a
b
c's
of TRANSISTORS

by George B. Mann

- What they are
- How they operate
- Popular circuits
- Servicing methods

abc's of
TRANSISTORS

by George B. Mann

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FIRST EDITION

HOWARD W. SAMS & CO., INC.

THE BOBBS-MERRILL COMPANY, INC.

Indianapolis · New York

ABC's OF TRANSISTORS
Catalog No.: TRA-1

PREFACE

Very few developments have electrified the electronics industry as much as the transistor. Back in the '20's, radio was hailed as some sort of magic carpet which carried one's voice all over the world. Now comes the transistor to shrink the size of that magic carpet; by replacing vacuum tubes with transistors, manufacturers can produce receivers that are just a shadow of their former selves. Transistors have made a reality of the wristwatch radio. What other miracles can they evoke? Only time will tell!

Today's electronics technician or student must know transistors as well as he knows vacuum tubes. Much literature has already been written about transistors. Why, then, did I decide to add this book to the stack? The reason is plain—because of the definite need expressed by technicians and students for a basic, easily-understood volume on the subject.

ABC's of Transistors is precisely that—an ABC of transistors. It is simple enough that the student and technician should have no trouble understanding it, yet not so simple as to insult the reader's intelligence. In short, *ABC's of Transistors* is a primer of transistors.

This book does not involve you, the reader, in a labyrinth of technical information, nor does it dwell on specific servicing procedures for each type of transistor circuit. I felt that if you understand basic transistor circuits, you will know how to service them. If you carry away an understanding of the fundamentals of transistors and a desire to learn more about them, this book will have served its purpose.

George B. Mann

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1 TRANSISTOR FUNDAMENTALS

Transistor is a term applied to a large group of solid-state devices having three or more terminals connected to the semiconductor material. The transistors of primary interest to the service technician are the NPN and the PNP junction types used in automobile radios, audio preamplifiers, audio amplifiers, portable radios, and table-model radios. Transistor fundamentals, basic circuits, circuits in present-day home entertainment equipment, practical servicing procedures, and special handling considerations—as presented in this book—will be helpful to the technician interested in servicing transistor equipment.

The NPN and PNP transistors currently used in home entertainment equipment are essentially two junctions of semiconductor material. A study of basic transistor fundamentals should therefore begin with the semiconductor material.

SEMICONDUCTORS

The semiconductor material in most transistors employed in radio and audio equipment is either germanium or silicon. Semiconductors, as the term implies, fall in a category between good conductors and good insulators. The semiconductor material is not used in its pure state. Controlled amounts of certain impurities are added which, by imparting certain conduction properties to the material, produce what is known as a doped semiconductor.

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The doping material (impurity) may be one of two general types:

1. Donor impurity—donates electrons to the semiconductor. Donor impurities produce N-type semiconductors.

2. Acceptor impurity — accepts electrons from the semiconductor material. Acceptor impurities produce P-type semiconductors.

The primary difference between P and N material is in the method by which current flows. In N-type material, current flow is by electrons; in P-type material, current flow is by holes.

ELECTRONS AND HOLES

Electron is a familiar term associated with electronics and current flow. Current flow through wires, tubes, and other components is generally accepted to be by electrons, which are negatively charged particles. The term hole is fairly new to electronics and has a meaning opposite from the electron. Hole denotes a positive charge, or the lack of an electron— just as the term vacuum denotes the lack of air.

To describe the foregoing more fully, we must touch briefly on the atomic structure. Atoms are made up of a nucleus surrounded by rings of electrons. Each ring of a particular atom consists of a specific number of electrons. The electrons in the outer ring lie in a band termed the valence band (Fig. 1-1). A discrete level of energy in this band provides the force that binds all the electrons in the valence band of one atom to the electrons in the valence bands of other atoms and makes up the crystal structure (Fig. 1-2).

If we could add atoms with five valence electrons to the structure shown in Fig. 1-2, the material would then contain free electrons that would not be held by a valence band. This addition can be performed in semiconductors by adding a donor impurity, which produces an N-type semiconductor. The electrons (negative charges) not bound in the crystal structure can now be used as current carriers. In N-type material, the electrons are called majority carriers because the

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majority of the current flow will be by electrons. This statement presupposes that current can flow by holes, and this supposition is correct. The holes are minority carriers in N-type semiconductors.

Fig. 1-1. Exaggerated sketch of an atom, showing the various parts.
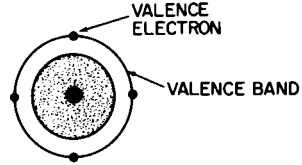
Just as we can add a donor impurity that donates electrons to the semiconductor material, we can add an acceptor impurity that accepts electrons. Thus, we have produced a P-type semiconductor. In the P-type semiconductor, we have atoms that lack an electron in the valence band. This lack of an electron is termed a hole, or positive charge. The hole, being the lack of an electron in the valence band of an atom, does not move out of this band; therefore, conduction takes place in the valence band. This action can occur in solids only (such as P-type semiconductors); it does not apply to vacuum-tube theory. Because the majority of current flow in P-type semiconductors is by holes, the holes are the majority carriers and the electrons are the minority carriers.

Fig. 1-2. Composition of crystal structure from atoms.
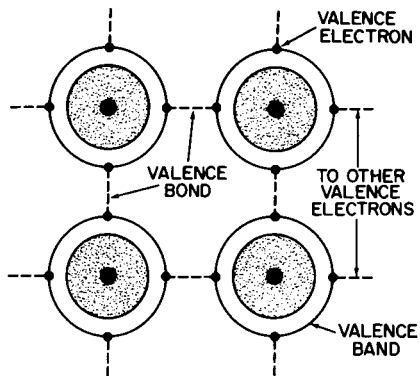
To understand this theory, the reader must remember that (1) an electron is a negatively charged particle which will be

attracted by and will move toward a positive charge and (2) the hole has a positive charge which will be attracted by and will move toward a negative charge.

An electron leaving the valence band will leave a hole in the valence band, and an electron-hole pair will be formed. The electron and the hole will have equal charges but opposite polarities. If an electron fills a hole in the valence band, the charges will be canceled.

The main points to remember are that electrons are negatively charged particles and that holes are positive charges. Both can move and, as such, can be current carriers. In N-type semiconductors, the electrons are the majority carriers; in P-type semiconductors, the holes are the majority carriers.

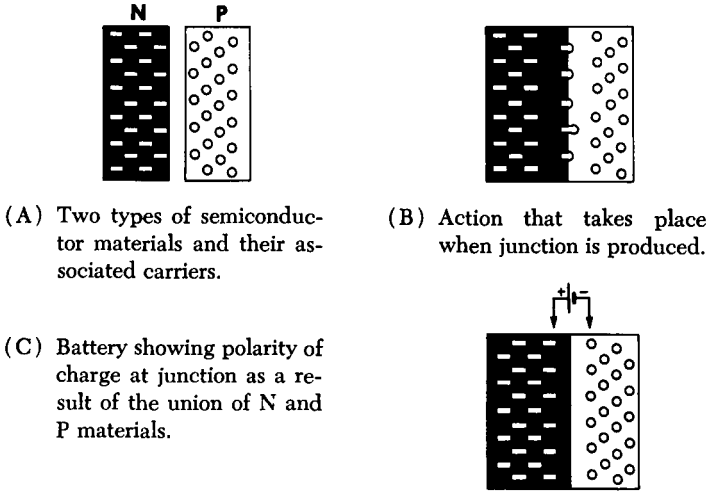### JUNCTION OF P AND N SEMICONDUCTORS

Transistor operation normally is based upon the action of the carriers at the junction of P and N materials. A pictorial method of describing the action of the carriers at a junction will probably be the easiest to follow. For this purpose, the blocks labeled N and P in Fig. 1-3A will represent the doped semiconductor materials. The N material is shown as having electrons as majority carriers, and the P material is shown as having holes as majority carriers.

In the N material or the P material, a net charge balance is maintained by the even distribution of majority carriers throughout the material. It must be recognized that the majority carriers are bound into the crystal structure of the semiconductor. The material itself has no charge, and current will not flow between two types of material if they are just placed in physical contact. The term junction implies that the materials are bound together at the molecular level by a process such as fusion or melting.

When P and N semiconductors are formed together to produce a junction, the majority carriers near the junction move toward each other and cancel out (Fig. 1-3B).

Because of this canceling action at the junction, a charge has now been created between the semiconductor materials.

Since some of the majority carriers (electrons in the N-type and holes in the P-type) have been effectively canceled, the material at the junction assumes a positive charge in the N semiconductor material and a negative charge in the P semi-

(A) Two types of semiconductor materials and their associated carriers.

(B) Action that takes place when junction is produced.

(C) Battery showing polarity of charge at junction as a result of the union of N and P materials.

Fig. 1-3. Action of the carriers at a junction.

conductor material. Remember, as we previously noted, the majority carriers were bound in the crystal structure and, before the junction was formed, there was an even distribution of these carriers in the semiconductor materials. Therefore, the material by itself had a zero net charge.

The electrons in the N material now are repelled by the negative charge in the P material, and the holes (positive charges) are repelled by the positive charge in the N material. These majority carriers therefore maintain positions back from the junction. The charge and its polarity at the junction are represented by the battery in Fig. 1-3C. This charge, or potential, is extremely small—in tenths of a volt—but does produce an effective potential hill or barrier to the passage of the current carriers. To pass from one side of the junction to the other, the electron or hole must gain energy equal to this potential hill.

The sources of external energy that can move the carriers across a junction may be radiation in the form of heat, light, or

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X rays; or the source may be a more usual one, like a battery or power supply.
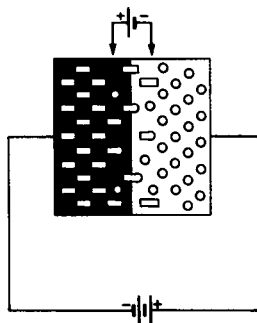
FORWARD AND REVERSE BIAS

The PN junction acts as a one-way valve, or rectifier, to the flow of current. There is through the junction a forward, or low-resistance direction, and a reverse, or high-resistance direction. Current flowing in the low-resistance direction is called forward bias; current flowing in the high-resistance direction is called reverse bias.

