1 volt
DC Collector Current.	—50 ma
Large-Signal DC Current Transfer Ratio.	70

The voltages are generally given with respect to the base and the values indicated in volts. Current is given in milliamperes or microamperes and the power dissipation values are given in watts or milliwatts.

Typical Operating Characteristics are also given to serve as a guide to the engineer who may be designing equipment or the technician servicing the equipment. The following information is for the RCA type 2N109 transistor. This transistor is used primarily for Class B operation, and the operating characteristics are as follows:

Typical Push-Pull Operation:

DC Collector-to-Emitter Supply Voltage. .	—4.5	—9	volts

DC Base-to-Emitter Voltage	—0.15	—0.15	volt
Peak Collector Current (per transistor)	—35	—40	ma
Zero-Signal DC Collector Current (per transistor)	—2	—2	ma
Max.-Signal DC Collector Current (per transistor)	—11.5	—13	ma
Signal-Source Impedance (base to base)	1500	1500	ohms
Load Impedance (collector to collector)	400	800	ohms
Signal Frequency	1	1	kc
Circuit Efficiency	60	69	%
Power Gain	30	33	db
Total Harmonic Distortion	7	7	%
Max.-Signal Power Output	75	160	mw

Characteristic curves are also included as part of the specification sheet. These curves are similar to the curves furnished for vacuum tubes and serve a similar purpose. A typical curve is illustrated in Figure 2-31.

Temperature Effects—All semi-conductors are subject to temperature limitations. In well designed germanium transistors the maximum rated temperature is approximately 185°F (85°C). In most applications temperatures seldom exceed 150°F, therefore, there is a sufficient margin of safety. In special applications, as in military equipment, it is desirable to operate the equipment over a wide range of temperatures. It is here that the silicon transistor plays an important role. Silicon transistors are available that operate with temperatures of 350°F with no destructive effects.

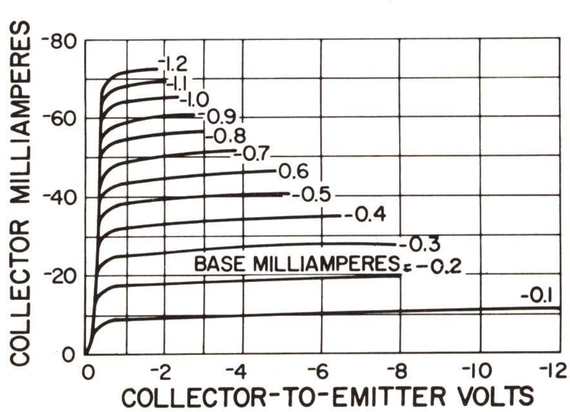


FIGURE 2-31

Frequency Cut-Off—The upper frequency limit of transistors is determined by the time required (transit time) for the electrons to pass from the emitter to the collector. By making the base of the transistor thinner the element of time will be reduced and consequently, a higher frequency cut-off obtained. It is along these lines that research engineers are constantly working.

In order to obtain transistor performance which is equal to the vacuum tube, the maximum operating frequency should be about 20% of the frequency cut-off. Therefore, in applying this rule, it appears that the minimum cut-off frequency for a portable or home radio receiver with an IF of 455 KC is at least 2-2.5 mc. For mixer operation of the broadcast band a cut-off of 8 mc is required. A television VHF RF transistor amplifier operating at 200 mc would need a 1000 mc cut-off frequency. There are commercial transistors available that satisfy the requirements for radio and VHF television receivers.

There are other types of transistors which we will discuss in the next section, some of which are capable of operating at UHF television frequencies.

Reliability—The early transistors were incased in plastic. This afforded protection to the unit. Incased transistors used in hearing aids provided good service for over three years. There are several disadvantages, however, in this method of protection: the plastic units did not stand up well at high temperatures, nor could they survive under extreme moisture conditions. As a result, extensive effort was directed toward the development of hermetically sealed, metal cased units. This method presented new problems; at first it was noticed that some units were subject to abrupt failure in varying percentages due to air leaks. Second, some of the units that were truly sealed, died slowly as the result of the gradual release of internal contaminants. Today, due to experience gained in the past few years, these problems are practically eliminated. To insure the best possible service, accelerated life tests at high temperatures are used to predict long and useful transistor life.

2-7 Types of Transistors

In the past few years the development of transistors has led to many variations in their design and construction. Let us briefly consider the features of various types.

The Alloy-Junction Transistor—The alloy method of constructing a junction transistor is illustrated in Figure 2-32. The base of the transistor is a wafer of N-type semi-conductor. The collector and emitter regions are formed by placing pellets of a trivalent impurity on opposite sides of the N-type wafer and applying heat so that the impurity alloys into the N-type semi-conductor. This alloying process forms regions of semi-conductor material of the P-type which constitute the emitter and collector. Complete control of this process provides separation between the emitter and collector of about .0005 inch which permits a short electron transit time from emitter to collector. In addition, the resistance between the base connection and either the emitter or collector is low because of the relatively thick N-type wafer used. Finally, the various capacitive effects of the emitter and collector are kept to a minimum because of the very small areas of the P-type regions. Transistors made by this process exhibit 12 db of gain at 10 mc and a frequency cut-off of approximately 75 mc. This method of construction is feasible for both PNP and NPN types of transistors.

The Drift Transistor—The high frequency performance of transistors is limited by three basic factors. These are the time it takes for a hole or electron to travel through the base region, the input resistance, and the collector capacitance. The drift transistor structure minimizes these factors and makes possible devices capable of operating at very high frequencies.

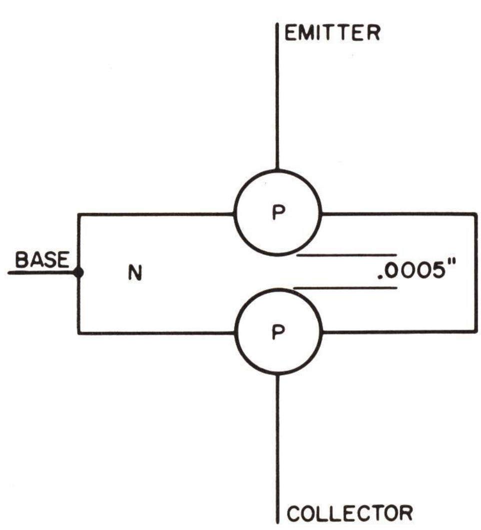


FIGURE 2-32

The method used in a drift transistor to reduce the transit time for a given base dimension is to establish a field within the base region that will directly aid the passage of holes or electrons. This field is established by varying the conductivity of the base region so that the conductivity is high near the emitter and low near the collector. The drift transistor illustrated in Figure 2-33 shows by means of vertical lines the regions of high and low conductivity. The conductivity of the base material is controlled by the distribution of impurity atoms during manufacture. The highest concentration of impurity atoms is near the emitter and the lowest concentration near the collector. In such a non-uniform conductivity distribution, the electron density (in N-type base material, for example) is greatest in the high conductivity region. The electrons tend to drift out of the region of high concentration. As a result, an electric field is set up due to the positive charge on the atoms from which the electrons left.

The positive charge of the drift field tends to keep the remaining electrons near the emitter side of the base. The holes injected by the emitter are accelerated by the drift field toward the collector because of their opposite charge. The drift field reduces the transit time to one-fourth of that of a conventional alloy-junction transistor of the same base dimension. In addition to an improvement in transit time, the high frequency performance is improved because the high conductivity of the base region near the emitter reduces the input resistance. Also, the low conductivity near the collector region results in a low collector capacitance. Thus, the upper frequency limit of the drift transistor is much higher than that of a conventional PNP transistor. These devices are capable of oscillating at frequencies up to 300 mc and are usable as amplifiers at VHF television frequencies.

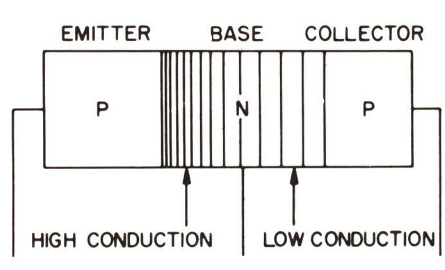


FIGURE 2-33

The Tetrode Transistor—The tetrode transistor derives its name from an additional lead attached to the base region. Thus, there are four leads extending from a tetrode transistor. Figure 2-34 illustrates the tetrode transistor. The additional lead is attached to the base region at a position which is on the side opposite to that of the original base connection. The bias voltages necessary to operate this type of transistor are similar to those required by a conventional NPN type of transistor. The emitter is biased in the direction of greatest electron flow, and the collector is biased in the direction of least electron flow. The fourth lead is biased at a negative potential which is considerably greater than the normal emitter to base potential. The presence of this negative potential restricts the electrons flowing through the base region so they flow through a relatively narrow area of the base region. The flow of electrons is illustrated in Figure 2-34.

The advantage of the use of the tetrode structure is an improvement in high-frequency operation. This improvement is obtained from the reduction of emitter and collector capacitance due to the reduced effective area of each region adjacent to the base region, as well as a reduction in base resistance due to the shorter path travelled by the base current. A limitation of the tetrode is its power handling capabilities. In forcing the electrons to flow in a narrow channel in the base region there is a reduction in the collector current capability. Fortunately, the power requirements for the high frequency stages in many commercial applications are very low. Therefore, this limitation is not of prime importance. A transistor of this type is suitable for use in IF stages of television receivers.

Power Transistors—Along with high current and voltage capabilities, the effective dissipation of heat is one of the prime requirements for a power transistor. In some circuit configurations an increase in transistor temperature will cause a bias point shift resulting in an increase in dissipation and hence increase the device temperature even more. This cycle can continue until "thermal runaway" occurs, damaging the transistor. In properly designed circuits this effect can be minimized. However, unless the heat generated can be removed efficiently, the transistor junction temperature will rise to an undesirably high level and, in time, the performance of the transistor will be significantly degraded.

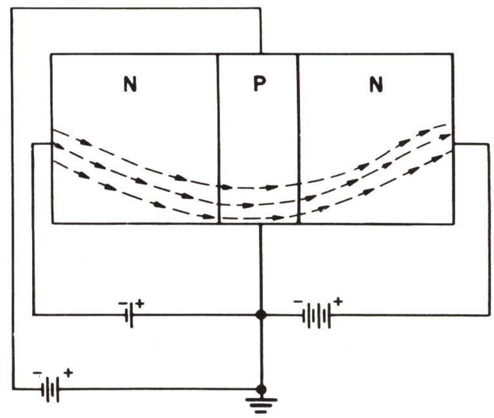


FIGURE 2-34

Most of the heat dissipated in a transistor is generated at the collector junction. In order to simplify removal of this heat the collector dot is generally fastened directly to the case of the unit (see Figure 2-35). Provision is then made for the case to be directly connected to a chassis or other heat dissipating surface. Power transistors of the structure described are now available and are capable of dissipating up to 25 watts in practical applications.

Surface Barrier Transistors—The structure of the surface barrier transistor is similar to that of an alloy transistor. One major difference in structure is that instead of alloying dots deeply into the base material to obtain a narrow base width, two wells are electrochemically etched into the base material until they are separated by only a few tenths of a mil. Indium is then plated on both sides and emitter and collector contacts made (see Figure 2-36). Such a unit has frequency cut-off in the order of 40 mc.

Recently, the micro-etching techniques used to make surface barrier transistors have been applied to "drift" transistor structures. The units produced by this process have been termed micro-alloy diffused transistors. Such a unit has a frequency cut-off greater than 250 mc and finds wide application in high speed computer circuits.

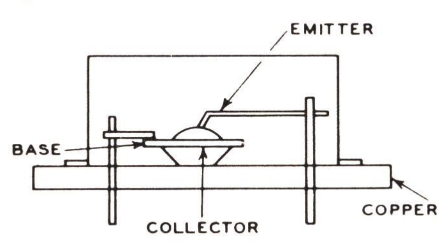


FIGURE 2-35

Photosensitive Transistors—Photosensitive transistors can be divided into three groups according to their construction; they are, the point contact, the PN junction and the photo-transistor. These various types of photosensitive transistors are used to control photoelectric equipment such as flame detectors, automatic door openers, automobile light dimmers, burglar alarms and counters. The mechanical features of these photosensitive transistors are similar to the conventional transistor in that they are lightweight, rugged, etc.

A photosensitive transistor of the *point contact* type is illustrated in Figure 2-37. The heart of the device is a wafer of germanium. One side has a spherical "dimple" ground into it. This is done to reduce the thickness at the center to about .003 inch. The wafer is force-fitted into one end of a metal cartridge and a pointed phosphor-bronze wire is brought into contact with the wafer at its center. This wire is called the collector. The other end of the wire fastens to a metal pin contact embedded in an insulating plug which is positioned at the opposite end of the case. The second electrical contact to this phototransistor is the case itself.

The wafer is made of N-type semi-conductor and is biased in the direction of *least* current flow. When light is directed on the germanium wafer a number of covalent bonds are broken, thus producing an equal number of holes and electrons. Under the influence of the applied electric field, the electrons travel to the positive terminal of the battery and the holes go to the negative battery terminal. It is because of the additional carriers of current made available by the action of light on the N-type germanium, that there is an increase in current flow through the circuit.

To insure that maximum current response is obtained when the light rays fall in the vicinity of the point contact a small glass lens is used to focus the light rays into a narrow beam which is restricted to the desired area of the N-type wafer.

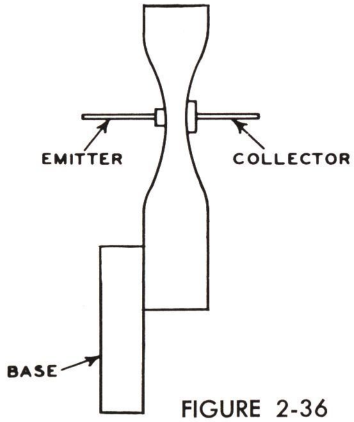


FIGURE 2-36

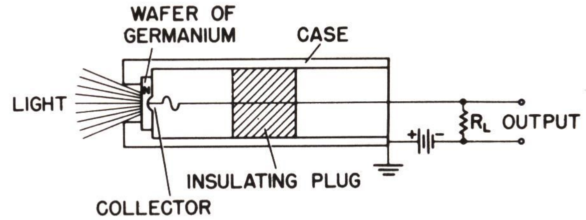


FIGURE 2-37

A photosensitive transistor of the PN junction assembly may also be devised with comparable results. A junction phototransistor is illustrated in Figure 2-38. The response will be greatest when the light is directed at the junction.

Another form of a photosensitive transistor is the phototransistor. This unit employs an NPN type of construction as illustrated in Figure 2-39. Only the central base section is made photosensitive. The bias battery is adjusted so that very little current flows through the transistor, however, when light is focused on the base section, holes are formed in sufficient quantity to produce an increase in current to operate a relay directly. A practical application of this type of phototransistor is in the automatic auto headlight dimmer.

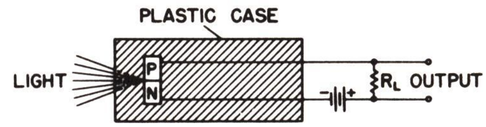


FIGURE 2-38

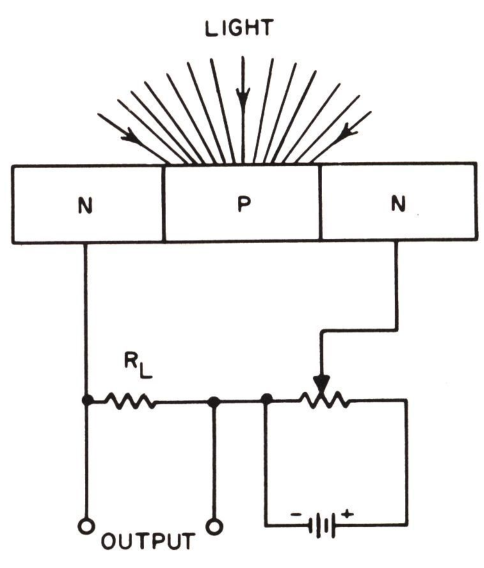


FIGURE 2-39

TRANSISTOR APPLICATIONS

3-1 Transistor Amplifiers

Before undertaking the study of transistor amplifiers it should be pointed out that the manner of amplification in a transistor differs from that of a vacuum tube. It is well known that a vacuum tube is a *voltage* operated device. That is, an AC voltage is applied to the grid of the vacuum tube to control the current flow between the cathode and plate. A transistor, however, is a *current* operated device. That is, the *current* flowing in the emitter-base circuit controls the current flowing in the collector circuits. The symbols α (alpha) and/or β (beta) are used to indicate the current gain in a transistor as compared to the symbol μ (mu) to indicate voltage gain in a vacuum tube. Another important factor is the transistor input and output resistances. It is the current flowing through this resistance that determines the voltage or power gain of a transistor amplifier.

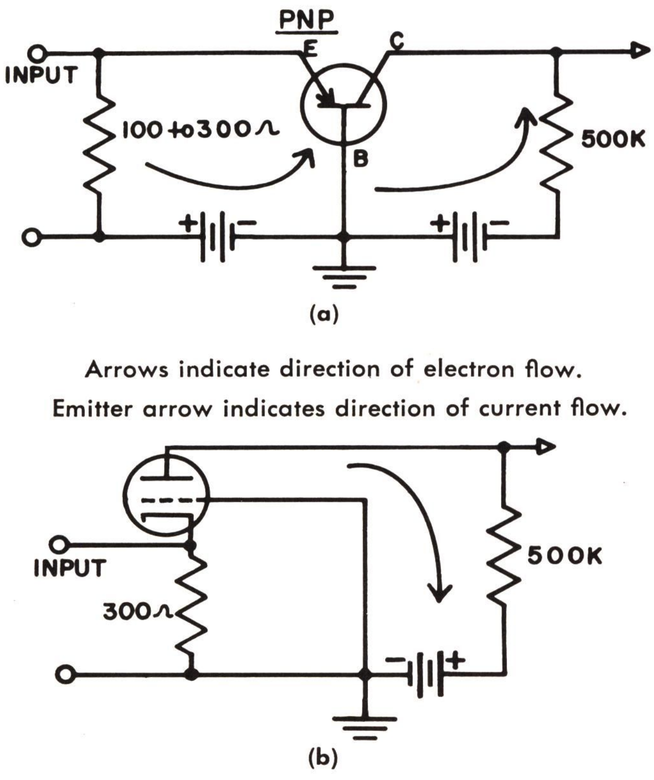


FIGURE 3-1

There are basically three types of transistor amplifiers; the common or grounded base, the common or grounded emitter and the common or grounded collector. The term *grounded* will be used throughout the lesson since it has greater usage in the field than the word common.

Grounded-Base Amplifier — The grounded-base amplifier circuit is similar to the grounded-grid vacuum tube amplifier which has extensive use as an RF amplifier in television tuners. A comparison of these two basic circuits is shown in Figure 3-1. As can be seen, the base of the transistor and the grid of the vacuum tube are grounded. The emitter is

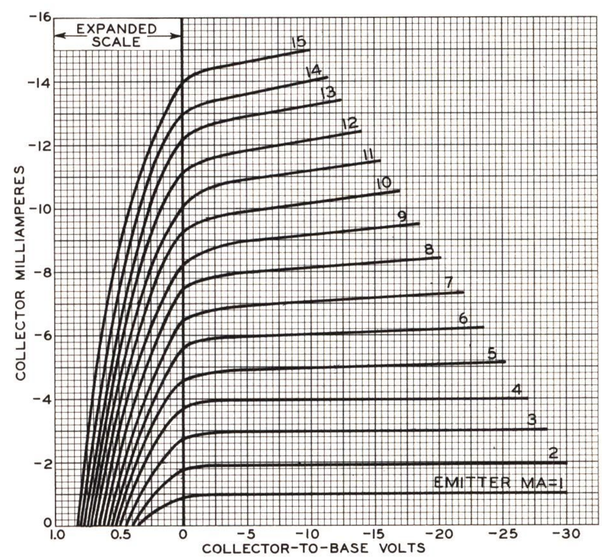


FIGURE 3-2

biased in the direction of greatest electron flow and the collector is biased in the direction of least electron flow. With this bias arrangement the input of the transistor has a low resistance in the order of 20 to 50 ohms and the output has a high resistance which is approximately 1 to 2 meg ohms. The current gain (or alpha) is always less than unity in this type of circuit and is usually in the order of 0.98 to 0.99. The resistance gain between base and collector is very high. The voltage gain in this type of circuit may be in the order of 1500.

The characteristic curve of a grounded-base circuit is shown in Figure 3-2. It can be seen from the characteristic curve that the collector current never exceeds the emitter current. The maximum dissipation allowable for the 2N105 is 35 mw. Therefore, it is very important to maintain the proper collector voltage and emitter current so as not to exceed the maximum dissipation of the transistor. The grounded-base circuit is used when a circuit calls for a very low input impedance and very high output impedance.

The biasing arrangement of the grounded-base circuit can be simplified as shown in Figure 3-3. Figure 3-1 shows two bias supplies, one for the emitter and the other for the collector. The insertion of a resistor in the base circuit biases the emitter positive with respect to the base. Thus, by selecting the proper resistance the proper emitter current can be obtained. Signal degeneration will be introduced by this resistor, therefore, it is by-passed with a capacitor to effectively put the base at AC ground.

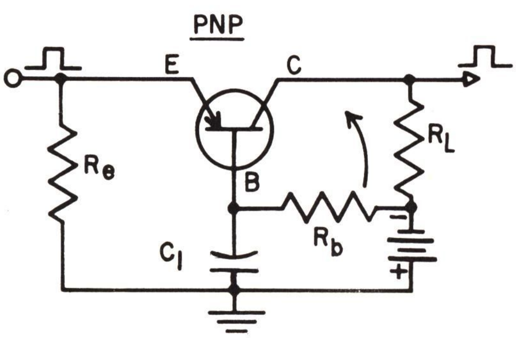


FIGURE 3-3

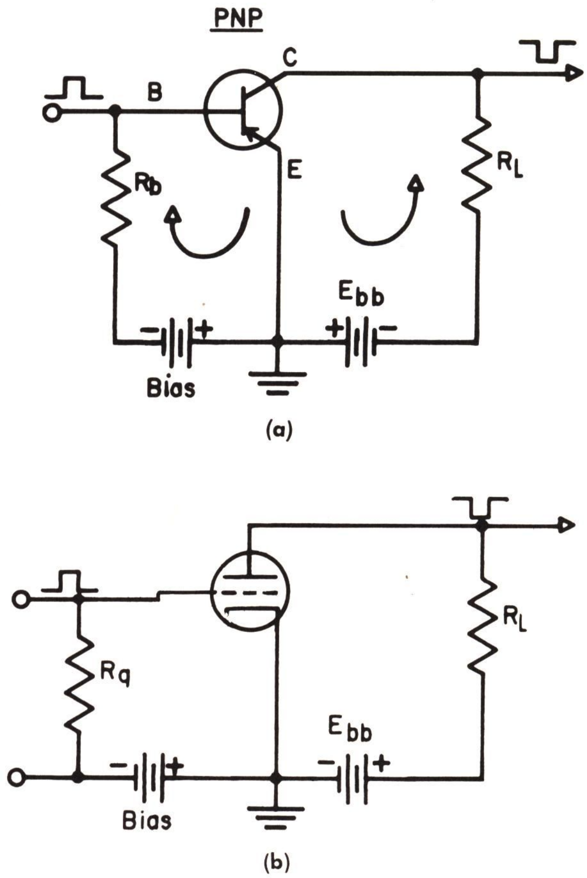


FIGURE 3-4

Grounded-Emitter Amplifier — The grounded-emitter amplifier is similar to the conventional, grounded-cathode, vacuum tube amplifier. The signal is applied to the base of the transistor, whereas in the vacuum tube the grid is the driven element. A comparison between the transistor and vacuum tube circuits is shown in Figure 3-4.

As in the case of the grounded-base amplifier, the emitter is biased in the direction of greatest current flow and the collector is biased in the direction of least current flow. The resistance of the input circuit is normally in the range of 1,000 to 2,000 ohms, however it may be as low as 100 ohms or as high as 10,000 ohms. The output resistance is normally about 50,000 ohms, however, it may be as low as 5,000 ohms and as high as 500,000 ohms.

The characteristic curve of the grounded emitter circuit is shown in Figure 3-5. This curve is for the RCA Type 2N105, P-N-P, junction transistor and is compared with the I_p-E_p curve of an RCA Type 6AG5 vacuum tube. The major difference lies in the fact that in a transistor the collector current is controlled by the emitter current, whereas, the vacuum tube plate current is controlled by the grid to cathode bias voltage. Aside from this, the curves are used in a similar manner. From the characteristic curve shown in Figure 3-5(a), it can be seen that for a very small change in base current, a relatively large change in collector current is possible. For example, as shown in Figure 3-5(a), with a collector voltage of minus 4 volts, a change of base current from 20 to 30 micro-amperes produces a change of collector current from 1.1 to 1.7 milli-amperes. We can say then, that a 10 micro-ampere change in base current produces a 600 micro-ampere change in collector current; thus, a current gain is realized under these operating conditions for the RCA Type 2N105 transistor. This current gain is called the *beta* (β) gain between the base and collector as compared to the alpha (α) gain

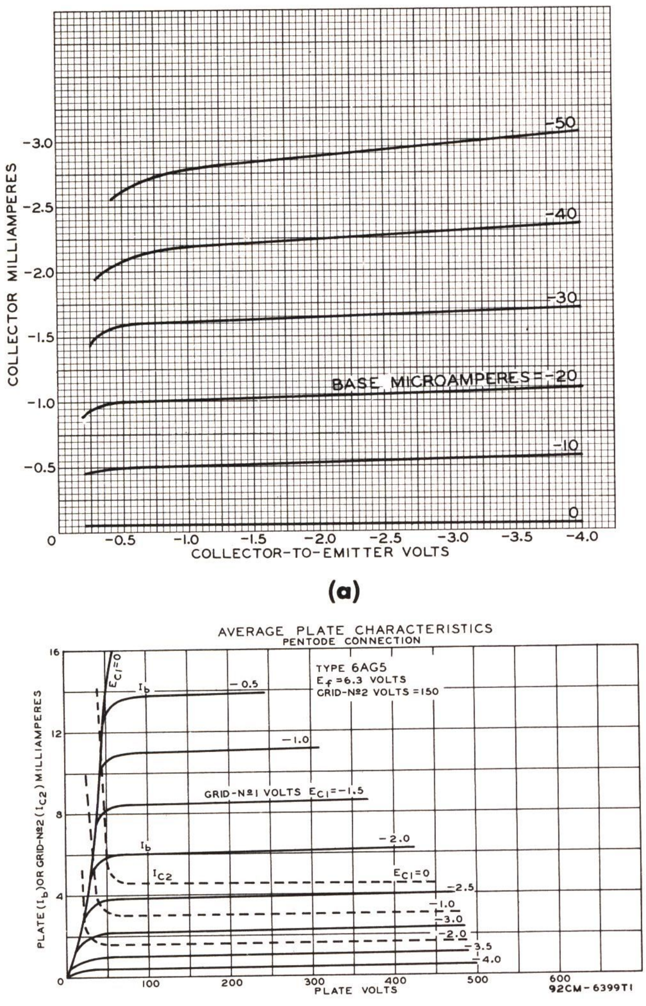


FIGURE 3-5

between the emitter and collector in the grounded-base amplifier.

Power gains of 42 db or approximately 10,000 times can be realized with this circuit arrangement. The voltage gain of this circuit arrangement is the same as that of the grounded-base connection, but the current gain is considerably higher. Due to this increase of gain over the grounded-base connection, this circuit is popular for many circuit designs.

As with the grounded cathode vacuum tube circuit, a voltage reversal takes place between base and collector. A positive signal at the base opposes the bias voltage causing a smaller base current, thus decreasing the collector current. The decrease in collector current causes the collector to become more negative. Therefore, a positive signal at the base develops a negative signal at the collector.

Various methods have been established for biasing the base in the grounded-emitter circuit. In Figure 3-4, two separate bias supplies are used. It can be noted, however, that both the base and collector are negative with respect to the emitter. Therefore, the bias arrangement can be simplified as shown in Figure 3-6. This method can be called *fixed bias*.

The base current can be established by choosing the proper value of base resistance R_b. For example, if a base current of 30 microamperes is desired:

$$R_b = \frac{E_{bb}}{I_b}$$

$$= \frac{6 \text{ volts}}{30 \times 10^{-6} \text{ amps}}$$

$$= 200\text{k ohms}$$

This value of base resistance includes the internal emitter to base resistance, however, this represents only a few hundred ohms and the internal resistance can normally be neglected.

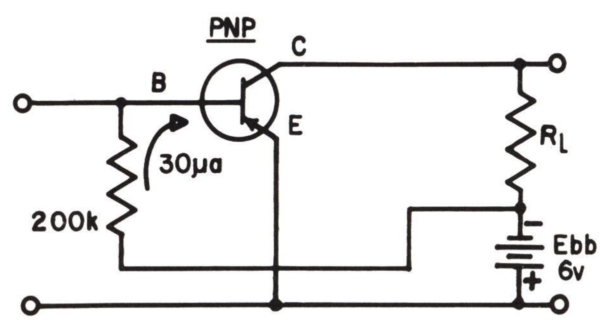


FIGURE 3-6

Fixed bias is not the most satisfactory method of biasing the base. Due to variations between transistor units and their sensitivity to temperature changes, it is difficult to maintain a critical base current. One method of partially overcoming this problem is to tie the base resistor directly to the collector as shown in Figure 3-7. This arrangement provides degeneration in a form of *automatic control* of the base bias and can be called *self bias*. To determine the value of R_b, the supply voltage

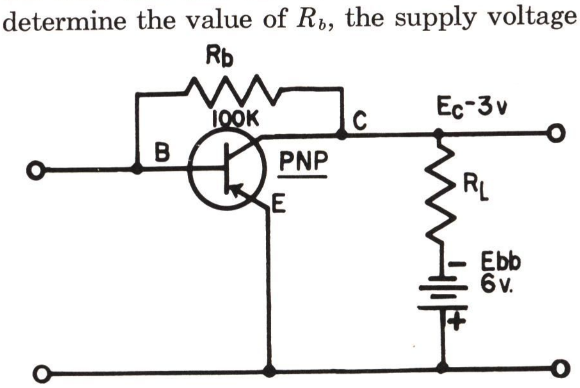


FIGURE 3-7

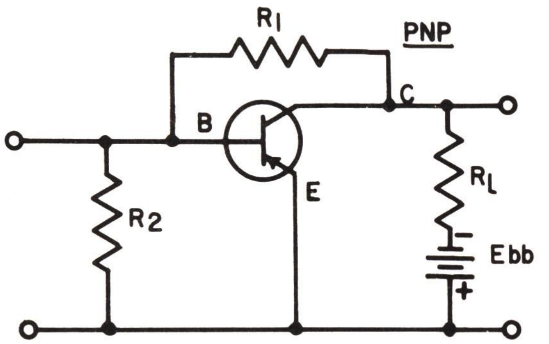


FIGURE 3-8

(E_{bb}) is replaced by the collector voltage (E_c) in the previous formula:

$$R_b = \frac{E_c}{I_b}$$

$$= \frac{3 \text{ volts}}{30 \times 10^{-6} \text{ amps}}$$

$$= 100\text{k ohms}$$

This method of self bias causes *AC* negative feedback which, although it overcomes many of the disadvantages of fixed bias, reduces the effective gain of the amplifier.

Both fixed and self bias can be used to provide even better circuit stability. This method is illustrated in Figure 3-8. Here a voltage divider composed of R_1 and R_2 biases the base negative with respect to the emitter. Bleeder current through the voltage divider fixes a bias at the base. However, any change in collector voltage due to a change in emitter current will automatically change the base bias. This circuit is commonly used due to its inherent stability.