The potential hill at the PN or NP junction, represented by the battery at the junction in Fig. 1-3C, must be overcome before current can flow. When a battery is connected so that it aids or increases the potential hill at the junction, the carriers are pulled farther away from the junction (Fig. 1-4). The minus charge of the battery attracts the holes to the right, and the positive terminal of the battery attracts the electrons to the left. Such a reverse-biased junction can have a DC resistance reading in the megohm region.
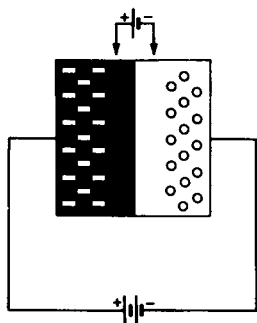
Fig. 1-4. Result of connecting a battery to aid, or increase, the potential hill (reversed biasing).

Fig. 1-5. Result of connecting a battery to reduce the potential hill (forward biasing).

As the applied voltage is increased, the potential hill increases, and the resistance of the junction also increases. Unlike a resistor, the reverse-biased junction increases its resistance as the voltage increases.

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The resistance of a reverse-biased junction depends upon the applied voltage. The current through a reverse-biased junction is relatively constant. As the voltage across a resistance is changed, the current changes. With a junction diode, however, the reverse-bias voltage produces a resistance change, but the current remains nearly the same. This condition can be shown by the Ohm's law formula $I=E/R$. Thus, if E (voltage) increases across a resistor and if the resistance is constant, I (current) will increase. If E increases and if the resistance increases proportionately (as it does in the junction diode), then I will remain constant.

> NOTE: The same diode will present different resistance readings on ohmmeters with different internal battery voltages or with different internal resistances.

The forward biasing of a junction will reduce the potential hill. When a battery with opposite polarity from that of the potential hill is applied to the junction, the carriers are moved up to the junction (Fig. 1-5). Holes and electrons now flow across the junction. This action results in a current flow in the external circuit. Another way of describing this action is by saying that the battery will inject excess holes in the P material by removing electrons and will inject electrons into the N material.

The forward bias is different from the reverse bias because the voltage necessary to overcome the potential hill is rather small; but once this potential is reached, the current has little opposition. As current increases, the resistance of the junction decreases. The applied voltage remains nearly the same. (A small rise in voltage is necessary to overcome the resistance of the semiconductor material.)

Summary

Resistance of a reverse-biased junction depends upon the applied voltage and is relatively independent from the current.

Resistance of a forward-biased junction depends upon the current flow and is relatively independent from the applied voltage.

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Forward bias is a voltage applied to a junction to overcome the potential hill. This bias is applied in what is called the low-resistance direction.

Reverse bias is a voltage applied to a junction in the high-resistance direction to increase the potential hill.

The action of the carriers at a junction should be well understood because the transistor is, in effect, two PN junctions. If the physical structure of the junction is changed, various results can be achieved.

THE JUNCTION TRANSISTOR

The transistor is composed of an emitter E, a base B, and a collector C. The arrangement in Fig. 1-6 is for an NPN transistor with an N-type emitter and collector and a P-type base. Notice that the base region of the transistor is drawn thin in
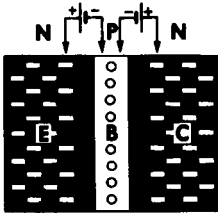
Fig. 1-6. Arrangement of an NPN-type transistor.

comparison to either the emitter or the collector regions. There is a reason for this thin base region: it affects both the majority and the minority carrier action at the junctions.

The proper base-to-emitter bias for an NPN transistor is shown in Fig. 1-7A. When the base-to-emitter battery is connected in the forward direction, the majority carriers are forced up to the junction, and a current flow is produced between the base and the emitter. The holes move into the N material, and the electrons move into the P material. Recombination takes place at the junction, but the combining of electrons and holes can also take place after the carriers have passed this barrier. The existence of such minority carriers (electrons in this example) in the base region is of prime importance to the operation of a transistor.

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When free electrons exist in the emitter region of an NPN transistor, they are majority carriers; but when these same electrons cross the barrier into the base region, they are considered minority carriers. These electrons eventually combine with holes in the base region unless some field or force intervenes.

(A) The proper base-to-emitter bias for an NPN-type transistor.

(B) Action caused by connecting a second battery in the reverse bias direction of an NPN-type transistor.

(C) Effect of a thin base region on transistor action.

(D) The PNP-type transistor showing reversed action.
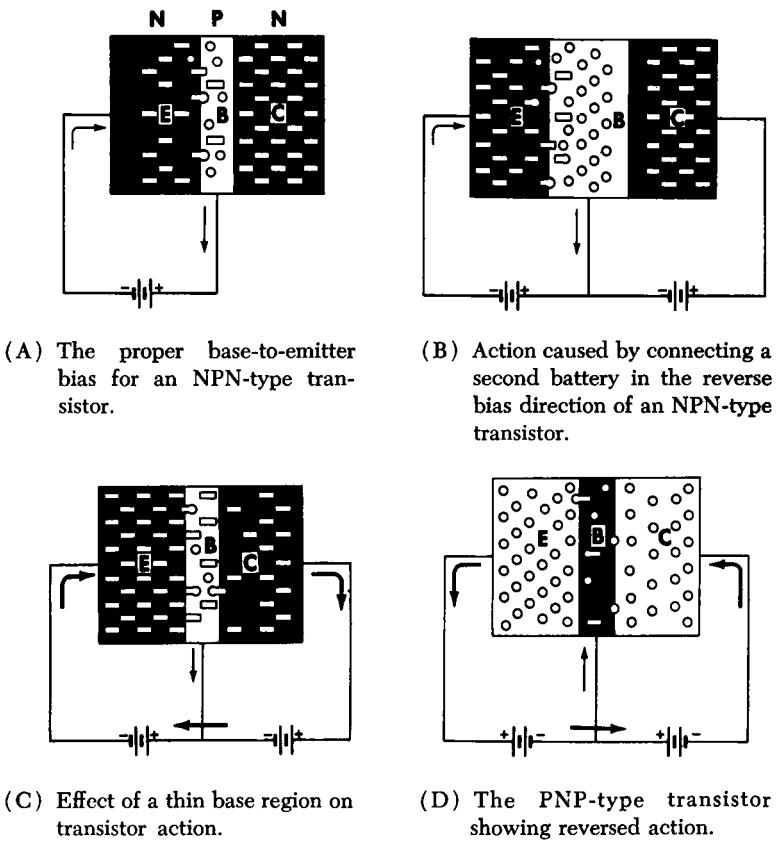
Fig. 1-7. The effect of forward and reverse biasing of a transistor.

In Fig. 1-7B a second battery is connected to the transistor. This battery is connected in the reverse-bias direction and has thus caused the carriers to move away from the base-to-collector junction. A wide base region permits all of the electrons from the emitter to recombine with holes in the base region. In this situation we actually have two diodes, one forward

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biased and one reverse biased; and no transistor action takes place.

In Fig. 1-7C the base region has been made thin. The electrons forced into the base region by the forward bias at the emitter-to-base junction are now attracted by the positive charge of the N-type material at the junction of the collector and base. A large number of electrons now traverse the base region and reach the collector before recombination takes place. A small number of electrons and holes do recombine in the base region to produce a current in the base-to-emitter circuit.

Summary

The forward bias of the emitter-to-base junction produces electron flow into the base region. The proximity of the base-to-collector junction causes the electrons to be attracted to the collector. The result is a current flow from the emitter to the collector.

The PNP transistor action is identical to the action of the NPN except that the roles of the electrons and the holes are reversed, as shown in Fig. 1-7D.

The forward bias on the base-to-emitter junction causes holes to be injected into the base region. The negative charge of the collector causes these holes to progress through the base region and into the P-type material of the collector. Recombinations of some holes with the electrons in the base region result in a small current flow in the base circuit.

CURRENT CONTROL

The forward bias or the injection of carriers into the base region controls the amount of current that will flow in the collector circuit. Increasing or decreasing the electron flow into the base region of an NPN transistor will increase or decrease the electrons available to the collector circuit. For a PNP transistor, the availability of holes to the collector is controlled by the injection of holes into the base from the emitter.

The forward bias of the emitter-to-base junction provides energy to the carriers on each side. Because of the energy

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added to the carriers, they can pass over the potential hill more easily. In other words, because the height of the potential hill has been effectively reduced, the carriers can pass more readily. Incidentally, the potential hill does not decrease to zero. As the potential hill gets smaller, the number of recombinations increases to maintain a barrier. If more carriers cross the junction, more minority carriers will be available in the base region or will be available to the collector.

The collector current depends upon the number of available minority carriers in the base region. Increasing the collector voltage does not increase the number of available carriers. Therefore, the collector current will remain relatively constant as the collector voltage changes.

The height of the potential hill between the emitter and the base is determined by the emitter-to-base bias. The height of the potential hill also determines the collector current. Decreasing this hill increases the available carriers, and increasing the hill decreases the available carriers. Thus, the collector current can be controlled, although amplification is not necessarily produced.

AMPLIFICATION AND GAIN

Amplification and gain, whether they be of power, current, or voltage, are measures of the difference between the input and the output. The transistor can perform as an amplifier in various circuit configurations, and in each, the basic operation of the transistor itself will remain the same.

The input circuit of a transistor is associated with the injection of carriers into the base region. The output circuit is associated with the flow of carriers from the emitter to the collector. The larger portion of the current flow is from emitter to collector, and only a small current will flow between emitter and base. Circuits like the one in Fig 1-8 can be used to demonstrate this effect.