To minimize loss of gain either of the two circuits shown in Figure 3-9 may be used. In Figure 3-9(a) a resistor is added to the emitter circuit and R_2 is returned to the negative terminal of the battery instead of the collector. The emitter resistor (R_e) provides additional stability and is usually 1/5 to 1/10 the value of R_1. To prevent emitter degeneration, capacitor C_e is added. The value of this capacitor is usually about 50 mfd; however, the value may be much higher depending, among other things, upon the lowest frequency to be amplified. The emitter resistor in this case is similar to the cathode resistor in an electron tube circuit.

Another method is shown in Figure 3-9(b). Here the voltage divider is split and all *AC* variations are bypassed by capacitor C_1. The value of R_3 is usually 5 to 10 times the value of R_2. The total resistance of R_2 and R_3 should equal the resistance of R_1 shown in Figure 3-8. In some circuit applications a combination of Figures 3-9(a) and 3-9(b) may be used. In other cases a bypassed emitter resistor may be added to the circuit of Figure 3-8. Voltage gain and circuit stability are usually the determining factors when selecting the proper circuit.

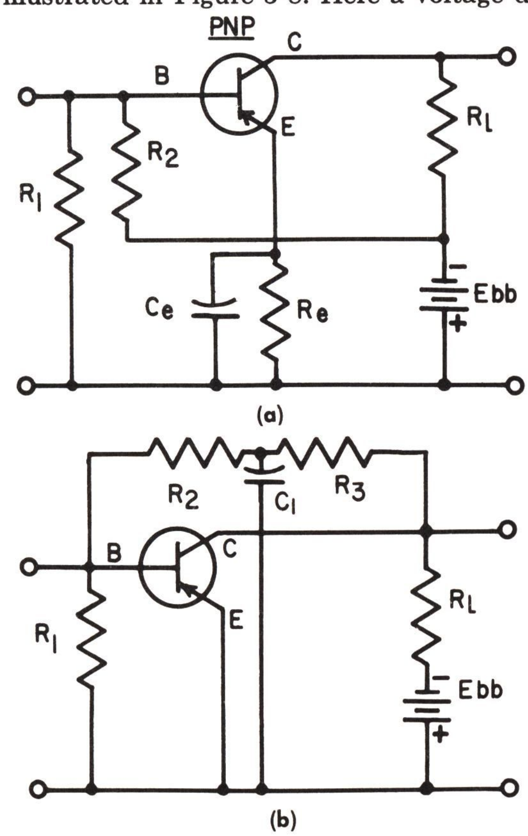
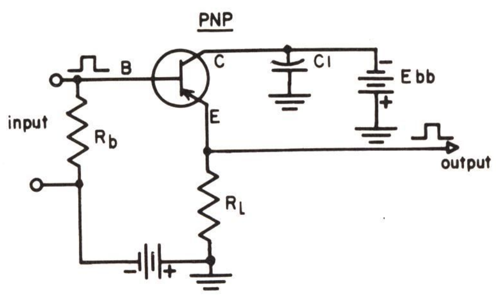


FIGURE 3-9

Grounded-Collector Amplifier—The grounded-collector amplifier circuit is similar to the vacuum tube cathode follower circuit. Both circuits are illustrated in Figure 3-10. The input impedance (resistance and reactance) of the transistor circuit is high and the output impedance is low, being similar to the vacuum tube circuit. The output impedance of the transistor circuit is dependent on the input impedance, however, this is not the case in electron tube circuits. The voltage gain is less than unity and the power gain of the stage is usually lower than either the grounded emitter or grounded base stages. The circuit is mainly used as an impedance matching device.

As in the case of the grounded base amplifier there is no phase reversal of the signal between the input and output. The same is true in the cathode-follower vacuum tube circuit and the grounded grid tube circuit.



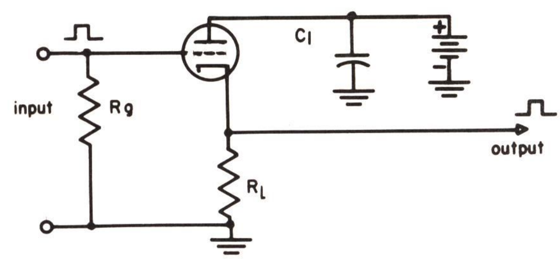


FIGURE 3-10

3-2 Methods of Coupling

The basic methods of coupling transistor stages are similar to those used in vacuum tube circuits. The major difference lies in the fact that the input and output resistance of transistors as compared to vacuum tubes vary widely. These resistances depend on the type transistor used and the operating conditions. Also a change in input or output load resistance reflects into the input or output, whichever the case may be. For example, as the load resistance increases, the input resistance decreases. This is not generally true with vacuum tubes since changes in the plate load do not normally reflect into the grid circuit. In some cases, however, plate to grid capacitance becomes a factor and plate loading will affect the input impedance of an electron tube circuit.

The coupling requirements for transistors can be met by various methods, such as, transformer, R/C, impedance and direct coupling. Each of these methods will be discussed.

Transformer Coupling—The method of transformer coupling transistor stages is illustrated in Figure 3-11. As can be seen, this grounded emitter circuit employs fixed and self bias and an emitter resistor *(R_e)* for stabilization. The biggest advantage of this circuit is that the input and output impedance of the transistor can be matched for maximum power gain. A step down transformer, T_1, is used from the collector of the preceding stage to the base of the following grounded emitter stage as shown in Figure 3-11. Due to this step down it would seem that a voltage loss appears across the secondary of T_1 and would defeat our purpose. However, it must be remembered that a transistor is a *current operated* device, not a voltage operated device such as the vacuum tube. This step down provides best power transfer and the change in base current, due to the presence of the signal, activates transistor action and a power gain can be measured across the primary of T_2. This step down can be compared to the output stage of an audio amplifier, where a step down transformer is required to drive a loudspeaker, which is a current operated device. The purpose of the transformer is usually for maximum power transfer.

The circuit components include a voltage divider (R_1 and R_2) which provides the proper bias. The voltage divider is bypassed by C_1 to avoid signal attenuation. The emitter resistor (R_e) is the stabilizing resistor which allows variations of the transistor and circuit elements to be absorbed automatically without adverse effects. This resistor (R_e) is bypassed by C_2 to prevent loss of gain due to degeneration. The supply voltage E_{bb} is also bypassed to prevent feedback due to possible AC signal voltages being developed across the power supply. Capacitors C_1 and C_2 may be replaced by a single capacitor connected between the emitter and the bottom of the secondary of T_1.

Transformer coupling in IF stages can present problems in design. Basically, the IF transformer is used to select the desired signal frequency and has a band width capable of passing the sidebands of the desired signal fre-

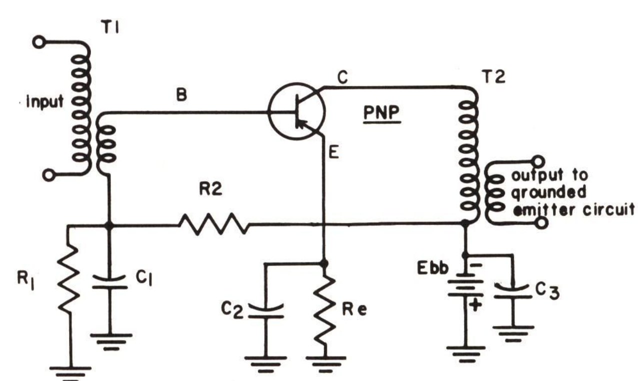


FIGURE 3-11

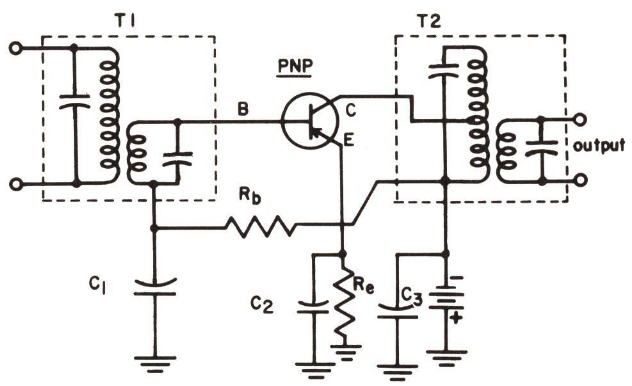


FIGURE 3-12

quency but rejects adjacent signals. This means the Q of the IF transformer must be carefully specified and maintained. In the case of vacuum tube circuits the output resistance of an amplifier is sufficiently high that adjusting the transformer to have the proper Q is no problem. If the output resistance is low (100K or under) the Q of the transformer is lowered, possibly causing poor selectivity. This is the case when using transistor amplifiers. A typical output resistance of a transistor radio IF stage (455KC) is approximately 25K ohms. If the collector is shunted across the entire primary of transformer T_2, as shown in Figure 3-11, the selectivity will be seriously affected due to the output resistance of the transistor reducing the Q of T_2. To overcome this problem, the circuit is connected as shown in Figure 3-12. By selecting the proper tap on T_2 for the collector connection, the Q of the circuit can be satisfied as well as properly matching the output resistance of the transistor.

An exact match is not always desirable since feedback is also a major problem in transformer design. In some cases neutralization is incorporated as was done in old triode IF amplifiers. In other circuits the primary is not tapped for the collector connection. By selecting the proper L/C ratio the correct Q can be maintained, however, neutralization may be necessary. Also some circuits use a center tapped secondary in order to balance the feedback currents. In this case no neutralization is necessary.

R/C Coupling—Transformer coupling can be used to advantage in IF strips or any RF application where selectivity is required. They are also used in large signal audio circuits such as drivers and output stages. However, R/C coupling is desirable where low level audio signals are involved since transformers are more susceptible to hum pick-up and also take up space. Figure 3-13 illustrates a two stage R/C coupled circuit. The method of bias is similar to that used in transformer coupling. The major additions are R_L (collector load) and C_c (coupling capacitor). The coupling capacitor (C_c) must be made very large (2 to 10 mfds) due to the small output and input resistances involved.

It should be noted that electrolytic capacitors are used for coupling whereas they are not used in electron tube circuits. Therefore, polarity should be observed or damage to the capacitors and possibly to the transistor may occur. Leakage current is not as critical in transistor circuits as in electron tube circuits.

When cascading R/C coupled amplifiers as shown in Figure 3-13, it is necessary to decouple one or more stages in order to prevent feedback. One method of decoupling is illustrated in Figure 3-14. This is accomplished by inserting resistor R_1 in series with the base resistor and bypassing R_1 by means of capacitor

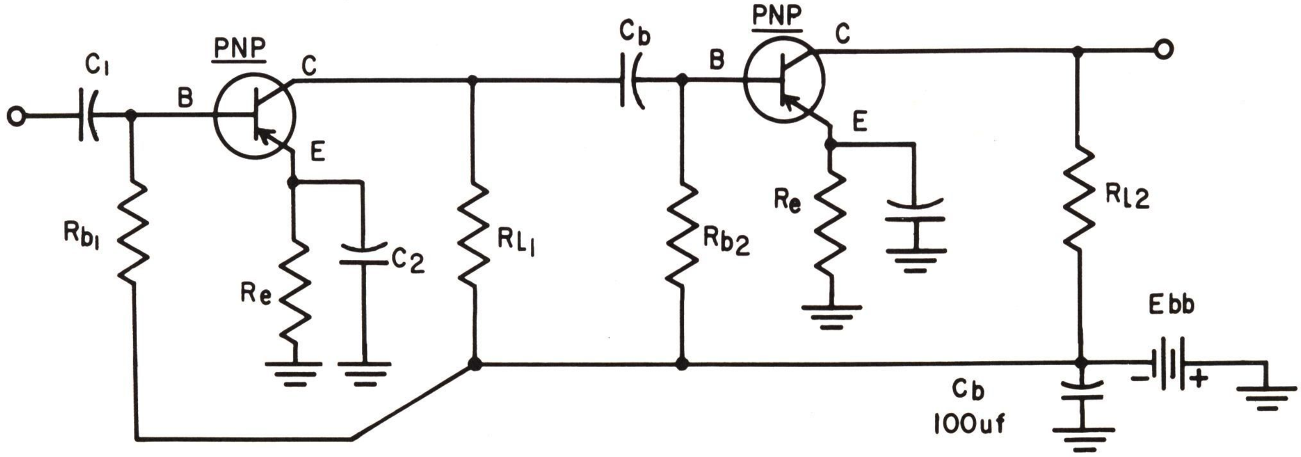


FIGURE 3-13

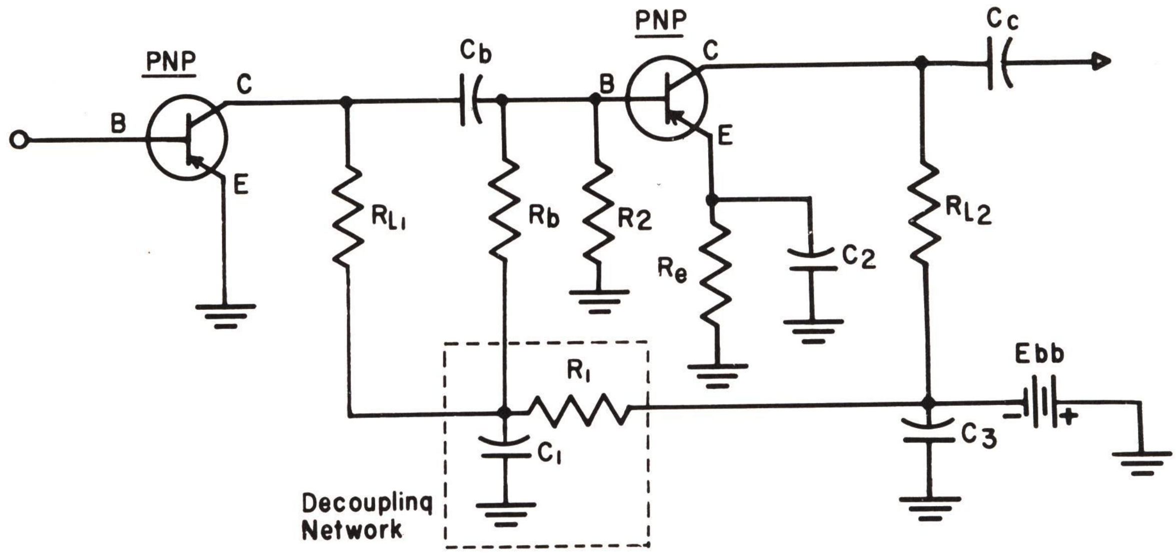


FIGURE 3-14

C_1. The R_1C_1 time constant should be adjusted to insure that the lowest frequency to be amplified is adequately bypassed. Generally the value of R_1 must be kept small so that the supply voltage is not drastically reduced to the previous stages. Therefore, the value of C_1 must be very large, usually 100 mfd or larger.

Impedance Coupling — Impedance coupling is similar to R/C coupling. The major difference lies in the fact that inductances are used to replace the load resistors in Figure 3-5. This type of coupling may be used for circuit applications above audio frequencies. Resistors R_1 and R_2 are still necessary in order to provide the proper emitter-base bias.

Both series and shunt peaking can be accomplished in this type of coupling. Peaking coils similar to those associated with vacuum tube circuits in television receivers may be used in transistor video amplifiers.

Direct Coupling—Direct coupling is used generally where cost is a factor. However, it is also used where partial *DC* restoration is required in television receivers and where the *DC* component must be amplified. A direct coupled amplifier is shown in Figure 3-16. In cases where the *DC* component must be retained in whole the capacitors must be eliminated. As can be seen in Figure 3-16, resistor R_1 serves as both the collector load of Q_1 and the bias resistor of Q_2.