In this circuit, meter M1 will indicate the bias current or the current flow between the base and emitter. Meter M2 will indicate the collector current. When resistance R1 is changed,

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the current in M1 will change, but the current change in M2 will be much larger. A small change in the base current has produced a larger change in the collector current.

The voltage drop across resistor R1 will be small, not greater than the voltage of battery B1. The voltage across resistor R2 will be much larger, particularly if the voltage of
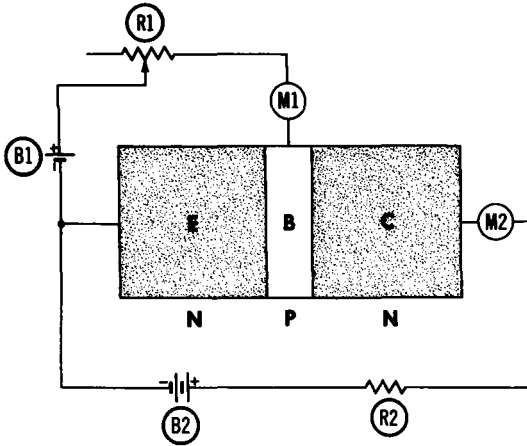
Fig. 1-8. Circuit illustrating basic operation of the NPN-type transistor as an amplifier.

battery B2 is larger. In this circuit then, a voltage gain has been realized.

In practice, the circuitry can be arranged to produce either voltage or current gain, or both; but in either case, the basic operation of the transistor remains the same.

2 *PHYSICAL CONSTRUCTION*

The operation of many electronic devices can be explained by physically breaking down the item. For example, each component (grid, plate, cathode, and heater) of a vacuum tube can be removed and inspected. This method lends strength to the understanding of vacuum tubes.

A transistor junction, the heart or functioning part of the transistor, is so small that good observation of it requires a microscope; even then, there is some doubt whether anything will be observed, other than a small piece of metal with three or more contacts fastened to it. Even the power transistor types contain a small wafer of semiconductor with very small contact areas. Little information can be gained from a visual examination of the collector, base, or emitter.

The transistor is a solid-state device in which current control takes place inside a solid crystal of specially fabricated metal. Purity of the metal throughout the processing is extremely important in order that the desired properties can be maintained. The exposed transistor crystal with leads attached will function properly in a circuit; but exposure to moisture, gases, light, or heat will soon affect the operation of the crystal. The unit must be hermetically sealed in some type of envelope or case if consistent operation is to be expected over a long period of time.

The envelope or case may be constructed of such non-porous types of materials as metal, glass, plastic, or ceramic. A number of these materials were used in early production types. More recently, the structure of the envelopes that enclose the semiconductor has been fairly standardized throughout the industry. Some general types of transistors in use today are shown in Fig. 2-1.
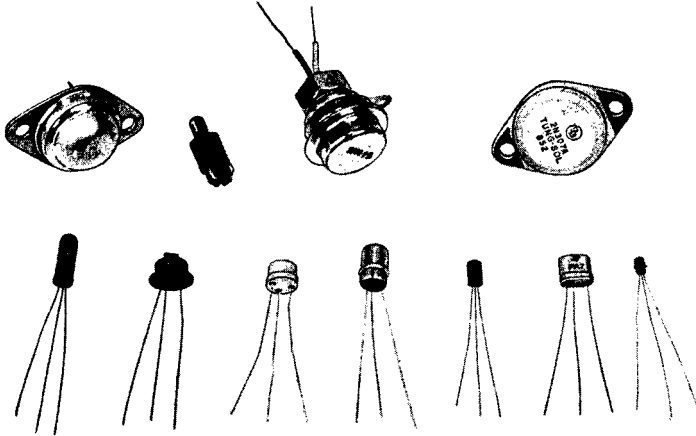
Fig. 2-1. General types of transistors.

The transistor case must be constructed of an opaque substance that excludes light, since light will affect the operating characteristics of the transistor. (The one exception is the phototransistor; because light is the current-control medium, a portion of the envelope must be transparent.) Metal is used in most envelopes because it is easy to shape, excludes light and most other forms of radiation, and is an extremely good conductor of heat.

The case of the transistor is hermetically sealed to exclude contaminants. Many transistors contain an inert gas or a powder that conducts heat from the semiconductor to the case. Therefore, the amount of power the transistor can handle is increased.

SHOCK

Transistors are not shockproof. Although they can with-stand a great deal of abuse, they should not be subjected to an undue amount. The transistor usually is mounted in such equipment as a portable receiver; and if the receiver is dropped, the case absorbs most of the shock. The transistor should be handled rather carefully, since it can be damaged by being dropped on the bench or floor.

POWER TYPES

The power transistor, because of its construction, permits maximum dissipation of heat. The transistor is heat sensitive, since its operating characteristics change as its operating tem-perature changes. Therefore, the design of a power-transistor
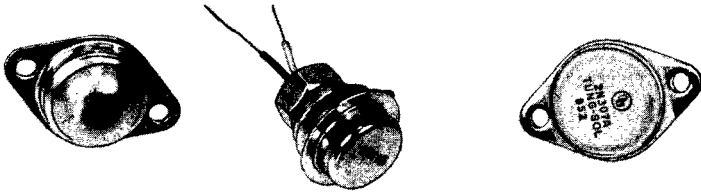

Fig. 2-2. Several examples of power transistors.

envelope is closely associated with the amount of power that must be dissipated. A number of power transistors are shown in Fig. 2-2.

The envelope of the power transistor is constructed of a good heat conductor, such as aluminum, copper, and/or com-binations of heat-conducting metals. The construction of one type of power transistor is shown in Fig. 2-3. The case is formed of copper or copper alloy, and the collector of the junc-tion is mounted directly to this case. This direct contact be-tween collector and case provides a maximum of heat transfer from junction to case.

The total power that a transistor can safely handle depends upon the efficiency of the heat sink or heat radiator. When a transistor is operated without a heat sink, the power input must be reduced to protect the transistor. High power
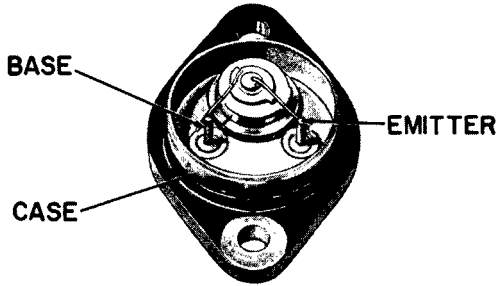

Fig. 2-3. Construction of a power transistor.

output requires that large amounts of heat be dissipated into some form of heat sink. A few of the arrangements for increasing the heat dissipation of power transistors are shown in Fig. 2-4.

The heat sink of Fig. 2-4A is both a heat sink and a radiator. Note that the radiator is insulated from the chassis. In Fig. 2-4B the heat sink is also insulated from the main chassis. The transistors in Figs. 2-4A and 2-4B are both fastened directly to the heat sink. This metal-to-metal contact affords maximum heat transfer to the heat sink.

In Fig. 2-4 the transistor is mounted on the receiver chassis, but is insulated from the chassis by the glass fiber pad. Contact is made to the collector by a solder lug clamped directly to the transistor case.

When properly mounted to the heat sink, the transistor can operate at its rated output level. If the heat transfer is reduced by improper mounting, if the size of the heat sink is reduced, or if air circulation is blocked, the transistor can be ruined. When a heat sink is used with a transistor, the heat sink must be considered part of the transistor.
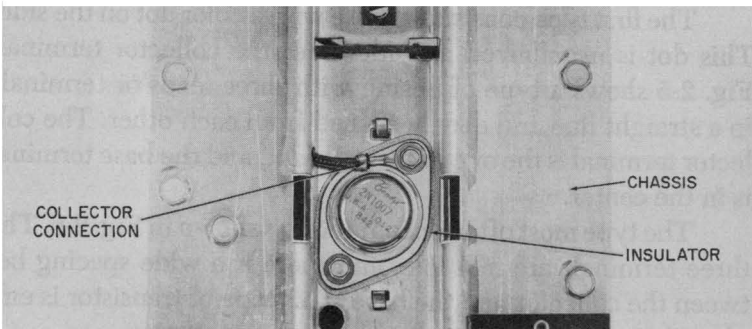
The transistor is easily damaged if voltage and current are improperly applied. The correct polarity of voltage must be

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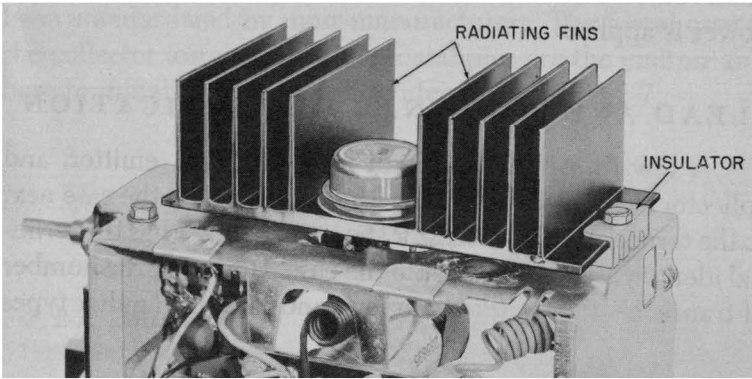
(A) Heat sink using radiating fins.
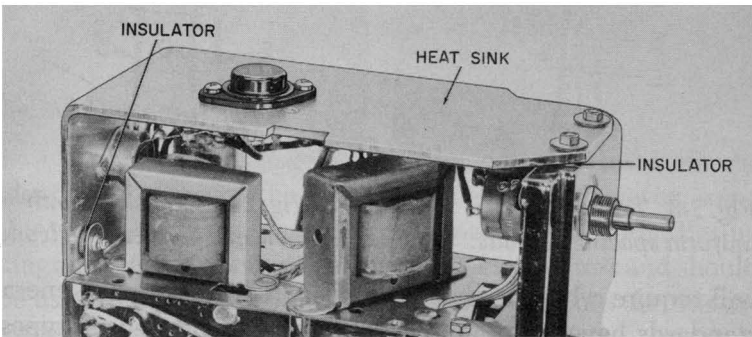
(B) Insulated portion of chassis used for a heat sink.

(C) Receiver chassis used as a heat sink.

*Fig. 2-4. Three types of heat sinks.*

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observed, and the terminal connections must be correct before power is applied.

LEAD AND TERMINAL IDENTIFICATION

A few transistor types will have the base, emitter, and collector terminals identified with B, E, and C on the case next to the terminals. The transistor shown in Fig. 2-7 has the terminal identification stamped into the case. However, the number of transistors thus marked are few, and most unfamiliar types
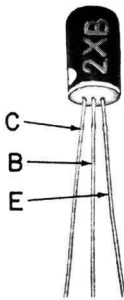
Fig. 2-5. Transistor with uniform spacing of leads.
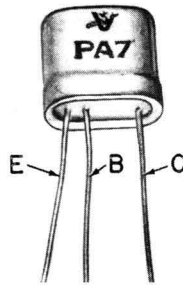
Fig. 2-6. Transistor with uneven spacing between leads.

will require a basing diagram for lead identification. General standards have been adopted for the most often-used types. These types fall into three groups and can easily be recognized when they are encountered.

The first type consists of those with a color dot on the side. This dot is usually red and identifies the collector terminal. Fig. 2-5 shows a type of basing with three leads or terminals in a straight line and evenly spaced from each other. The collector terminal is the one nearest the dot, and the base terminal is in the center.

The type most often encountered is shown in Fig. 2-6. The three terminals are in a line, and there is a wide spacing between the collector and the base. This type of transistor is employed extensively in transistor portable receivers.

The power transistor shown in Fig. 2-7 is the type generally found in automobile radios, converter power supplies,

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and other power applications. The case of this transistor has been standardized by most manufacturers. The metal case is the collector terminal, and the metal pins are the emitter and base terminals. These items are identified in Fig. 2-7.

Fig. 2-7. Bottom view of power transistor.
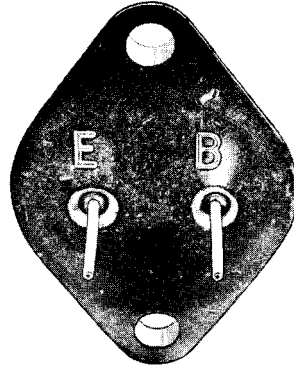
Basing Diagrams

Most transistors in general use have terminals that can be identified by one of the preceding methods. However, some transistors use other systems of terminal identification. Basing diagrams can be obtained for all types of transistors and should be used to positively identify the terminals before the transistor is connected into a circuit.

BASIC TRANSISTOR CIRCUITS

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The circuit symbols for the PNP and NPN transistors are shown in Fig. 3-1. The symbols in Fig. 3-1A are generally accepted, and can be used either with or without the enclosing circle. The other symbols in Figs. 3-1B and 3-1C are less used, but will be encountered from time to time.

The arrow on the emitter lead is the only difference between the PNP and the NPN symbols, as shown by Fig. 3-1. The arrow also indicates the direction of hole flow and the location of the negative supply terminal.

On all symbols for solid-state devices, the direction indicated by the arrow is the direction of hole flow. This procedure also has been adopted for solid-state diodes and rectifiers. The diode or rectifier symbol is shown in Fig. 3-2. The bar is the cathode and the arrow is the anode.

POLARITY OF TERMINALS

The polarity of voltage applied to the PNP transistor is the opposite of that applied to the NPN. In Fig. 3-3 the PNP and NPN symbols are shown with the relative polarity of voltage that exists between each of the terminals.

The transistor can be operated in three circuit configurations—common base, common emitter, and common collector. The configurations are also referred to as grounded base,

grounded emitter, and grounded collector. The term "common" or "grounded" refers to the element that is common to both the input and the output circuits. In Fig. 3-3A the symbols are positioned in common-base configurations. The input is applied between the emitter and the base, and the output appears between collector and base.
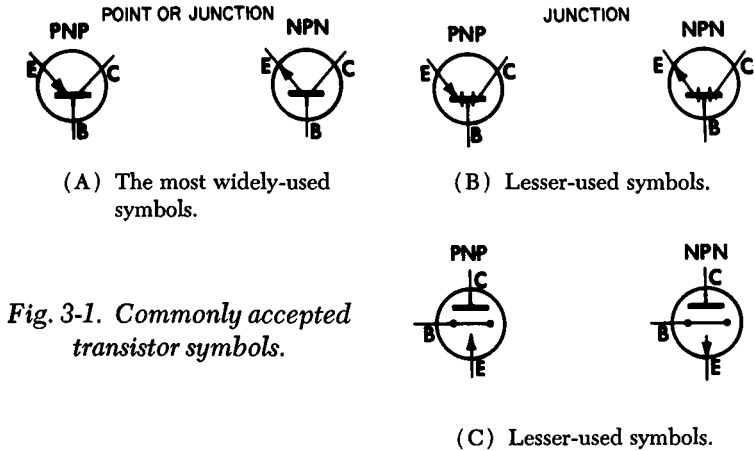

(A) The most widely-used symbols.

(B) Lesser-used symbols.

Fig. 3-1. Commonly accepted transistor symbols.

(C) Lesser-used symbols.

In Fig. 3-3B the emitter is the common terminal. The signal is applied to the base terminal, and the output is taken from the collector.

Fig. 3-3C shows the common-collector configuration, which is also referred to as an emitter follower. The base is the input terminal, and the emitter is the output terminal. This configuration is the least popular of the three configurations. It is used primarily to match a high impedance to a low impedance.

Fig. 3-2. The common semiconductor diode symbol.

CATH.

DIRECTION OF HOLE FLOW
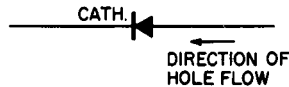
The polarity of voltages applied to the terminals of the NPN transistor is the same for each of the three configurations; only the points of input and output are changed. The polarity of voltages applied to the NPN transistor is the exact reverse of the polarity applied to the PNP types.

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Two simple rules can be employed to remember the three transistor configurations:

1. The base must be one terminal of the input circuit.
2. The collector must be one terminal of the output circuit.

(A) Common base.

(B) Common emitter.

(C) Common collector.
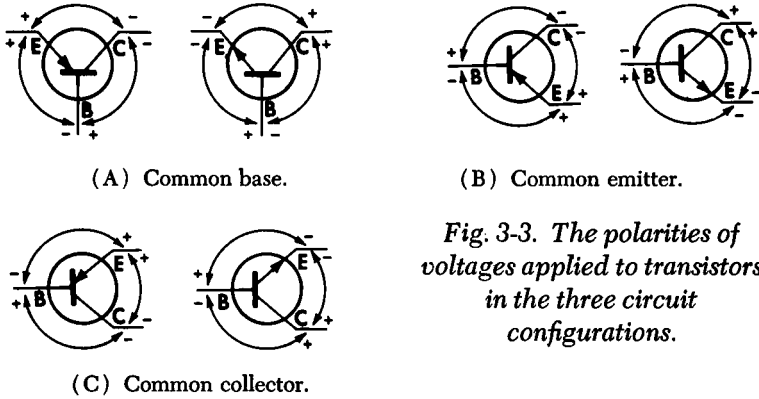
Fig. 3-3. The polarities of voltages applied to transistors in the three circuit configurations.

TRANSISTOR BIAS

The bias of a diode junction has been described as the flow of current or the application of voltage in a forward or reverse direction (forward or reverse bias). The bias of a transistor is the voltage applied to, or the current flowing between, the emitter and base. This bias determines the operating characteristics of the transistor, and can be considered as being either current bias or voltage bias, or both. The description used depends upon which one best describes the circuit being considered.

(A) NPN electron flow.
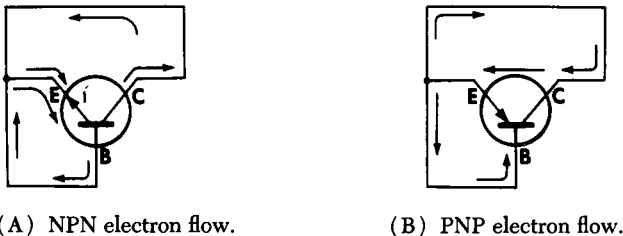
(B) PNP electron flow.

Fig. 3-4. Direction of electron flow in transistors of opposite conduction types.

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The current bias of a transistor will vary from a few micro-amperes to a few hundred microamperes. The bias voltage will seldom exceed a maximum of one volt, and part of this voltage is made up of the IR drop through the semiconductor material of the emitter and base. Most transistor specifications will list the transistor bias in terms of current flow in the base circuit.

The forward current at the emitter-to-base junction controls the current flow between the emitter and collector. Increasing the base current increases the current from the emitter to the collector. Decreasing the base current decreases the current between the emitter and collector. The arrows in Fig. 3-4 indicate the direction of electron flow in NPN and PNP transistors. The emitter current is equal to the base current plus the collector current.
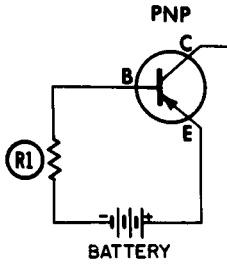
(A) Constant-current bias method.
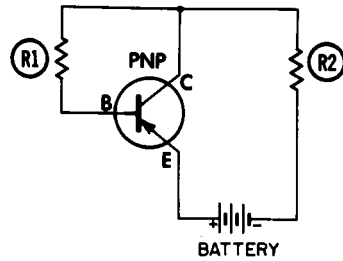
(B) Constant-current bias with DC compensation.
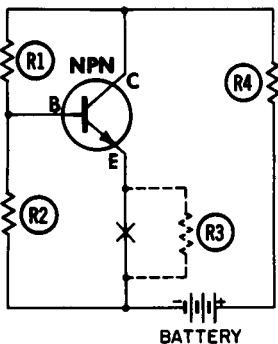
(C) Voltage-divider biasing with DC compensation.