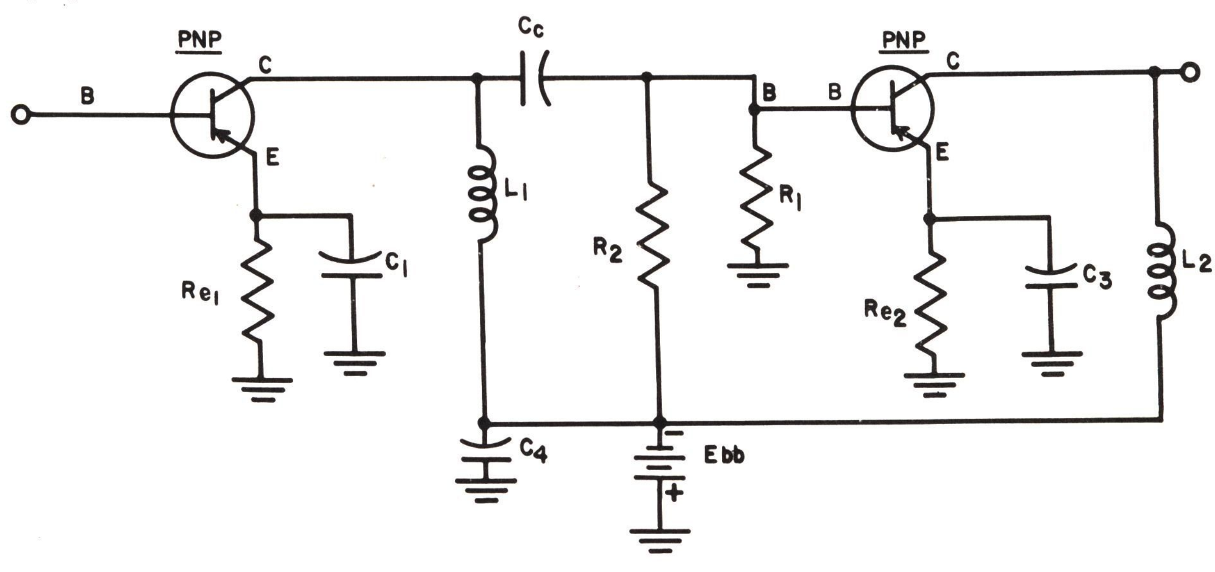


FIGURE 3-15

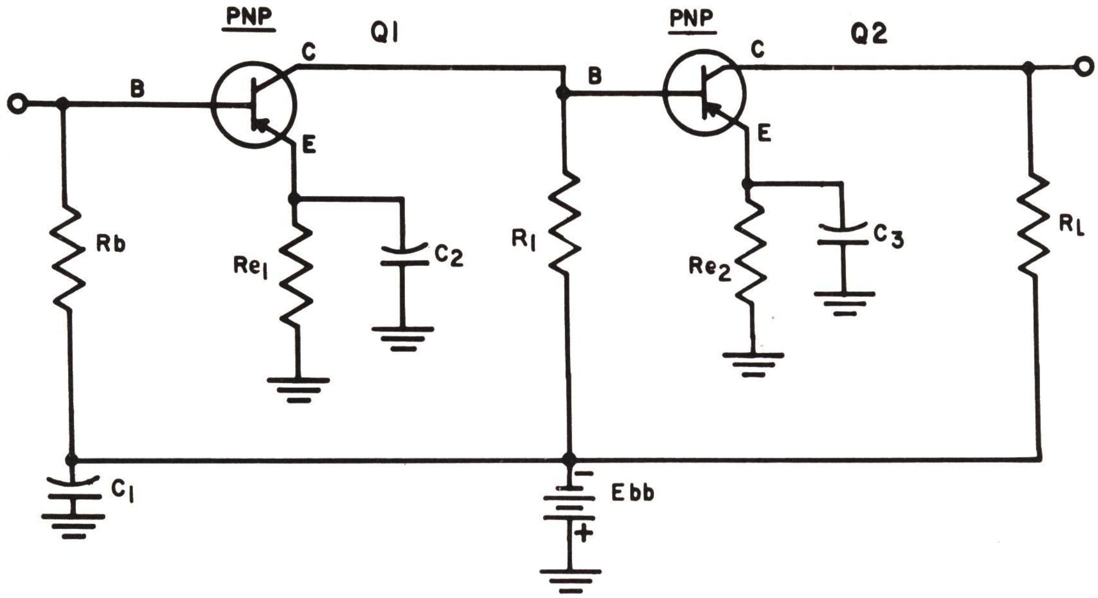


FIGURE 3-16

3-3 Gain Controls

As in vacuum tube circuits, volume controls must be used in transistor audio amplifiers to provide means for suitable audio level adjustment by the listener. Although these controls are generally associated with *R/C* coupled amplifiers, they are also used where transformer or direct coupled circuits are involved.

A volume control circuit is illustrated in Figure 3-17. The circuit includes the volume control and the 1st audio amplifier. The capacitor C_2 prevents the volume control R_2 from changing the DC operating point of the previous stage. Capacitor C_3 prevents the base current from flowing through the volume control. Resistors R_3 and R_4 provide the base bias. The base must be negative with respect to the emitter for PNP transistor operation. The coupling capacitors C_2 and C_3 must be large in value due to the low circuit impedances involved.

Where transformer coupling is used, a circuit as shown in Figure 3-18 may be used. The resistance of the volume control R_1 should be about 2 to 3 times the impedance of the secondary of the coupling transformer to prevent excessive loading.

3-4 Power Amplifiers

Transistor power amplifiers can be divided into two basic types: single ended and push-pull. Also, as in vacuum tube circuits, transistor power amplifiers can be classified by their modes of operation, such as, Class A amplifiers, Class B amplifiers, etc.

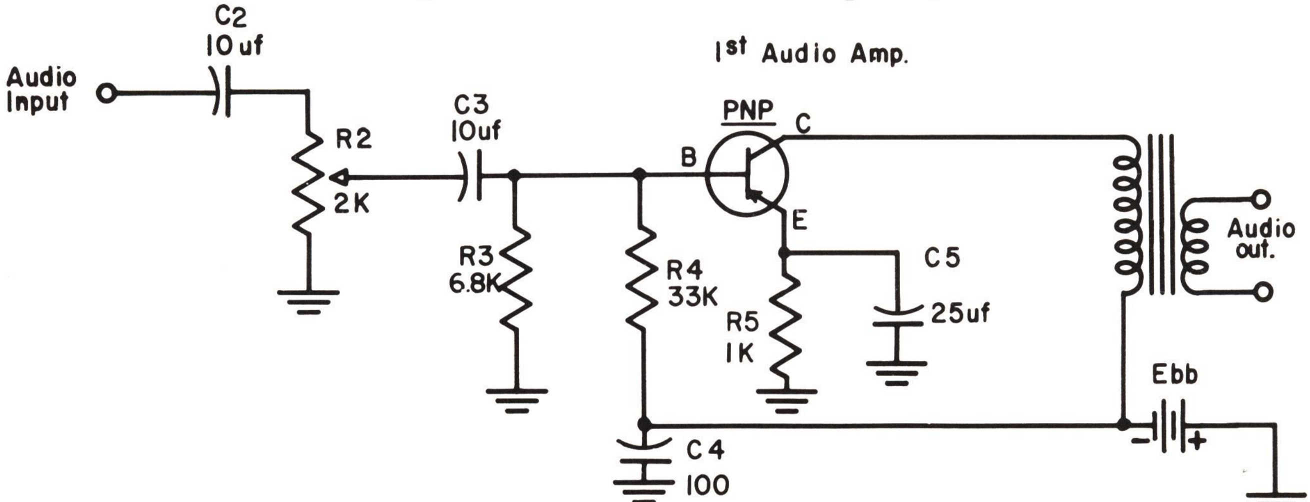


FIGURE 3-17

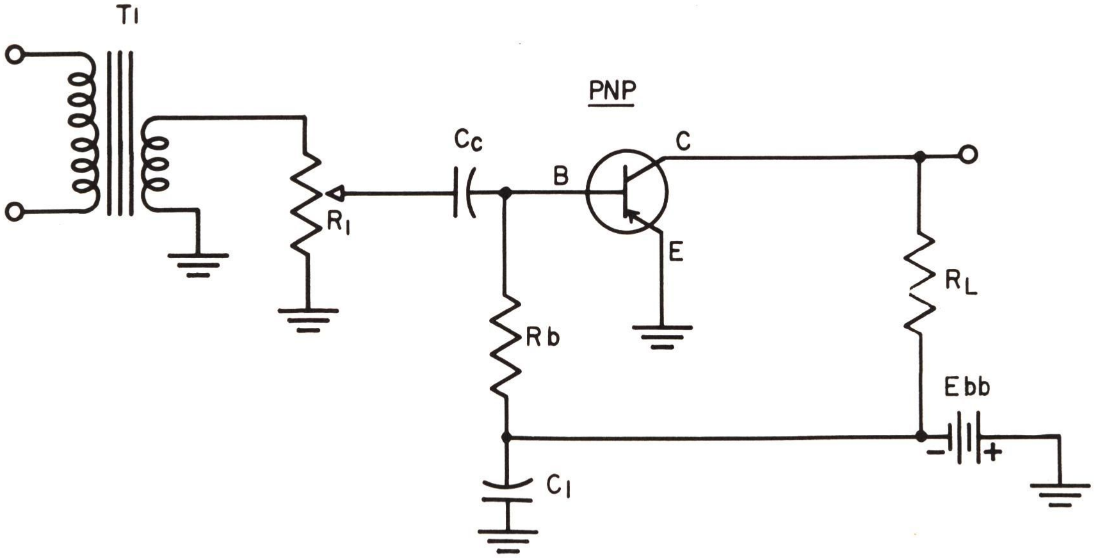


FIGURE 3-18

Class A Amplifiers—A typical class A, single ended, power amplifier is shown in Figure 3-19. The base-emitter circuit is biased in the direction of greater current flow by the bleeder arrangement of R_1 and R_2. This causes the emitter to be positive with respect to the base. The emitter current is stabilized by R_3 and the *AC* component is bypassed by capacitor C_1. Since this amplifier is used to drive a loudspeaker, a matching transformer, T_1, must be used. Capacitor C_2 is often used to limit the bandwidth to prevent high frequency distortion.

This type of circuit is limited as to power output. The circuit is arranged so that the collector current with no input signal is 11 ma. and the collector to emitter voltage is 6 volts. This means the transistor is dissipating 66 milliwatts. Since this exceeds the maximum dissipation of a 2N109 transistor a "heat sink" must be used to prevent transistor destruction. The case of the transistor is usually connected to a large metal object such as a speaker frame by means of a heavy braided metal strap.

A load line can be constructed as shown in Figure 3-20. The supply voltage is 9 volts,

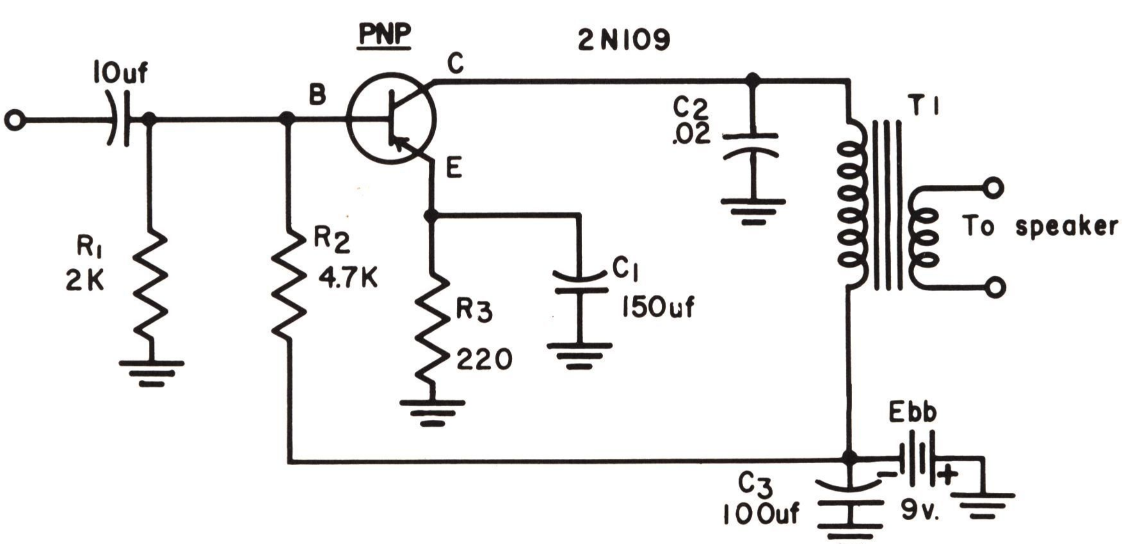


FIGURE 3-19

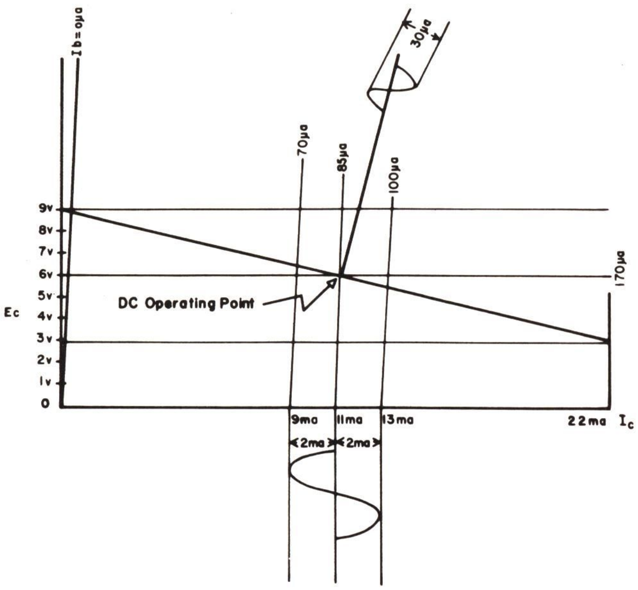


FIGURE 3-20

therefore, the collector voltage *(V_{ce})* when the collector current *(I_c)* is zero is also 9 volts. The load line is drawn from the 9 volt point through the *DC* operating point of the I_c-E_c curve. As can be seen the output will be linear from zero base current *(I_b)* to 170 microamps of I_b. Any greater swing in base current will cause distortion of the output signal. Therefore, the maximum undistorted output can be calculated as follows:

$$\text{Power Out.} = \frac{V_{ce}\ (\text{peak to peak}) \times I_c\ (\text{peak to peak})}{8}$$

$$= \frac{9\text{-}3 \text{ volts} \times 22 \times 10^{-3} \text{ ma}}{8}$$

$$= \frac{6 \times 22 \times 10^{-3}}{8}$$

$$= 16.5 \text{ milliwatts}$$

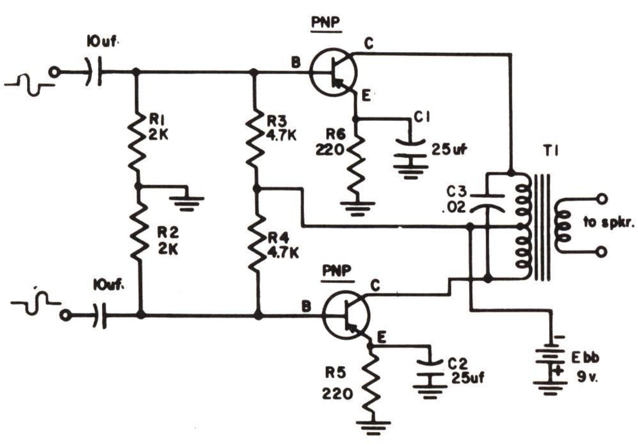


FIGURE 3-21

A greater output can be obtained, but, it will be distorted due to clipping of the input signal.

In order to provide a higher power output with less distortion, a push-pull circuit arrangement should be used. A Class A push-pull audio amplifier is illustrated in Figure 3-21. A similarity can be noted between the single ended and push-pull circuits. Actually identical components are used, the difference being that the two transistors in the push-pull stage are driven 180 degrees out of phase.

The chief advantage of this circuit is one of less distortion at greater power outputs.