(D) Voltage-divider biasing with current feedback.

Fig. 3-5. Methods of biasing common-emitter circuits.

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Common-Emitter Biasing

The circuit most often encountered is the common-emitter configuration. The common-emitter circuit has a distinct bias advantage in that one battery will supply both bias in the emitter circuit and power in the collector circuit.

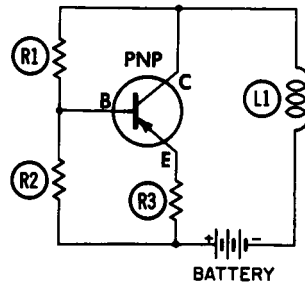Various biasing arrangements are shown in Fig. 3-5. The circuit of Fig. 3-5A provides a constant-value bias current. Resistance R1 is much larger than the base-to-emitter resistance. The battery voltage will produce a given current flow through resistor R1, and any change in base-to-emitter resistance will have almost no effect upon the current. This is a constant-current method of biasing a transistor.

If the characteristics of the transistor change or if a new transistor with different characteristics is substituted, the same amount of current will not provide the proper operating point. For most applications, the circuit must be so designed that variations within the transistors themselves or variations between the same types will not have a detrimental effect upon circuit operation.

Figs. 3-5B, C, and D show biasing arrangements that provide DC compensation for transistor variations. In Fig. 3-5B, resistor R1 is connected from collector to base. Increased collector current will lower the voltage at the collector because of the increased drop across collector load R2. The reduced voltage at the collector reduces the bias; and as a result, the collector current decreases. This action tends to stabilize the circuit and permits wider-tolerance components to be used.

In Figs. 3-5C and 3-5D, a voltage-divider arrangement provides a proper bias condition. Resistor R3, in series with the emitter, provides current feedback. When the load resistance is large, the current change through R3 is small. In Fig. 3-5D, the load is shown as an inductor. Because there is little DC voltage drop in this circuit, R3 now becomes important in maintaining the operating characteristic of the stage. Current feedback is particularly useful in stabilizing the RF and IF stages of transistor radios.

Emitter resistor R3 in Fig. 3-5C causes the emitter to follow changes in the collector current. As the collector current

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increases, the emitter voltage level rises, moving closer to the potential on the base. This decrease in potential difference between base and emitter reduces the bias current and tends to return the transistor to its correct operating characteristic.

Common-Collector (Emitter-Follower) Biasing

The common-collector circuits in Figs. 3-6A and 3-6B are identical. In the circuit in Fig. 3-6A the emitter, which is the output terminal, is at the top right. In the circuit in Fig. 3-6B
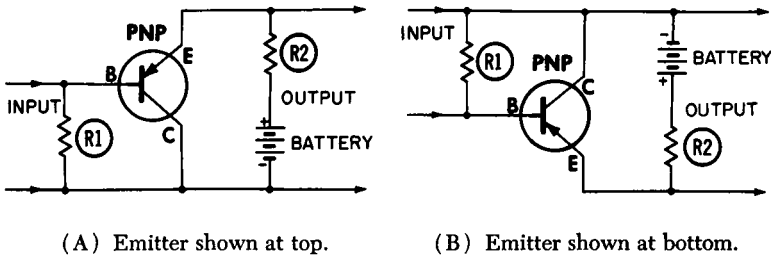

(A) Emitter shown at top.   (B) Emitter shown at bottom.

Fig. 3-6. Method of biasing common-collector circuits.

the collector is at the top right in the conventional manner. Resistor R1, the base-to-emitter junction, and load resistor R2 form a series load across the battery. The collector-to-emitter path and resistor R2 form another series circuit. Because input current and output current both flow through load resistor R2, it is common to both circuits. Increased current flow in the collector will move the emitter potential nearer to the base potential. The increased IR drop across R2 will reduce the current through resistor R1 and through the base-to-emitter junction. The reduction in bias current will prevent large current changes from taking place in the collector.

This emitter resistor is the load resistor, and current feedback is nearly 100%. The emitter-follower circuit is extremely stable.

Common-Base Biasing

The common-base circuit requires two voltage-supply points or two batteries, one for power and one for biasing. In Fig. 3-7 resistor R1 and battery A give the correct operating

bias. The bias current from battery A flows through resistor R1, the emitter, the base, and back to the battery. The output current path is from battery B through battery A, resistor R1, the emitter, the collector, load R2, and back to the battery. In this circuit, the input and output currents differ only by the amount of bias current flowing in the base.
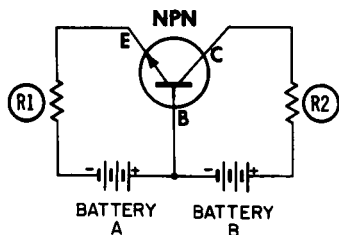
Fig. 3-7. Biasing for the common-base circuit.

The emitter and collector circuits are practically independent from each other, although the same current flows in both. The input current is moved by battery A, and the output current is moved by battery B. The collector current through resistor R1 provides a current feedback that tends to stabilize the transistor stage. Higher temperatures will increase both the collector current and the voltage drop across R1; thus the bias current will be reduced. This action tends to return the transistor to its proper operating point.

AMPLIFICATION

The meaning of amplification can be extended to cover a great deal of territory. For instance, a relay that requires only a small wattage for its operation can control hundreds of watts by simply closing or opening contacts. Relay action, even though an on-off sequence, can be considered as being amplification. Transistors can be made to perform as on-off switches at low speeds or at speeds in excess of those obtainable mechanically.

The change generally referred to as amplification is a constant but smooth change of signal that is reproduced in its entirety. The term "amplification" includes signals that are increased or decreased in voltage, current, and power, or in any

combination of these units. Amplification for any one stage may be as high as ×1000 or as low as ×3, and even less than one (<1 or ×0.85).

Amplification is an expression of the difference between the input and the output signals of a circuit or of a series of circuits. Amplification is equal to the output current or voltage

CHARACTERISTICS	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
VOLTAGE GAIN	MEDIUM (IOO to 2OO)	HIGH (3OO to 6OO)	<I
CURRENT GAIN	<I (.98)	MEDIUM (2O to IOO)	MEDIUM (2O to IOO)
POWER GAIN	MEDIUM	HIGH	LOW
INPUT IMPEDANCE	EXTREMELY LOW	LOW	EXTREMELY HIGH
OUTPUT IMPEDANCE	EXTREMELY HIGH	MEDIUM	EXTREMELY LOW
PHASE CHANGE INPUT TO OUTPUT	0°	180°	0°

Fig. 3-8. Characteristics of the three amplifier configurations.

level divided by the input current or voltage level and is also equal, in the case of AC, to the change in output level divided by the change in input level.

The chart in Fig. 3-8 lists the relationships between the three circuit configurations and their gains and impedances. The figures and notations are relative to each other; for instance, in the common-emitter circuit, the input resistance is lower than that of the common-collector circuit, but is higher than the input resistance of the common-base circuit.

Common-Emitter Amplifier

In the common-emitter circuit of Fig. 3-9A, the input (bias battery A) and the output voltage source (battery B)

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are equal in voltage. This arrangement establishes the levels of current flowing in the input (1) and output (2) circuits. A variable resistor R1, which sets the bias current at 1 milliampere, is employed.
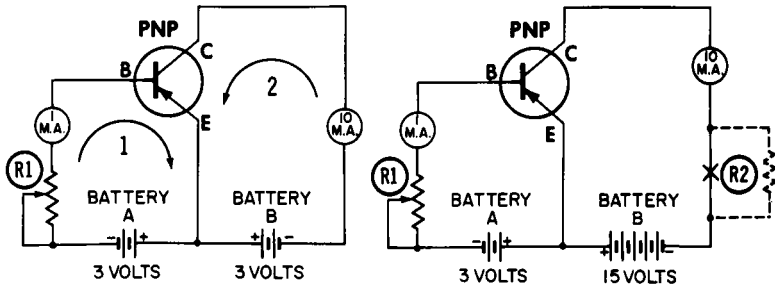
(A) With a 3-volt collector supply.   (B) With a 15-volt collector supply.

Fig. 3-9. The common-emitter amplifier.

With a static current gain of ten, the collector current will be 10 ma. This action is termed a static current gain because both the input and the output have static values. One milliampere of current in the input controls ten milliamperes in the output. If the input current is reduced to 0.8 ma and if the output current drops to 8 ma, the change will be 2 ma in the output divided by 0.2 ma in the input, or an AC current gain of 10.

In Fig. 3-9B supply battery B has been changed to 15 volts, and the collector current remains at 10 ma. (The current in the collector circuit is relatively independent from the collector voltage.) A resistance R2 can be inserted into the collector circuit to produce an IR drop. This voltage will vary as the input varies, and a voltage gain will be produced. Because of the small voltage necessary to change the base current, the voltage amplification can be quite high. Voltage gains over 100 are not unusual for a transistor amplifier.

Common-Base Amplifier

The chart of Fig. 3-8 lists the current gain of the common-base circuit at about 0.98. This is a gain of less than one be-

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cause more current flows in the input circuit than in the output circuit (Fig. 3-10A).