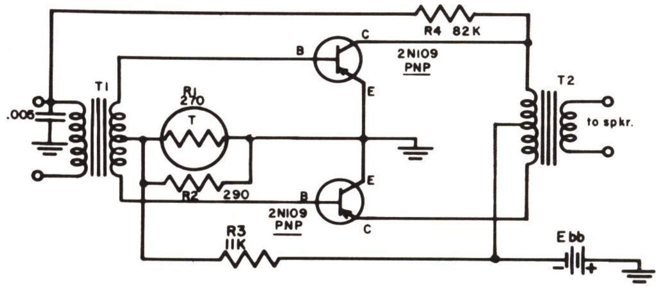


FIGURE 3-22

Class B Amplifiers—One of the disadvantages of a transistor Class A amplifier is that collector current flows at all times. The transistor dissipation, therefore, is high even when no AC signal is present. The dissipation can be greatly reduced by the use of an emitter-base bias such that very little collector current flows when no input signal is present. This type of operation is called Class B. When PNP transistors are operated under Class B conditions collector current flows only during negative signal excursions; when NPN transistors are used, collector current flows only during positive signal excursions. The resulting distortion is minimized by the use of two transistors connected in push-pull.

A Class B push-pull audio amplifier is illustrated in Figure 3-22. The base-emitter circuit is biased near collector cutoff so that very little collector power is dissipated under no signal conditions. Ideally, the transistors would be biased to cutoff and no power would be dissipated under no signal conditions. However, at low signal inputs the resulting signal would be distorted as shown in Figure 3-23(a). This is known as *cross-over* distortion. By biasing the transistors so that a small collector current flows at all times the greater portion of this distortion can be eliminated. Figure 3-23(b)

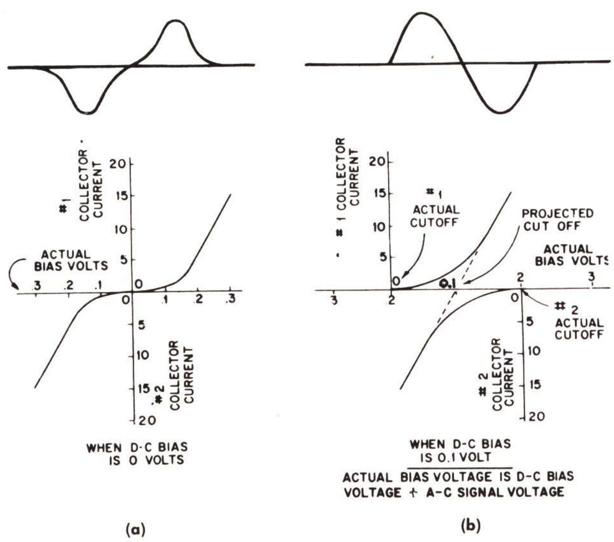


FIGURE 3-25

shows how the coincidence of the projected cutoff points corrects this distortion. Any residual distortion can be minimized by the use of negative feedback. In Figure 3-22 this feedback is provided by resistor R_4.

Resistors R_1, R_2, and R_3 form a bleeder network which provides proper bias for the transistors. To minimize distortion at low signal levels and prevent thermal destruction of the transistors the characteristics of this network must be very carefully chosen. It was pointed out earlier that the collector current, collector dissipation, and DC operating point of a transistor vary with the ambient temperature. To minimize the effects of these variations a thermistor (R_1) is used in the biasing network. When the ambient temperature increases the resistance of the thermistor decreases, and vice versa, so as to maintain constant voltage across the biasing network. Since the bias voltage controls the emitter and collector currents, the thermistor stabilizes the DC operating level over a wide range of ambient temperature.

3-5 Oscillator Circuits

In general, transistor oscillators function in the same manner as electron tube oscillators. To sustain oscillation an amplifying device having a gain greater than 1 is required. The output of the amplifier is fed back in phase with the input signal with sufficient amplitude to overcome circuit losses. Two basic types of feedback will be discussed. One type uses tuned reactive circuits and the other type uses R/C networks.

Tuned *L/C* Oscillators—A transistor oscillator and its vacuum tube equivalent are illustrated in Figure 3-24. The electron tube circuit in Figure 3-24(a) is a typical Meissner oscillator. The plate signal is fed back in phase with the grid signal in order to sustain oscillations. The frequency can be varied by the variable capacitor C_1. This type of oscillator can be adjusted to produce continuous sine waves or be self-quenching by choice of the proper time constant for C_c and R_g.

The transistor circuit shown in Figure 3-24(b) is just as versatile. For sine wave output resistor R_1 (base resistor) is adjusted for enough bias to prevent the transistor from cutting off on positive voltage swings. The circuit can be made self-quenching by readjustment of R_1.

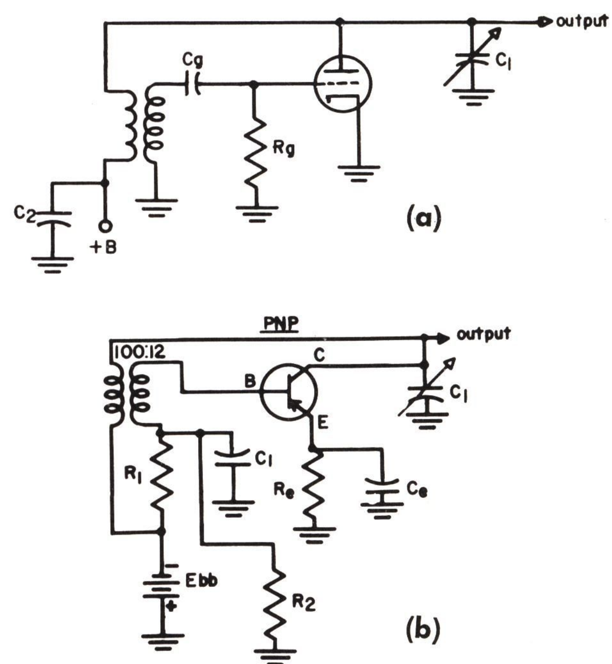


FIGURE 3-24

Since the transistor is a current operated device, a voltage step down is used between the collector and base. Thus, a small current change in the collector causes a large current change in the base. This action sustains oscillations by overcoming circuit losses. A stabilizing resistor R_e is normally included in the emitter circuit to compensate for variations between production transistors. Resistors R_1 and R_2 provide a low impedance bias source. To prevent self-quenching the time constant of R_1, R_2 and C_1 is made long compared to that of R_e and C_e. R_e and C_e have a function

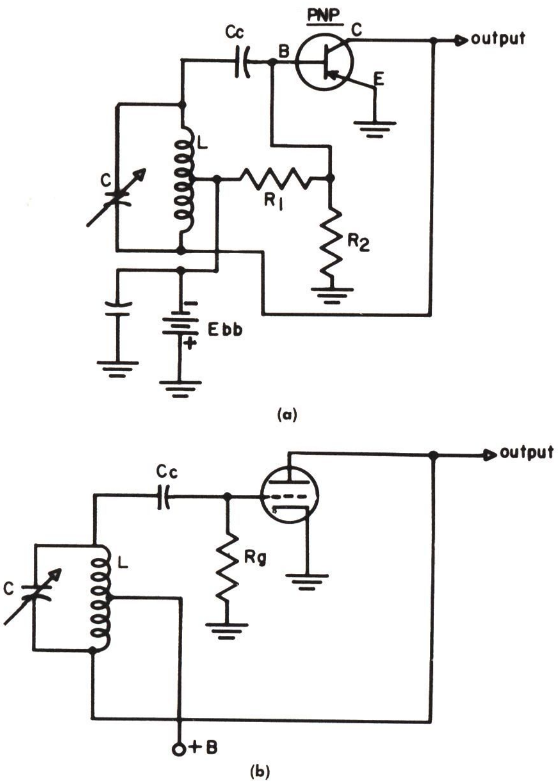


FIGURE 3-25

similar to that of C_g and R_g in the electron tube circuit. Therefore, the emitter time constant is an important consideration.

Another common type of oscillator known as the *Hartley* is illustrated in Figure 3-25 along with its vacuum tube counterpart. The L/C tuned circuit is common to both the input and output circuits. Voltage from the collector circuit is developed across a portion of L, inducing a current of the proper phase into the base circuit in order to maintain oscillation. Again since the transistor is a current operated device, there is a voltage step down from collector to base. However, there is a *current* step up to meet the requirement for the oscillator mode of operation.

The *Colpitts* oscillator is another widely used circuit. The transistor circuit and its vacuum tube counterpart are illustrated in Figure 3-26. As in the Hartley circuit the tuned circuit is common to both the input and output. Capacitors C_1 and C_2 split the signal to provide the proper feedback in order to maintain oscillation. Resistors R_1 and R_2 of the transistor circuit provide the proper bias between the base and emitter.

In servicing these types of transistor oscillators the base voltage waveform can be checked with an oscilloscope to indicate the amplitude of the *AC* voltage. This waveform is not always a pure sine wave. For *RF* conversion in superheterodyne receivers a pure sine wave is not absolutely necessary. Therefore, for stability reasons in some transistor circuits the amplitude of the sine wave will appear somewhat compressed. Actual VTVM base to emitter voltage measurements are impractical since the voltage difference is very small. Care must be taken not to load the circuit. A medium to high impedance probe is generally required.

R/C Oscillator — A transistor R/C (multivibrator) oscillator circuit is shown in Figure 3-27. As can be seen from the circuit it is very similar to an electron tube circuit. Components C_{b1}, C_{b2}, R_{b1} and R_{b2} form a time constant which roughly fixes the operating frequency. However, the collector current cutoff point (I_{co}) and the emitter current cutoff point (I_{eo}) also must be considered. The output waveform is essentially a square wave.

3-6 Power Supplies

The power requirements of most transistor circuits, such as found in transistor radios, are very small as compared to vacuum tube circuits, and often allow economical and practical operation with batteries. The power require-

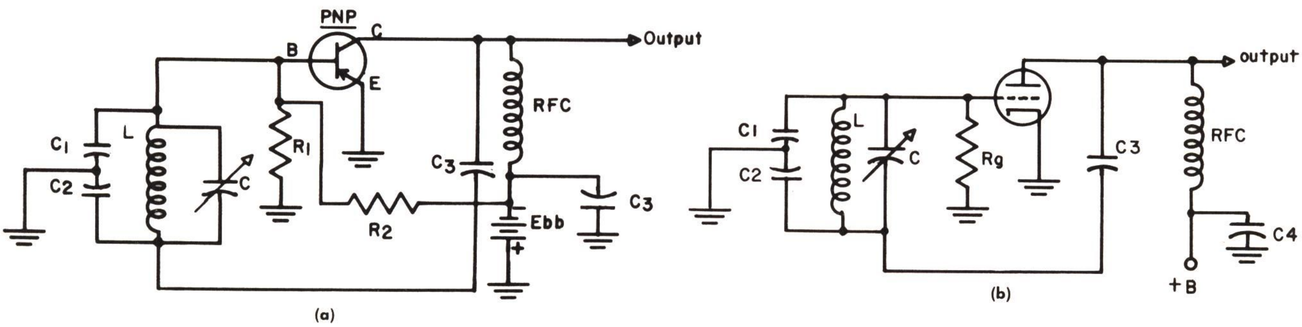


FIGURE 3-26

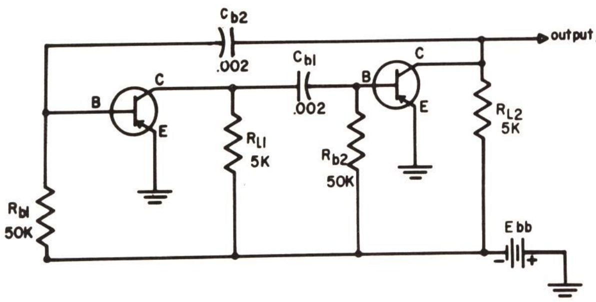


FIGURE 3-27

ments of some transistor circuits are so small that the operating battery life will nearly equal its normal shelf life. The familiar zinc-carbon batteries as used in vacuum tube portable radio receivers and flashlights may be used as a power source.

Another type of battery that can be used as

FIGURE 3-28

a power source is the mercury cell. These cells offer several advantages over the zinc-carbon type. They are more stable and rugged, both mechanically and electrically. They have a much longer shelf life and a greater current capacity than similar sized zinc-carbon batteries. Thus, they are well suited to the design of sub-miniature equipment.

The RCA type VS300 nine (9) volt mercury cell battery is illustrated in Figure 3-28. It is composed of seven individual mercury cells stacked together. Each mercury cell has a voltage output of approximately 1.4 volts. One of the cells is illustrated in Figure 3-29 showing the internal construction. (Electrical energy

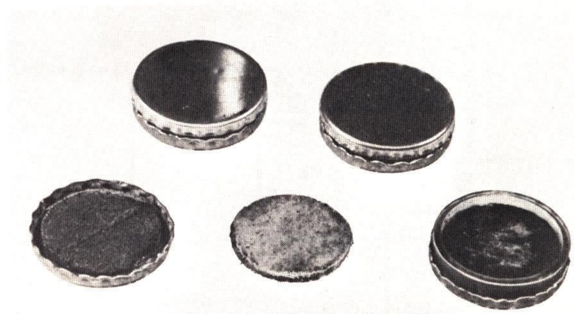


FIGURE 3-29

is produced by an electro-chemical reaction between amalgamated zinc powder and mercuric oxide, with potassium hydroxide solution used as an electrolyte. A layer of cotton saturated with the electrolyte separates the zinc and the mercuric oxide.)

The case of the mercury cell is made of steel. Due to the high stability of the chemicals and the inactive case material, there is no internal cell reaction until electrical energy is drawn from the cell. The shelf-life, therefore, is extremely long.

In more complex transistor circuits, intended for continuous operation, it is imprac-

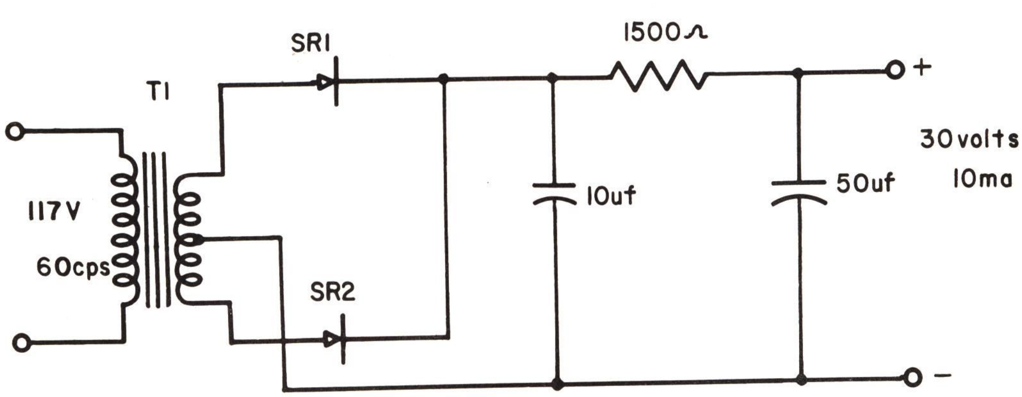


FIGURE 3-30

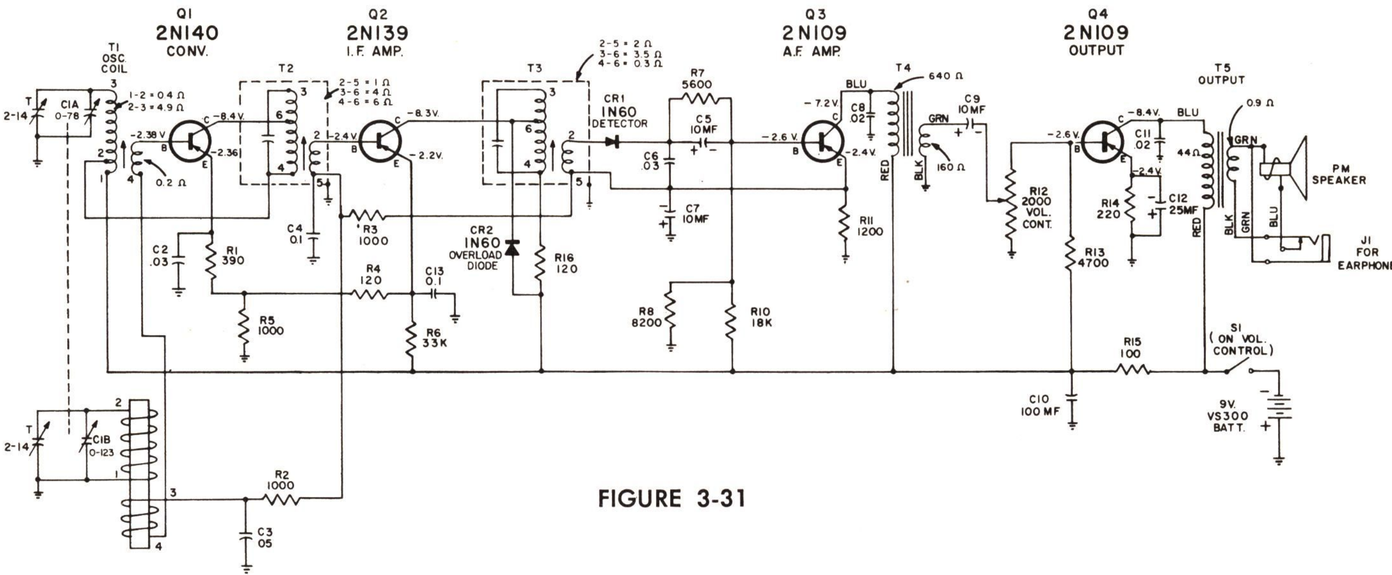


FIGURE 3-31

tical to use battery power supplies. *AC* power supplies are used in these applications. A transistor power supply is illustrated in Figure 3-30. The circuit is a full-wave rectifier with an *R/C* filter. This particular circuit supplies 30 volts at 10 ma of current drain.

3-7 Practical Transistor Circuits

Portable radios were the first to use transistors for entertainment type equipment. Transistors are also employed in automobile radios, computers, television receivers, etc. A discussion of several circuits which have been used in practical applications or have been developed experimentally will follow.

Pocket Radio—The circuit diagram of an extremely compact pocket radio is presented in Figure 3-31. This circuit covers the AM broadcast band from 550 to 1600 KC. The *IF* frequency is 455 KC, and the undistorted audio output is 25 milliwatts. A ferrite loop antenna is used to capture the signal energy which is transformer coupled to a low impedance secondary winding. The current developed in this secondary winding flows in the base-emitter circuit of Q_1 (2N140). Q_1 serves a dual purpose as an oscillator and converter. Transformer T_1 combined with *C1A*, tuning capacitor, forms the oscillator tank circuit. An *AC* regenerative voltage is fed back from the

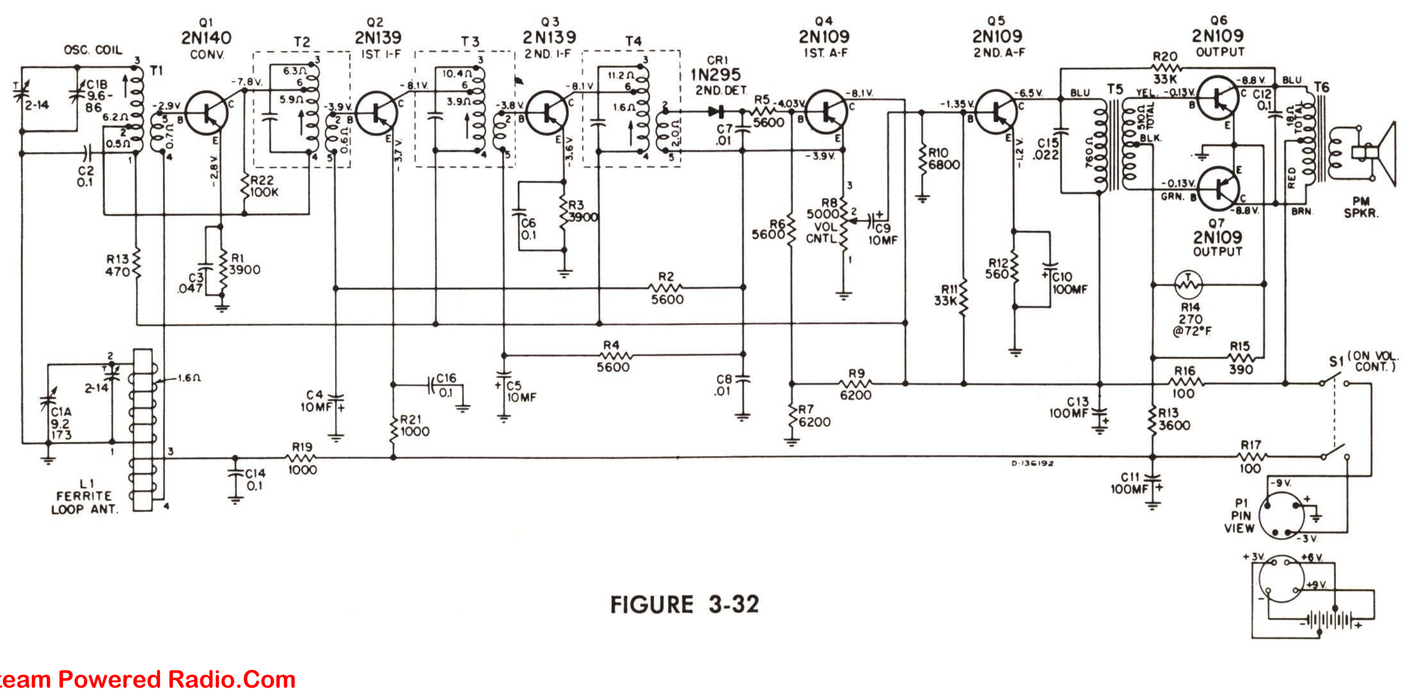


FIGURE 3-32

collector circuit to the primary of T_1. The secondary is a low impedance winding causing the feedback current to flow in the base-emitter circuit of Q_1. Therefore, both the signal and oscillator currents flow in the base circuit. Due to the non-linearities of Q_1, an *IF* signal current exists in the collector circuit. The *IF* transformer, T_2, transfers the 455 KC *IF* signal to the base of Q_2, the *IF* amplifier. The collector of Q_2 is terminated into another 455 KC *IF* transformer, T_3. The secondary is a low impedance winding which drives the crystal detector.

An *AGC* circuit is used to automatically control the gain of Q_1 and Q_2. The *AGC* voltage developed by the detector opposes the bias current of transistors Q_1 and Q_2, thereby operating them closer to cut-off. To prevent *IF* overloading on large signal strengths, an overload diode is incorporated in the collector circuit of Q_2. The overload diode is normally biased to cutoff by R_{16}. However, large signal peaks will cause conduction, loading the primary of T_3. This in turn lowers the stage gain improving the *AGC* action of the circuit.

The detected audio is *R/C* coupled to the base of the 1st audio amplifier, Q_3. The collector terminates into the audio interstage transformer, T_4. Capacitor C_8 rolls off the high frequency response preventing high frequency distortion. The volume control is connected across the low impedance secondary winding of T_4. It can be seen from this arrangement that the emitter-base bias is unaffected by the setting of the volume control. To prevent the base current from flowing in the secondary of T_4, capacitor C_9 is used as a *DC* blocking capacitor. The value of the capacitor must be made large for adequate low frequency coupling.

The audio output stage, Q_4, is a grounded emitter amplifier stage. The collector is terminated into the output transformer, T_5, whose secondary matches the impedance of the loudspeaker. An earphone jack is provided for private listening. The earphone should have an impedance of approximately 200 ohms.

The power supply consists of a single nine (9) volt mercury cell battery. Used in this circuit the battery has a useful life (intermittent service) of approximately seventy five (75) hours. The battery life is comparatively short since the Class A output stage consumes approximately 11 milliamperes with no signal input.

Portable Radio—The schematic diagram of a transistor portable is shown in Figure 3-32. This receiver utilizes seven (7) transistors and has an undistorted output of 250 milliwatts. The circuit is of the superheterodyne type consisting of: an oscillator-converter, two stages of IF amplification, a crystal diode detector, an AF amplifier, an audio driver and a push-pull Class B output stage.

The antenna and input circuits are very similar to the circuit shown in Figure 3-31. Two *IF's* are used in this receiver for better selectivity and gain. The output of the crystal detector is fed directly to base-emitter of Q_4, the 1st *AF* amplifier. A volume control is located in the emitter circuit of Q_4 and the collector is at *AC* ground. This circuit should not be confused with an emitter follower circuit. The common electrode is the emitter and the characteristics are the same as a grounded emitter amplifier.

The driver stage, Q_5, provides the peak to peak voltages required to drive the push-pull output stage to rated output. The output transistors Q_6 and Q_7 are operated Class B, and a thermistor is used in the base return of both transistors. As the ambient temperature increases, the thermistor decreases in value resulting in a lower bias applied to the base.

In Class B output circuits, the battery current increases with increased signal input. Therefore, prolonged operation at high volume levels will reduce the battery life. The current consumption of this receiver (with no signal) is approximately 8 milliamperes. Therefore, battery life under these conditions is greater than for the previously described radio. However, the current consumption at 50 milliwatts output jumps to 29 milliamperes.

Phonograph Pre-Amplifier—Transistors are ideally suited as phonograph pre-amplifiers for the following reasons: low noise, low hum due to the elimination of heater cathode leakage and no microphonics. A phonograph transistor pre-amplifier is illustrated in Figure 3-33.

A low impedance *moving coil* type pickup is used to drive the base of the PNP type transistor. Capacitor, C_1, is required to block the *DC* current from the pickup and also to maintain the proper base biasing. The B+ voltage from the amplifier's power supply is used to bias the transistor. The emitter terminal voltage averages 6 volts positive in this particular pre-amplifier. The combination of resistors R_1

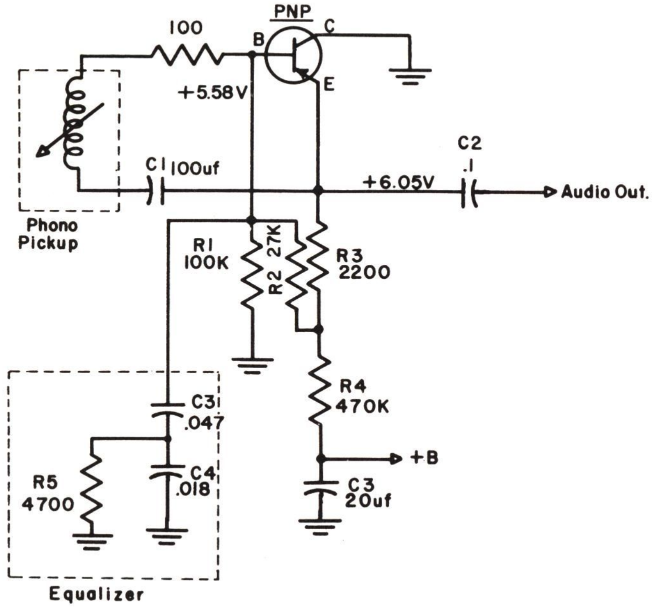


FIGURE 3-33

and R_2 provides a base terminal voltage of 5.85 volts positive. The base is biased slightly negative with respect to the emitter, as is normally required for PNP transistor operation. The collector terminal in this case must be grounded so that it is biased negative with respect to the emitter. This necessitates placing the load resistor R_4 in the emitter circuit. This type of circuit arrangement is not to be confused with the emitter follower. It can be seen in Figure 3-33 that the magnetic pick up is connected between the base and emitter. Since the collector is grounded, and the output is taken between the emitter and ground, the circuit is a common emitter type. Capacitor C_3 is a decoupling capacitor used to prevent interaction from other circuits using the same B+ supply.

Capacitor, C_2, couples the amplified audio signal to the tone control amplifier.

Video Amplifiers—Video output amplifiers differ from audio power amplifiers in that they operate into voltage operated devices such as picture tubes or oscillograph tubes rather than into current operated devices such as loudspeakers. Since transistors are current operated devices they present no problems in audio amplifier applications. However, the fact that the peak to peak driving voltages required by picture tubes are greater than the maximum voltages that can safely be applied to the collectors of most transistors has limited the application of transistors as video output amplifiers in television receivers and similar equipment.

A two stage transistor video amplifier capable of delivering an output of approximately 30 volts peak to peak is shown in Figure 3-34. The transistors used in this amplifier should have a high frequency cut-off of approximately 30 MC, and the one used in the output stage must have a collector voltage rating of at least 40 volts.

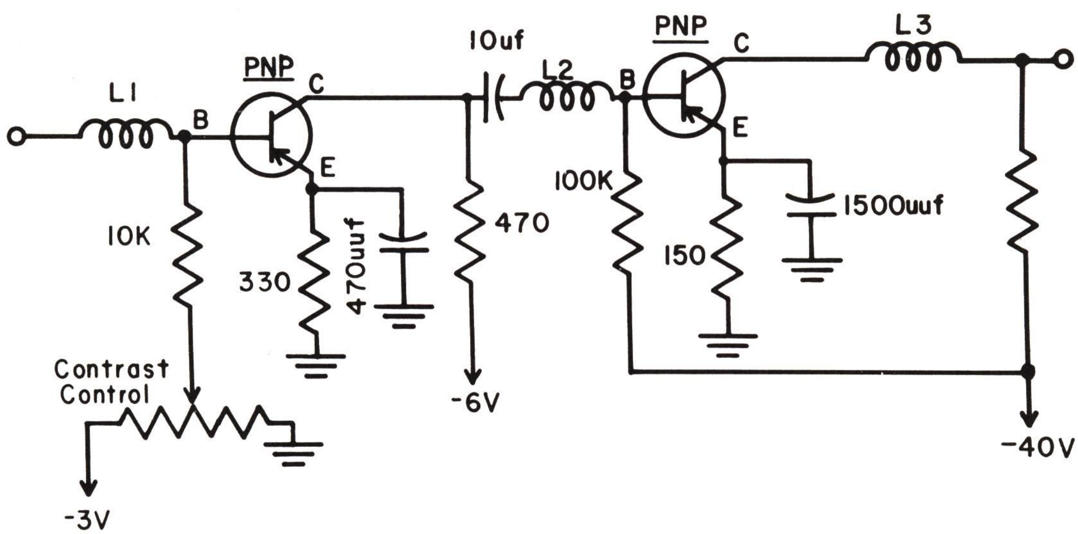


FIGURE 3-34

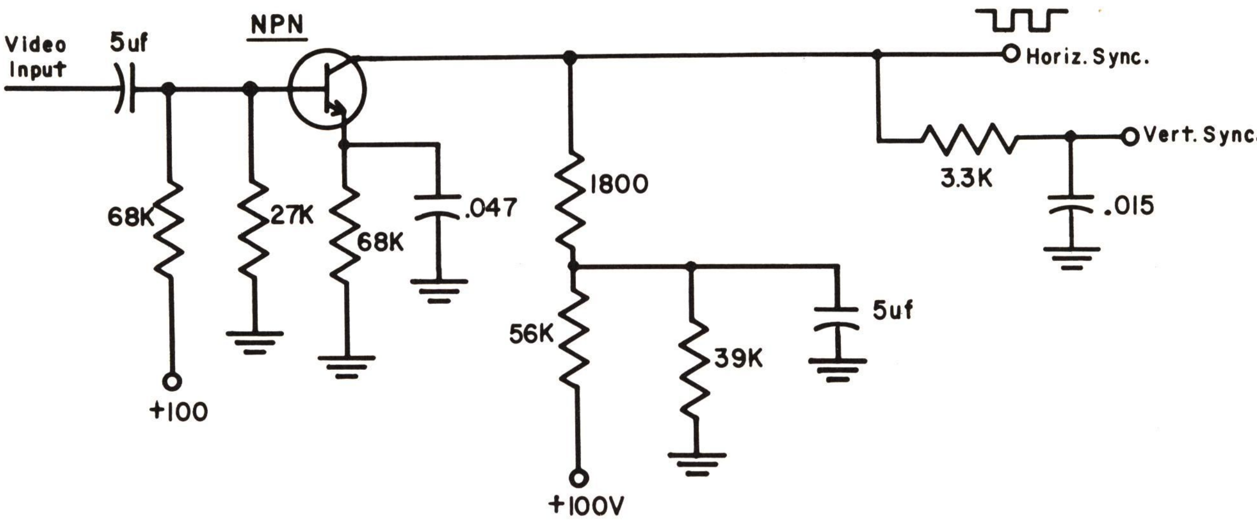


FIGURE 3-35

The *drift* type transistor which was discussed previously is well suited since it meets both requirements. The base region is thick enough to prevent voltage breakdown and the drift design assures the high frequency response.