The current in the input circuit is composed of the output current plus the bias current. The output current (in either
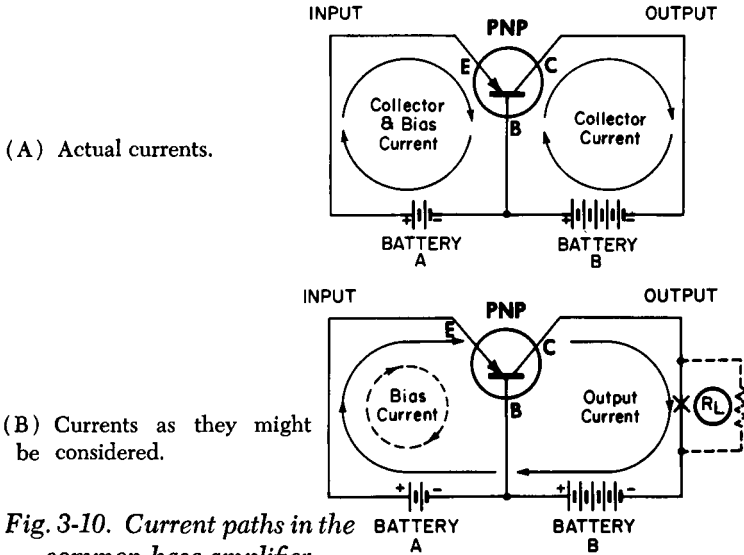

(A) Actual currents.

(B) Currents as they might be considered.

Fig. 3-10. Current paths in the common-base amplifier.

circuit) is collector current only. Observe that the base lead theoretically has two collector currents of opposite polarity; actually, these currents cancel each other and leave only the bias current flowing in the base lead.

The current paths of Fig. 3-10A can thus be described as shown in Fig. 3-10B, in which the output current flows in both circuits. Although the same current flows in both circuits, it must be considered as being two currents, the input current and the output current.

The collector current is controlled by the amount of bias or signal current impressed across the emitter-to-base junction. The impedance of the collector circuit will be determined by the collector supply voltage, and an increased supply voltage will increase the output impedance. A load, such as resistor R_L inserted into the output circuit in Fig. 3-10B, will have an IR drop (collector current × resistance) across it that will be greater than the voltage which moves this same amount of

current in the input circuit. A voltage gain is thus realized from input to output.

Common-Collector (Emitter-Follower) Amplifier

Fig. 3-11A shows the basic circuit for a common-collector amplifier. The input signal is applied to the base and collector, and the output is taken from the emitter and collector.
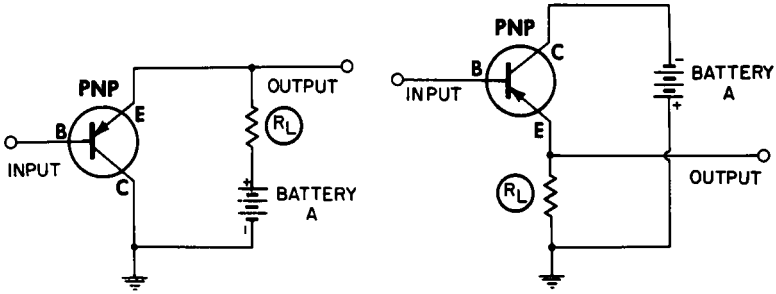
(A) The basic common-collector   (B) A common-collector amplifier
    amplifier.   with the collector ungrounded.

Fig. 3-11. The common-collector amplifier.

Fig. 3-11B shows that the output lead is separated from the input lead by the emitter-to-base junction. The voltage between the emitter and the base will change only about 1 volt between collector cutoff and full conduction; therefore, the voltage of the output signal will remain almost the same as the voltage of the input signal, but the current flow in the output circuit will be much greater than the current flow in the input circuit.

The circuit is called an emitter follower because of the action of the emitter. As the input voltage on the base of the transistor in Fig. 3-11B becomes more negative, the current flow in the transistor increases. This increased current flow produces a larger voltage drop across emitter resistor R_L. Thus, the changes in the emitter voltage tend to follow the changes in the base voltage.

The emitter follower has a current gain close to that of the common emitter; but, because there is no voltage gain, the power gain is much less. The main advantages of this circuit are the very high input and very low output impedances,

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which make this circuit useful as an impedance-matching device.

OSCILLATORS

The operation of an oscillator can best be described as being an amplifier, in which a portion of the output energy is returned to the input to produce a cyclic change in the amplifier conduction.

All amplifiers have power losses due to current flow through the resistance of the wiring, resistors, capacitors, and coils, and in the amplifying device itself. These items all consume energy and dissipate it as heat (I^2R loss). This energy loss is replaced by a battery or other power source. Additional energy must be supplied to produce an amplified version of the input signal.

The energy supplied to an amplifier is in the form of DC. The energy losses must be replaced in proper time relation to the input signal before oscillation can take place. Oscillator action is similar to a self-propelled swing. When children first learn to swing, they find it difficult to apply the right movements and cannot swing very high. After a good deal of practice, they swing very well. (In fact, many of them swing too well.) It's not the amount of energy they supply to the swing, but the manner in which it is applied that makes the difference.

Because a push is required to keep an oscillator operating, it is a form of swing. One type of oscillator requires an outside push, much like one child pushing another in a swing. The bi-stable, or flip-flop multivibrator is an example. Circuits for special applications can be so designed that, for each externally applied push, they will oscillate for part of a cycle, for one cycle, or for a number of cycles.

Of more immediate interest is the free-running oscillator, in which a portion of the amplified output is returned to the input. When the amount of energy returned to the input is equal to and in phase with the signal-energy losses, the amplifier will become unstable. If the feedback is increased beyond this point, the amplifier will oscillate.

The transistor amplifier has been described in its three basic circuit configurations. Since an oscillator is simply an amplifier that has a feedback arrangement for producing a
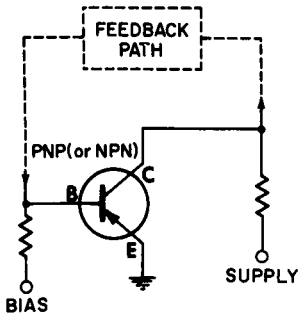
(A) The basic common-emitter oscillator.
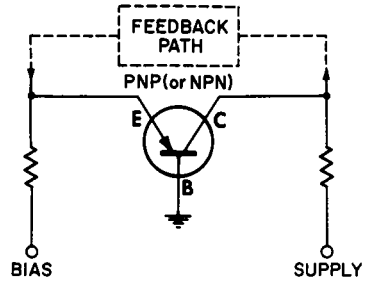
(B) The basic common-base oscillator.
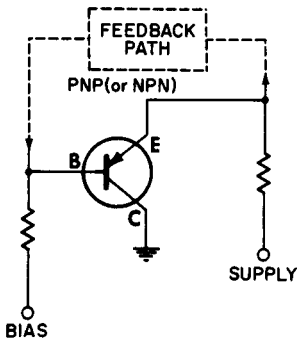
(C) The basic common-collector oscillator.

Fig. 3-12. The three basic oscillator configurations.

repetitive cycle, there are, therefore, three basic oscillator configurations. They are shown in Fig. 3-12. The operation of transistor oscillators is considered more fully in Chapter 5.

4 THE TRANSISTOR AMPLIFIER

The transistor amplifier circuits differ considerably from the familiar vacuum-tube circuits. At the same time there is a reasonable amount of similarity between the two. This might be a good place to point out some of the more outstanding differences and similarities between transistor circuitry and vacuum-tube circuitry.

The transistor has been described in the three circuit configurations, which also conform to the three vacuum-tube configurations. The comparisons are shown in Fig. 4-1. For each vacuum-tube configuration there are two transistor configurations, one for the PNP type and one for the NPN type.

The transistor circuit in Fig. 4-1A is the common-emitter circuit, which is used almost exclusively for most amplification purposes, just as the common- or grounded-cathode vacuum-tube circuit is also used extensively. The remaining circuit forms in Fig. 4-1 are used for more special applications, such as impedance matching to and from transmission lines or in place of matching transformers between amplifier stages.

AMPLIFIER CIRCUIT RECOGNITION

A familiar tube circuit can be redrawn into another form that will be almost unrecognizable. The circuits used with the transistor can be even more unfamiliar. First, the circuits are

new; and second, they can be arranged in two ways, with a PNP transistor and with an NPN transistor.

If the common-emitter circuit is drawn as in Fig. 4-2A and if an NPN transistor is used, the circuit will closely conform to what we are accustomed. The positive battery terminal is connected to the collector. Bias is obtained from the tapped bleeder made up of resistors R1 and R2. The bias current must be obtained from the positive battery terminal through R1.

This same circuit can be rearranged to look like Fig. 4-2B. The grounding of the battery terminal is the only difference between this circuit and the one in the previous paragraph.
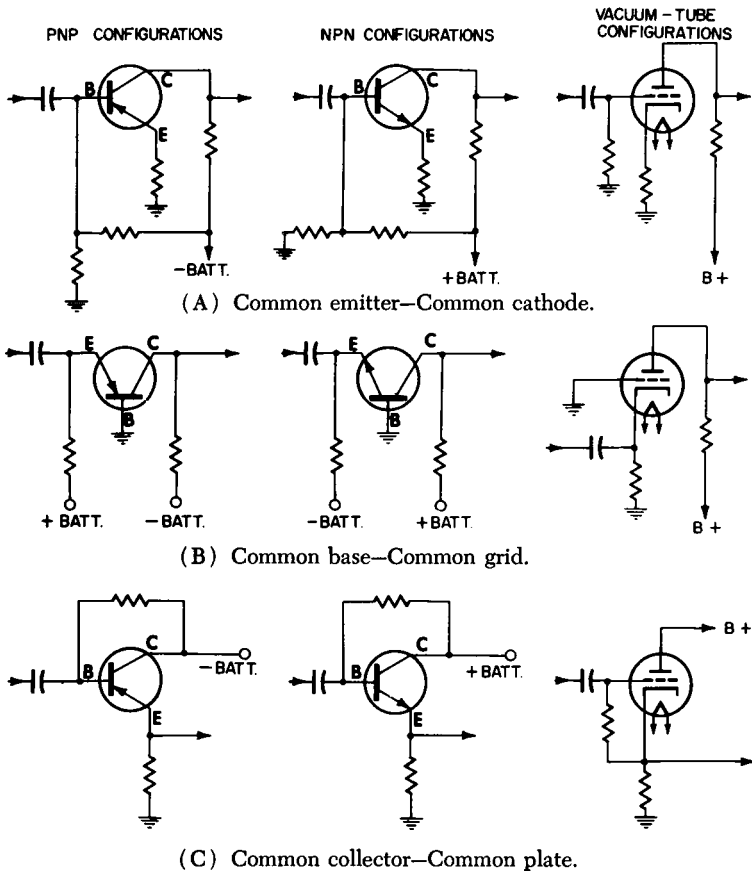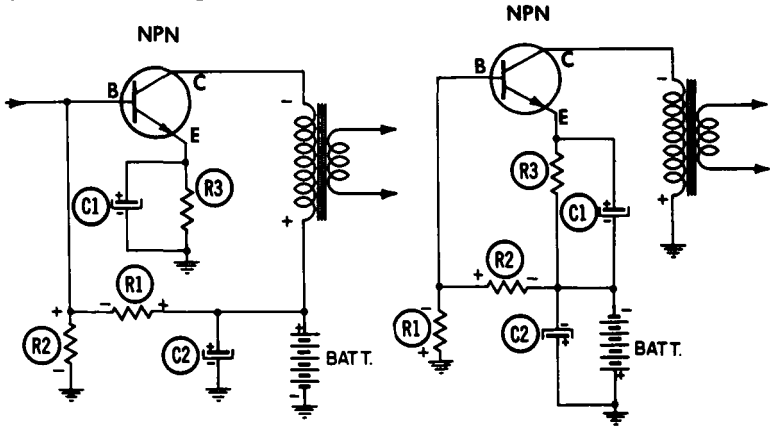

(A) Common emitter—Common cathode.

(B) Common base—Common grid.

(C) Common collector—Common plate.

Fig. 4-1. The transistor circuit configurations and their vacuum-tube counterparts.

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The same circuit is reproduced in Fig. 4-2C without a ground reference. Point A is grounded in Fig. 4-2A, and point B is grounded in Fig. 4-2B.

(A) The common-emitter amplifier circuit with the negative battery lead grounded.

(B) The circuit of (A) with the positive battery lead grounded.

(C) The circuit of (A) and (B) showing alternate points of grounding.
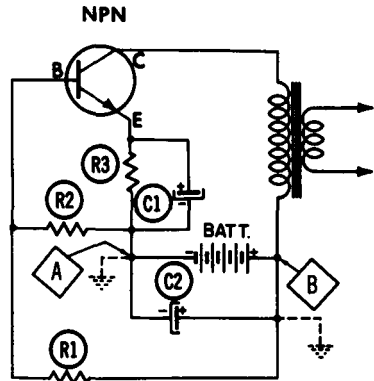
Fig. 4-2. A common-emitter amplifier circuit, showing different grounding points.

If a PNP transistor is used in this circuit, two drawings can again be made, one with the positive terminal grounded as in Fig. 4-3A and one with the negative terminal grounded as in Fig. 4-3B.

Compare the PNP circuit with the NPN circuit and notice that the current is reversed in all of the components. Therefore, all of the electrolytic capacitors must be reversed when the transistors are changed from PNP to NPN.

With the vacuum tube, the interchange of current and voltage polarities between PNP and NPN transistors did not exist. Because of this interchange in the transistor, circuits that

(A) Positive battery terminal grounded.

(B) Negative battery terminal grounded.
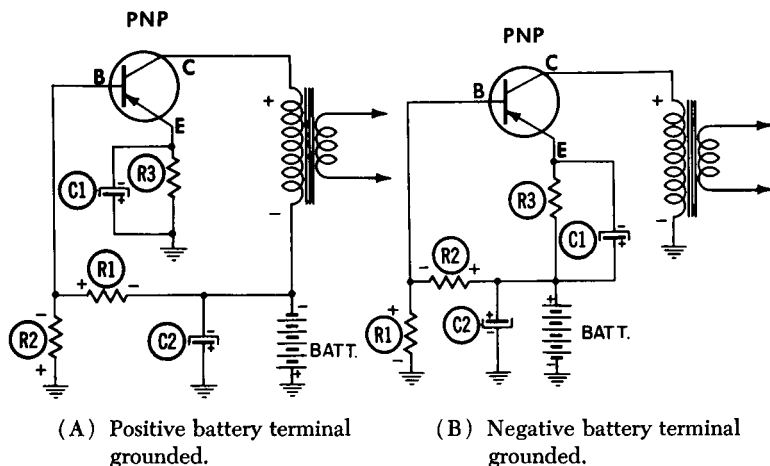
Fig. 4-3. A common-emitter amplifier circuit using a PNP transistor.

have no parallel in vacuum-tube circuitry can be produced. Nevertheless, the circuits of transistor equipment are quite similar in many respects to the circuits in vacuum-tube equipment.

INPUT AND BIAS

A signal can be coupled to a transistor stage in a number of ways. Each stage is designed for a particular purpose; and the efficiency of the coupling, the biasing of the stage, the amount of gain desired, and the component cost are all considered.

The most efficient system of coupling a signal to a transistor is with a transformer that will provide a correct match between the signal source and the transistor. Although the transformer may be the most efficient, it has certain drawbacks, such as cost, weight, and frequency response. Because of the high gain of the transistor, a less efficient coupling system can be used and there is a wide variety of these from which to choose. They will be described in this chapter.

An arrangement for providing feedback in a single transistor stage is shown in Fig. 4-4A. Resistor R1 biases the transistor and, at the same time, becomes part of a feedback system for the signal. The signal at the collector is impressed across resistors R1 and R2, and part of the output signal is applied to the transistor base.
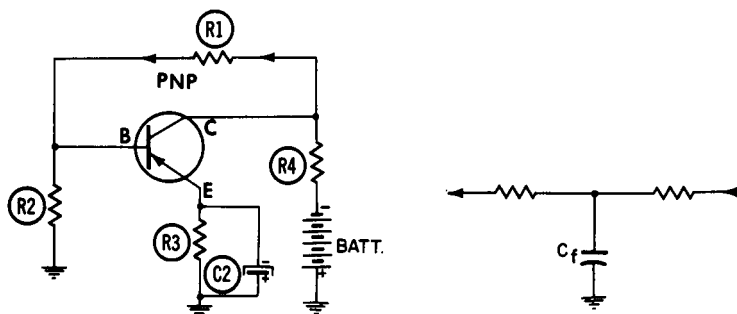
(A) A circuit which accomplishes biasing and feedback simultaneously.

(B) A frequency-selective network which replaces R1 in (A).

Fig. 4-4. Bias stabilization and signal feedback.

The signal at the collector is 180° out of phase with the signal on the base, and the feedback now is degenerative. Resistor 1 can be replaced by a network like the one shown in Fig. 4-4B. If the values of the capacitor and resistors are varied, the feedback can be made frequency selective. If capacitor C_f is made large, the signal can be bypassed to ground and no signal feedback will take place. However, the DC bias stabilization will still be maintained.

> NOTE: Observe that the load R4 is a resistance. This type of feedback circuit is seldom used with an inductive load. The DC voltage drop across an inductor is not great enough to provide sufficient bias feedback. Bias stabilization is the primary purpose of collector-to-base feedback.

The collector-to-base feedback of the signal is used principally in amplifiers designed to produce a particular fre-

quency response, such as phonograph preamplifiers and high-fidelity sound systems.

COUPLED AMPLIFIER

The input circuit in Fig. 4-5 is used more in audio amplifiers than probably any other circuit. This is an R-C coupled input with an electrolytic capacitor to block the DC voltage from
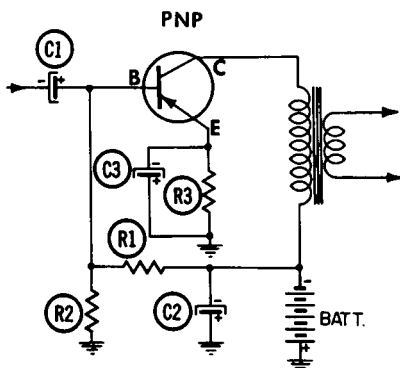
Fig. 4-5. A very common RC-coupled amplifier circuit.

the previous stage. The capacitances of the electrolytics in such transistor stages range from about 1 mfd to 100 mfd. Such high capacitance is needed to pass audio frequencies in a low-impedance circuit.

Coupling capacitor C1 in Fig. 4-5 may be connected in either polarity, depending on whether the DC voltage at the take-off point of the preceding stage is positive or negative with respect to the voltage on the base of the transistor.

Fig. 4-6A is an R-C coupled stage in which R2 is part of the bias network and acts as the volume control. The resistance of R2 becomes a current divider for the incoming signal. The signal current is divided into two paths, as shown in Fig. 4-6B.

The volume control of Fig. 4-6C is a voltage-divider type. The signal is developed as a voltage across resistor R4. Moving the slider changes the signal voltage at the transistor base and, at the same time, also changes the bias of the transistor. The signal level and the bias change simultaneously (less signal and less bias) and cause less battery power to be consumed on low volume than on high volume.

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The transformer is used for coupling when high efficiency and proper impedance matching are important. However, the transformer is more expensive than the resistors and capacitors necessary to couple two amplifier stages. Often, special transformers are required to obtain the desired frequency response.

(A) The volume control used as a current divider.

(B) The current division paths.

(C) The volume control used as a voltage divider.