As can be seen from Figure 3-34, both transistors are operated as grounded emitter amplifiers. Series peaking is used at the input of both stages and in the output of the second stage. Also, the emitter resistors are partially bypassed providing additional peaking. This peaking compensates for high frequency losses due to internal and external capacity associated with the transistors. A gain (contrast) control is used in the base circuit of the first stage. The gain of this stage is varied by regulating the base-emitter bias. As the base is made more positive, greater current flows between the emitter and base, thus increasing the stage gain.

A greater output can be obtained from a similar arrangement using a transistor which can operate with higher collector voltages. Another method is to use push-pull output transistors. In this case one transistor drives the cathode of the kinescope while the other transistor simultaneously drives the grid 180° out of phase with the cathode. In this case a Class A push-pull amplifier is used.

Television Sync Separator—A transistor sync separator is shown in Figure 3-35. In this example a positive voltage supply is available, thus an NPN transistor is used. The transistor is biased such that little current flows without the presence of signal. When a sync positive video signal is applied to the stage, the developed bias across the resistors in the base circuit produces a clamping action which cuts off the transistor during picture intervals and permits it to conduct only during sync pulse intervals. This dynamic biasing action produces clean, amplified sync pulses at the output of the stage. The gain of the transistor is sufficient to assure that, even on very weak input signals, the collector current saturates and clips off the tips of the sync pulses below the noise level. Horizontal sync pulses are prevented from reaching the vertical sweep circuit by the R/C network in the vertical sync output lead.

Other Transistor Circuits — There are other transistor applications too numerous to cover in this lesson. However, if the technician understands the basic operation of transistor amplifiers and oscillators, little additional reading is necessary to basically understand the operation of a completely transistorized television receiver.

3-8 Transistor Components

Due to the small size of the transistor it is desirable that the associated circuit components be small to allow compact transistorized electronic equipment design. Since the voltage and current requirements are usually low in this type of equipment, resistors, coils, controls, transformers and sockets can be made small in

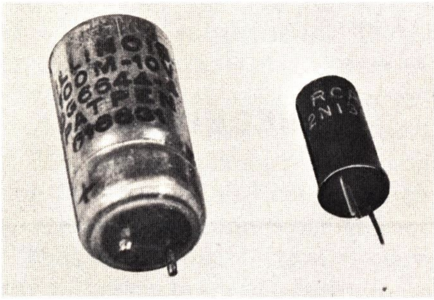


FIGURE 3-36

size without danger of voltage arc-over and overheating.

Electrolytic Capacitors — The capacitor has presented a different design problem. Due to the low circuit impedances involved, the value of capacitance must be large. Even though the working voltages are low the actual value of capacitance may range from 1 to 100 mf or higher. If ordinary electrolytic capacitors of this value were used in transistor circuits they would be so large that compact design and styling would be impossible.

However, a metal known as *tantalum* overcomes the capacitor size problem. Tantalum is oxidized and this oxide serves as a dielectric. Since tantalum is also used as the capacitor base material, miniature electrolytic capacitors can be made with large capacity values and low working voltages. Such a capacitor is pictured in Figure 3-36. The case diameter is $7/16''$ and the length is $3/4''$. It is rated 100 mfd at 10 volts.

Units of lower capacity can be encapsuled in even smaller cases. From the picture in Figure 3-37 the size of the electrolytic capacitors can be compared to the size of the transistors and other associated parts.

Transformers—The size of a transformer is generally determined by two factors: the amount of unbalanced direct current flowing in the windings and the amount of power to be handled at a specified frequency. If the transformer must handle large *DC* currents the core material must be large to prevent magnetic saturation which in turn will cause distortion of *AC* signal currents. Since the *DC* currents in transistor circuits are usually relatively small, the core material of the transformers can also be made small. However, in some applications, such as audio power amplifiers, the transformer may be as large or larger than those required by electron tube circuits. This is due to the fact that primary currents in the order of 10 amps may be encountered. Generally, *RF*, *IF* and oscillator coils are made small as pictured in Figure 3-38.

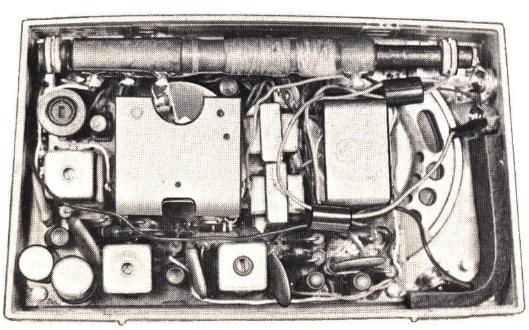


FIGURE 3-37

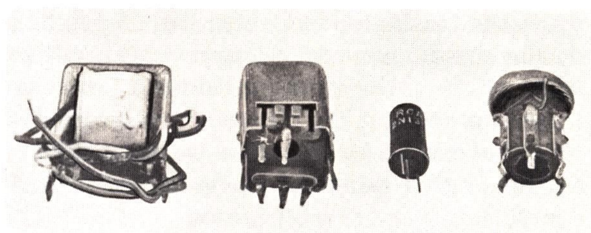


FIGURE 3-38

3-9 Servicing Transistor Circuits

Servicing transistorized electronic equipment presents no major problems when compared with vacuum tube type equipment. With the advent of printed wiring, component parts are neatly arranged with little or no stacking. However, care must be taken to prevent damage of the printed wiring.

One of the outstanding benefits of transistor equipment is the reliability of the transistor itself. Over ninety percent of the failures in electron tube equipment is due to failure of the electron tube. However, transistors have long life and this factor tends to decrease the amount of service required.

Precautions—Although transistors have the advantages of long life and reliability, certain precautions must be observed. Mechanically they are rugged but not indestructible so reasonable care should be employed. The leads are the most fragile part and whether they are the long flexible type or the short rigid type they should be treated in the same manner as the leads of a crystal diode. The transistors with long flexible leads are usually soldered directly into the circuit. When un-soldering or re-soldering, caution should be taken not to overheat the transistor. As in the case of crystal diodes, long nose pliers should be used to grip the lead between the transistor and point of soldering in order to control the heat. Transistors with short rigid leads are usually plugged into a socket. In some cases, however, these transistors are plugged directly into the printed board and then dip soldered. In this case long nose pliers cannot be used, therefore, the soldering iron should be hot before touching the solder joint and the transistor should be soldered or unsoldered as fast as possible to prevent damage. When un-soldering a component from a transistor socket, the transistor should first be removed to prevent damage from heat.

Due to the low operating voltages required, relatively small voltage changes can greatly upset the biasing of the transistor. Depending on the circuit, small bias changes can result in destruction of the transistor due to excessive transistor dissipation. Therefore, it is important that circuit components are not inadvertently shorted when servicing transistorized equipment.

Servicing Techniques — The actual servicing techniques used when servicing transistor equipment are similar to the techniques used when servicing electron tube circuits. Basically these techniques are:

1. Check Battery
2. Visual Inspection
3. Check Transistor
4. Voltage Check
5. Resistance Check
6. Capacitance Bridging
7. Probing
8. Signal Injection
9. Alignment
10. Component Substitution

Before performing any transistor service, the battery should be checked and direct substitution is generally the best method. However, it is usually best to first check the voltage of the original battery with the receiver on and maximum volume setting. If possible also tune in a strong local station. Generally, where a 9 volt battery is used, the receiver should operate with a battery voltage as low as 6 volts. This, of course, will depend on the design characteristics of a particular receiver. However, circuit trouble should be suspected if the receiver will not operate if the battery voltage is 7.5 to 8 volts. In some cases the customer will complain that batteries only last for a short duration. In all cases an ammeter should be inserted in series with the battery and the total current drain of the receiver measured. These current figures are usually stated in the service notes. If the current reading is high the leakage should be traced and corrected. If not, explain to the customer the operation and limitations of battery operated receivers. It is often desirable to check the operation of the receiver with a reduced battery voltage. This condition can be duplicated by inserting a small resistor in series with the battery. This is shown in Figure 3-39. The actual value of the resistor used depends on the condition of the battery and the voltage desired. Using a rheostat in this application allows a selection of voltages and allows the technician to check the sensitivity of the receiver under varying voltage conditions. In cases where an AC power supply is used, the supply voltages should be checked before attempting any service work. Improper supply voltages can cause odd effects and many headaches can be eliminated by first checking the power supply.

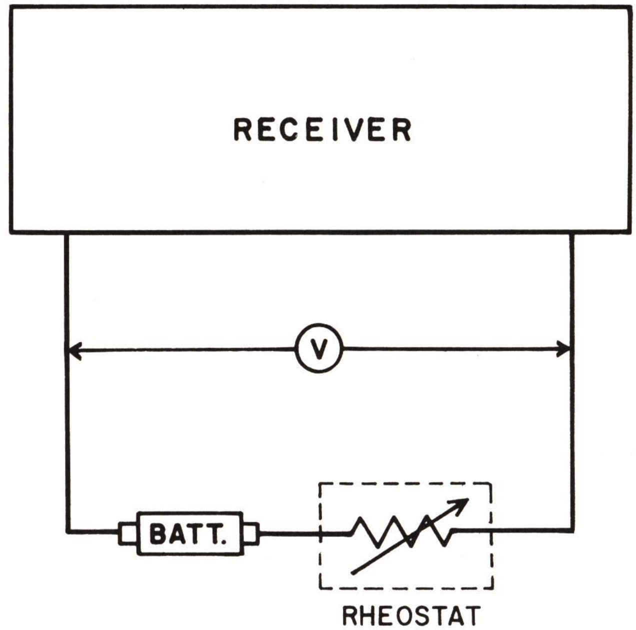


FIGURE 3-39

Visual inspection is also a good service technique. Occasionally a loose wire or faulty connection can be found before extensive voltage checks are made. Faulty components such as burned resistors are seldom encountered since the power of the supply voltage is usually very low.

Transistors, like electron tubes, can be checked by direct substitution. Transistors, however, have a characteristic known as *leakage current* which may affect the results obtained when using the direct substitution method. The leakage current can affect the amplification factor or gain of the transistor and is more critical in certain applications than others. Thus it is possible that a particular transistor will operate satisfactorily in one circuit and not in another. It also has been found that the amount of leakage current will increase slightly as the transistor ages.

Voltage measurements provide a means of checking receiver conditions similar to electron tube circuits. The major difference is the magnitude of the voltages encountered. For example, the bias voltage between the base and emitter is in the order of 0.05 to 0.2 volts. Therefore, a sensitive *VTVM* is usually required. When making voltage checks the polarity should be observed. In the case of electron tube circuits, if a positive voltage is measured on the grid of a tube a leaky coupling capacitor is indicated. However, in the case of transistors the base to emitter voltage may be positive or negative depending on the type of transistor used. For example, the PNP type normally operates with the base negative with respect to the emitter, whereas, the opposite is true in the case of NPN transistors. The schematic should be checked for the proper polarity as well as the magnitude of the voltage.

In some circuits it may also be desirable to make a current check, although with printed wiring this is not always possible. The amount of current can be calculated by measuring the voltage across a resistor in the circuit and also checking the value of the resistor with an ohmmeter. The current can then be determined with the aid of Ohm's Law. For example, if the collector current is to be measured, measure the voltage drop across the emitter resistor and check the resistor with an ohmmeter. Using Ohm's Law the collector current can be calculated.

Resistance measurements are not generally made in transistor service other than checking for open circuits in transformers and coils. Due to the low voltage power supplies used in transistor circuits the resistors have little tendency to burn up or change value. It is important that the transistor or component be removed from the circuit before attempting resistance measurements. Since the ohmmeter contains a battery, the wrong polarity voltage may be applied to a critical stage and cause permanent damage to the transistor. Always disconnect supply voltages before removing a transistor from its socket to prevent damage to the transistor by current transients.

Capacitance bridging, probing, and component substitution are all good techniques which are commonly used when servicing electron tube circuits and are equally good when servicing transistor circuits. They are generally resorted to when servicing the so-called "dog" troubles. Care must be taken to observe polarity when substituting or bridging electrolytic capacitors.

Alignment is another excellent service technique when checking *RF* and *IF* stages for sensitivity. A shorted turn in an *RF* or *IF* coil is quickly identified by poor response when tuning the coil. For example, turning the slug in an *IF* coil one-half turn normally has a great effect on the sensitivity of a transistor radio. If this adjustment produces little or no effect the transformer is probably defective or the associated stage inoperative for other reasons.

Signal injection is also an excellent service technique. A defective stage in a radio can be rapidly isolated by injecting a signal at the input to each stage starting at the loud-speaker and moving back to the antenna coil. The defective stage can be identified by a decrease in gain from the previous stage, or by a very slight increase where a large increase should occur.

All of the service techniques mentioned are suitable for all types of transistorized equipment. Keeping in mind the aforementioned precautions, servicing transistor receivers should present no greater problem than their electron tube counterparts.

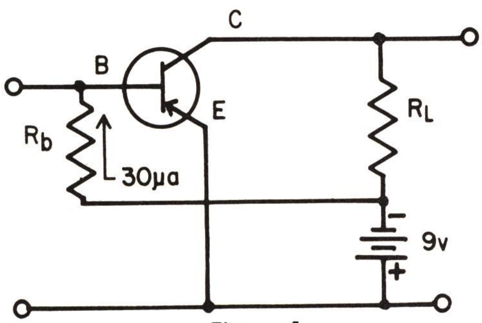


Figure 1

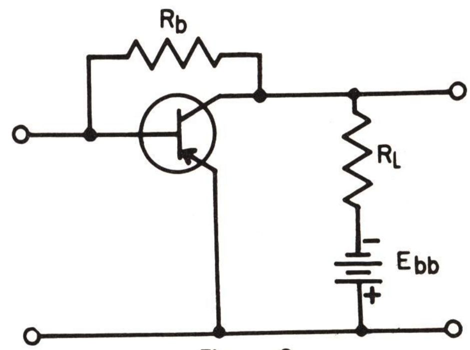


Figure 2

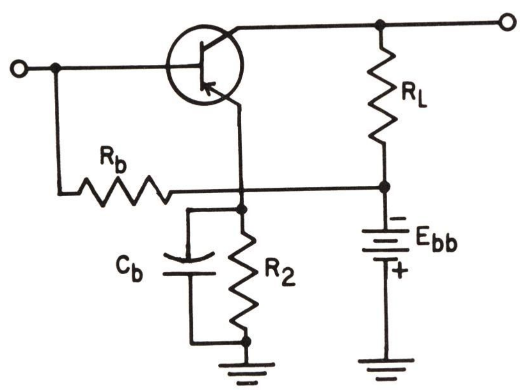


Figure 3

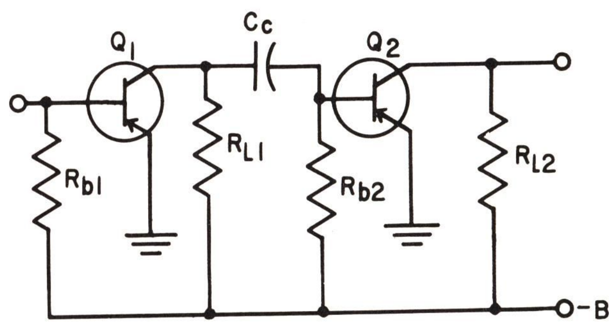


Figure 4

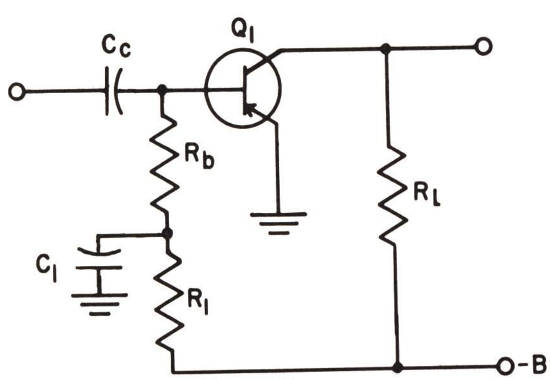


Figure 5

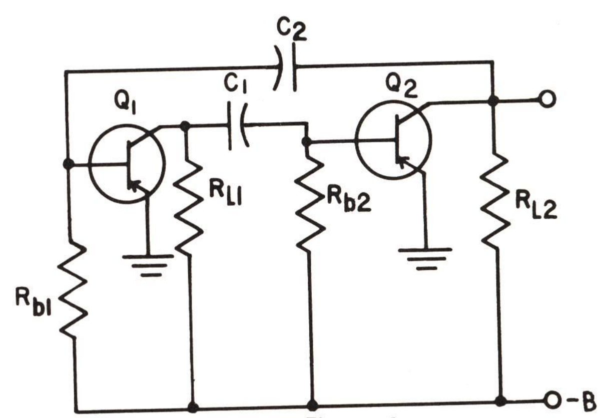


Figure 6

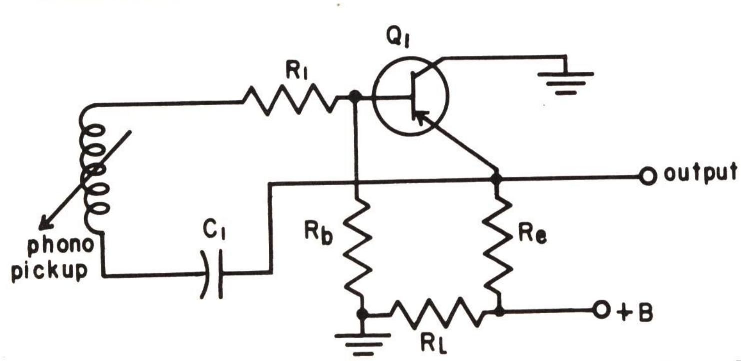


Figure 7

CIRCUIT DIAGRAMS FOR QUESTIONS

REVIEW QUESTIONS

The following multiple-choice questions are based on the material presented in the preceding text. Draw a line through the bold face letter corresponding to the completion you think is correct, thus:

a ~~**b**~~ **c** **d**

The correct answers are given at the end of the list of questions.

1. Collector current in a junction transistor of the PNP type will: (a) be less than unity as compared to the emitter current; (b) be more than unity as compared to the emitter current; (c) be greater than the total current; (d) always be constant. **a b c d**
2. In point contact transistors there is: (a) a constant current at all times; (b) a current gain less than unity; (c) a current gain greater than unity; (d) equal current in all regions. **a b c d**
3. The potential which exists at the junction of N and P type semi-conductors is called the: (a) potential high voltage region; (b) reverse bias potential; (c) forward bias potential; (d) potential gradient or potential energy barrier. **a b c d**
4. The nucleus of an atom exhibits: (a) a charge equal to zero; (b) a negative charge; (c) a positive charge; (d) a positive and negative charge. **a b c d**
5. The action of binding the valence rings together is known as the formation of: (a) covalent bonds; (b) trivalent bonds; (c) pentavalent bonds; (d) "Series E" Bonds. **a b c d**
6. Forward bias applied to a P-N Junction: (a) changes the semi-conductor to a higher resistivity; (b) increases the resistance to current flow; (c) has a net charge of +5; (d) decreases the resistance to current flow. **a b c d**
7. For best performance, the maximum operating frequency of a transistor should be what percentage of the frequency cut-off of the transistor: (a) 50%; (b) 100%; (c) 20%; (d) 80%. **a b c d**
8. When an impurity atom having a valence of +5 is added to germanium: (a) it changes to a liquid; (b) P-type semi-conductor is formed; (c) there is no change; (d) N-type semi-conductor is formed. **a b c d**
9. What is the most important factor of a power transistor: (a) impedance matching; (b) mounting; (c) output resistance; (d) heat dissipation. **a b c d**
10. In a point contact transistor the presence of holes in the vicinity of the collector causes: (a) a marked increase in the resistance of the collector region; (b) a marked increase in the collector current; (c) the collector current to decrease rapidly; (d) transistor action to cease. **a b c d**
11. The collector of a transistor is similar to: (a) the plate of a vacuum tube; (b) the grid of a vacuum tube; (c) the cathode of a vacuum tube; (d) the outer shell of a metal vacuum tube. **a b c d**
12. Germanium in its pure form is (a) a conductor; (b) an insulator; (c) a transistor; (d) a liquid. **a b c d**
13. P-N Junction is capable of: (a) rectification; (b) amplification; (c) replacing a pentode; (d) large power output. **a b c d**
14. Valence electrons are located in the: (a) outer electron ring of the atom; (b) inner ring of electrons of the atom; (c) nucleus; (d) protons. **a b c d**
15. The base of a transistor is similar to the: (a) suppressor grid of a vacuum tube; (b) plate of a vacuum tube; (c) cathode of a vacuum tube; (d) grid of a vacuum tube. **a b c d**
16. The "drift" transistor has a high frequency cut-off: (a) due to the high resistance of the base area; (b) since high collector voltages can be used; (c) due to the large base area; (d) due to its inherent low internal capacitance and low electron transit time through the base. **a b c d**
17. When transistor applications call for a temperature operating condition which exceeds 185°F, which element is most suitable: (a) antimony; (b) germanium; (c) silicon; (d) not possible to operate transistors above 185°F. **a b c d**
18. The output resistance of a PNP Junction transistor is: (a) the same as the input; (b) less than the input resistance; (c) much greater than the input; (d) zero. **a b c d**

19. A short electron transit time through the base region: (a) usually provides a higher frequency cut-off; (b) creates higher potential barriers; (c) provides a higher break down voltage; (d) reduces the amplification capabilities of the transistor. a b c d

20. Conduction within N-type semi-conductor material is carried on primarily by: (a) protons; (b) electrons; (c) holes; (d) neutrons. a b c d

21. An arrowhead drawn on the emitter lead on a transistor symbol indicates: (a) the direction of current flow; (b) the direction of electron flow; (c) it is a point contact; (d) the ground end of the lead. a b c d

22. The hole is the means of conduction within a: (a) P-type semi-conductor: (b) pentavalent semi-conductor; (c) molecule; (d) N-type semi-conductor. a b c d

23. An element which falls somewhere between being an insulator and conductor is called a: (a) N-type conductor; (b) intrinsic conductor; (c) semi-conductor; (d) P-type conductor. a b c d

24. The method of operating a transistor similar to that of a normal vacuum tube circuit is called a: (a) common or grounded base; (b) common or grounded emitter; (c) common or grounded collector; (d) normal base load connection. a b c d

25. A grounded emitter transistor amplifier circuit is similar to the electron tube: (a) grounded plate circuit; (b) grounded grid circuit; (c) grounded cathode circuit; (d) bootstrap circuit. a b c d

26. The current gain in a grounded emitter circuit is: (a) less than unity; (b) greater than unity; (c) equal to unity; (d) zero. a b c d

27. The input resistance as compared to the output resistance of a grounded emitter amplifier is: (a) smaller; (b) greater; (c) the same; (d) the same as electron tube amplifiers. a b c d

28. In Figure 1, the base current is 30 ua. What is the value of R_b?: (a) 100K; (b) 300K; (c) 200K; (d) 1K. a b c d

29. If the stabilizing resistor in the emitter is unbypassed the effective gain of an amplifier is: (a) increased; (b) reduced; (c) unaffected; (d) normal at low frequencies and increased at high frequencies. a b c d

30. The secondary impedance as compared to the primary impedance of an interstage coupling transformer in transistor circuits is usually: (a) higher; (b) lower; (c) the same; (d) not critical. a b c d

31. Large value coupling and bypass capacitors are required in transistor circuits due to the inherent: (a) low impedances; (b) miniaturization; (c) instability; (d) high impedances. a b c d

32. Class B amplifiers are usually preferred to Class A because there is: (a) less harmonic content; (b) better stability; (c) lower power requirement; (d) less critical to design. a b c d

33. To sustain oscillation in a transistor circuit what type of feedback is generally employed: (a) voltage; (b) sawtooth; (c) resistance; (d) current. a b c d

34. What is the main advantage of using a transistor as a phonograph pre-amplifier: (a) better stability; (b) increased sensitivity; (c) no microphonics; (d) no equalization required. a b c d

35. What type of transistor is used in video amplifiers: (a) drift; (b) hook; (c) diffused junction; (d) point contact. a b c d

36. What is the main limitation of video amplifiers using transistors: (a) low peak currents; (b) low peak voltage output; (c) poor frequency response; (d) will not pass sync pulses. a b c d

37. What metal is most widely used in miniaturized capacitors: (a) aluminum; (b) tantalum; (c) zinc; (d) cobalt. a b c d

38. Iron core transformers used in transistor circuits are readily miniaturized due to the: (a) low frequency response required; (b) few windings required; (c) lack of mounting space; (d) low DC current requirements. a b c d

39. What type of energy can cause destruction to transistors: (a) light; (b) sound; (c) heat; (d) AC voltages. a b c d

40. If resistor R_b in Figure 2 should increase in value which of the following would occur: (a) collector current increase; (b) collector current decrease; (c) base current increase; (d) no change in circuit operation. a b c d

41. If resistor R_L in Figure 2 should increase in value the input resistance would: (a) increase; (b) remain unchanged; (c) look capacitive; (d) decrease. **a b c d**

42. If condenser C_b in Figure 3 should open the signal gain of the circuit would: (a) decrease; (b) increase; (c) cause distortion; (d) remain unchanged. **a b c d**

43. If condenser C_e in Figure 4 should short, which of the following would occur: (a) R_{b2} would burn open; (b) Q_1 would be destroyed due to heat; (c) Q_2 would be in a non-conducting state; (d) signal distortion due to heavy conduction of Q_2. **a b c d**

44. If condenser C_1 in Figure 5 should short, which of the following would occur: (a) decreased gain; (b) increased gain; (c) Q_1 would destroy itself; (d) R_L would burn open. **a b c d**

45. If resistor R_{b2} in Figure 6 should open, which of the following would occur: (a) sine wave would be produced instead of a square wave; (b) Q_2 would conduct heavily; (c) little or no output of generated signal; (d) Q_1 would stop conduction. **a b c d**

46. If condenser C_2 in Figure 6 should open, which of the following would occur: (a) frequency would decrease; (b) stage would have no output; (c) greater output but would be distorted; (d) frequency would increase slightly. **a b c d**

47. If condenser C_1 in Figure 7 should short, which of the following would occur: (a) coil in phono pickup would burn open; (b) collector current would increase; (c) R_1 would open; (d) output would be distorted. **a b c d**

48. Excessive leakage current in a transistor can cause; (a) other components in the circuit to open; (b) decreased gain; (c) increased gain; (d) little or no effect. **a b c d**

ANSWERS TO REVIEW QUESTIONS

1. a	11. a	21. a	31. a	41. d
2. c	12. b	22. a	32. c	42. a
3. d	13. a	23. c	33. d	43. d
4. c	14. a	24. b	34. c	44. a
5. a	15. d	25. c	35. a	45. c
6. d	16. d	26. b	36. b	46. b
7. c	17. c	27. a	37. b	47. d
8. d	18. c	28. b	38. d	48. b
9. d	19. a	29. b	39. c	
10. b	20. b	30. b	40. b	

NOTES

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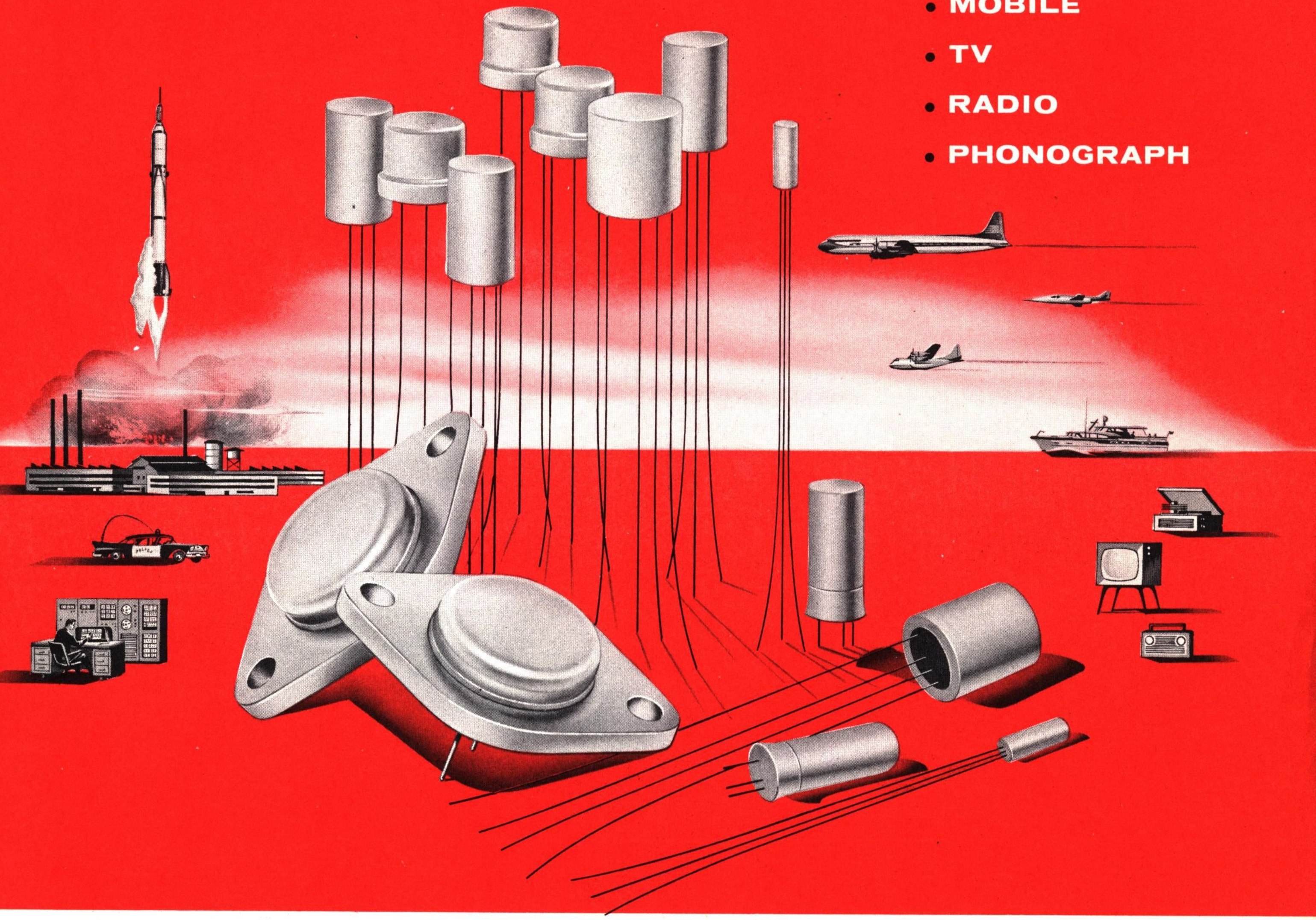

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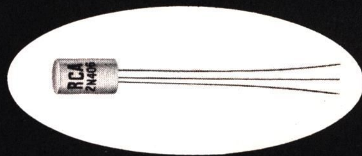
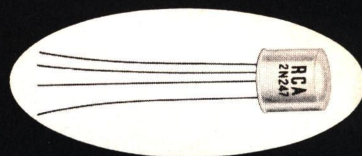

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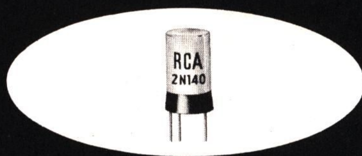

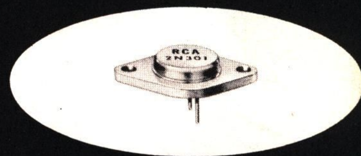
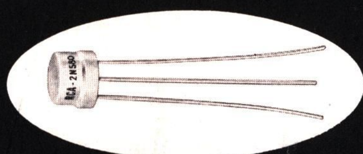
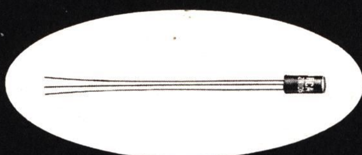

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