Fig. 4-6. Different types of volume-control circuits.
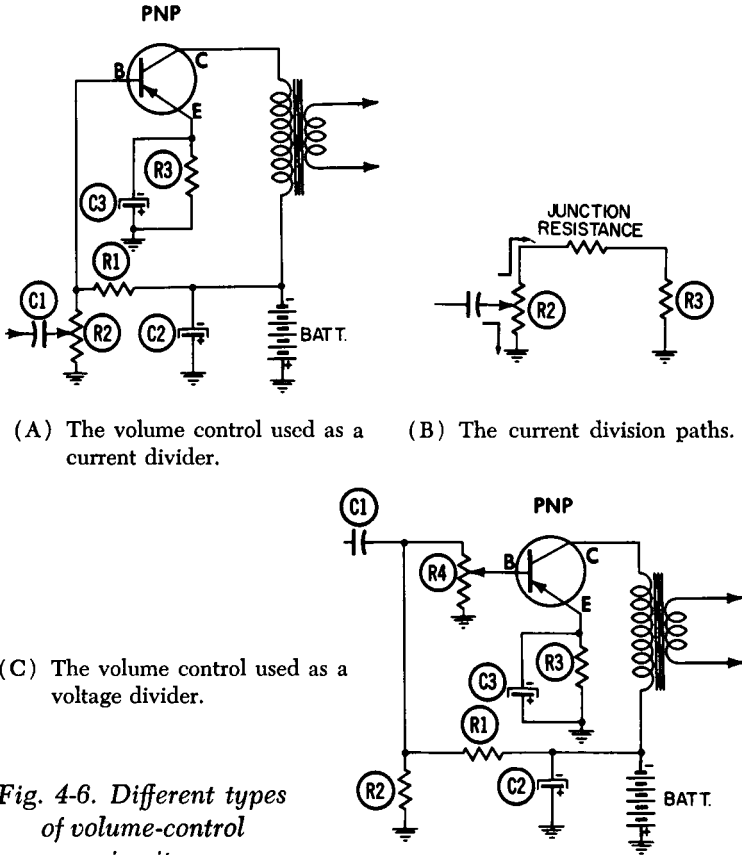
Many functions, such as accurately matching the output impedance of one transistor stage to the input of the next, are fulfilled extremely well by the transformer. With good matching, the maximum gain of the transistors can be approached.

A good example of transformer impedance matching between amplifier stages is the audio-amplifier and power-output

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stages of a hybrid auto radio. The diagram of such a circuit is shown in Fig. 4-7. The audio amplifier is a vacuum tube with a rather high output impedance, and the output stage is a power transistor with a very low input impedance. The differ-
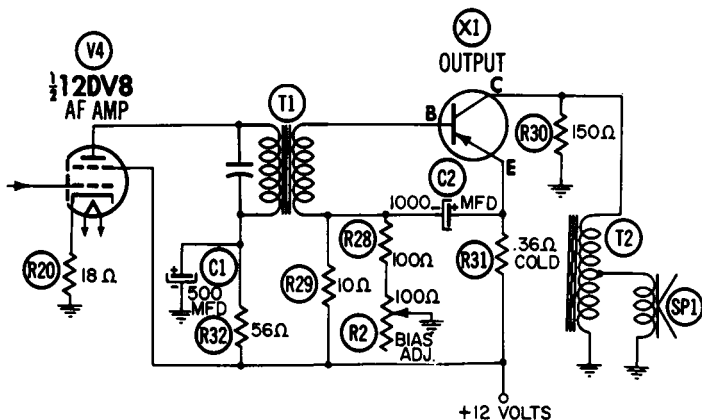

Fig. 4-7. An example of a vacuum-tube stage driving a transistor stage.

ence between the two impedances is so great that, without the transformer T1 (or some form of impedance-changing device), tube V4 cannot provide adequate drive signal to the base of transistor X1. The transformer T2 in the collector circuit of the transistor is used to match the collector impedance to the speaker impedance.

DIRECT (DC) COUPLED AMPLIFIERS

The main advantage of DC-coupled amplifiers is that they eliminate transformers and coupling capacitors. These latter two devices tend to limit the frequency response of an amplifier. The DC amplifier will amplify signals from zero frequency to the high limit imposed by the amplifying device (transistor or tube) and by the associated wiring. In other words, direct coupling is quite a desirable feature in an amplifier.

Because high-voltage DC supplies are needed, direct coupling has never been very popular in vacuum-tube circuitry. Each stage must have a higher supply voltage than that of the

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preceding stage; thus, the final signal must have an extremely high DC component.

The ideal system would be to have a small DC change above and below a given reference level, amplify this changing
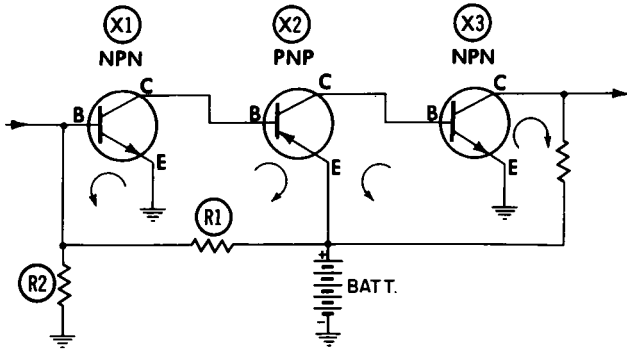

Fig. 4-8. A simplified DC amplifier.

voltage, and end up with an amplified change that still swings above and below the original reference point.

A transistor can operate as a DC amplifier. A simplified version of a DC amplifier using PNP and NPN transistors is shown in Fig. 4-8. The arrows indicate the direction of electron flow.

The single battery supplies the power to all of the DC-coupled transistors in Fig. 4-8. Transistor X1 is biased from the bleeder circuit of R1 and R2. The bias of transistor X2 is controlled by the current flow through the collector of X1. Similarly, X3 is biased by the current through X2.

Any current change at the first transistor X1 is amplified greatly at the last stage. This high amplification is a property of the transistor DC amplifier. However, high amplification is also a detriment because transistors are temperature sensitive; therefore, any change in conduction due to a change in temperature will also be greatly amplified. A high-gain DC amplifier must have some system of compensating for temperature changes.

The circuit in Fig. 4-9 is the audio portion of a transistor portable receiver. Audio amplifier X4 is direct-coupled to out-

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put transistor X5. Transistor X4 is biased near cutoff to permit only a small current to flow in the collector of X4 and in the base of the following stage. This current provides the bias for output transistor X5.
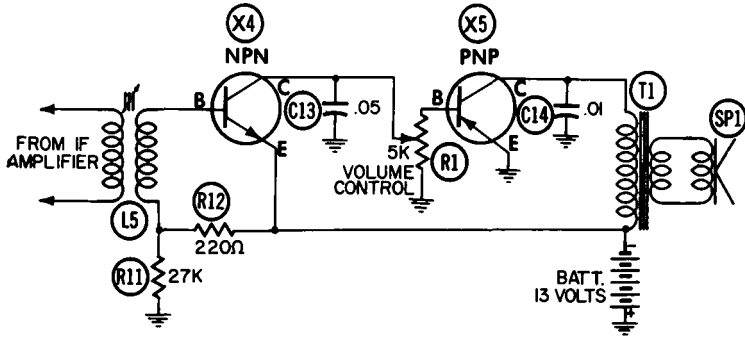

Fig. 4-9. A DC-coupled amplifier employed in a receiver.

The volume control not only controls the signal level, but acts as a divider for the bias current. The signal and bias are increased or decreased simultaneously; and at zero signal setting, output transistor X5 is cut off. This system provides a saving in battery current because the amount of current used depends upon the volume setting.

Transistor X4 operates as the detector and first audio amplifier. The transistor is biased near cutoff; therefore, practically no current flows between the base and emitter. The base-to-emitter junction acts as a diode and blocks the current flow on the negative swing of the IF signal, but conducts on the positive swing. These current pulses are amplified in the collector circuit. The RF is bypassed to ground by the .05-mfd capacitor C13, leaving an audio signal with an amplitude great enough to drive the output stage of the receiver.

Remember that a transistor, unlike a vacuum tube, may be biased by a part or by all of the output current of another transistor. This is particularly true of the DC-coupled amplifier.

This method of biasing is used particularly where both PNP and NPN transistor types are contained in the same piece of equipment.

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The RF or IF amplifier employs transformer coupling between stages. The impedance match from one stage to the next is of prime importance; for this reason the IF transformers of a transistor radio are quite different from those in vacuum-tube receivers.
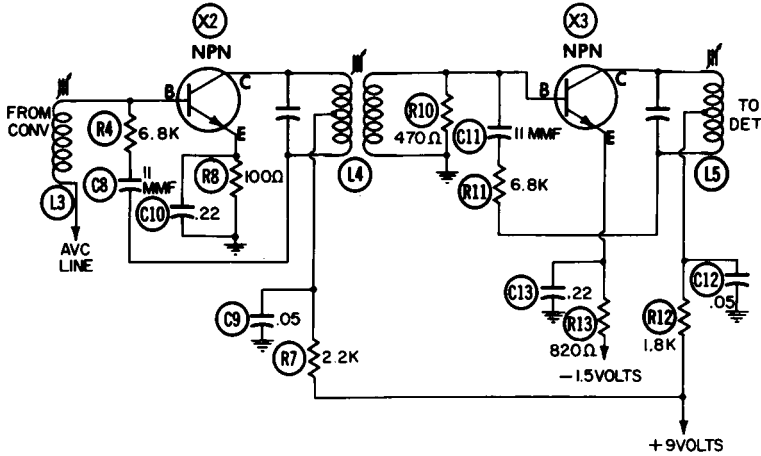
Fig. 4-10. An IF amplifier with single-tuned transformers.

The IF amplifier circuit shown in Fig. 4-10 incorporates a tapped-primary IF transformer, single-slug tuning, low-impedance untuned secondary, and feedback to the base.

The impedances of tuned circuits are high compared to the collector and base impedances. The former are matched by using a tapped-primary IF transformer. Only a portion of the total impedance of the tuned circuit exists from collector to ground. A secondary winding must have even lower impedance, since it must drive the base of a common-emitter circuit. Untuned secondary windings are normal in transistor receivers, although some double-tuned (primary and secondary) IF transformers will be encountered.

A double-tuned IF transformer is shown in Fig. 4-11. Both the primary and the secondary are tapped at impedance points that will match the collector of the converter to the base of the first IF stage. Double-tuned transformers are not generally used in the personal-sized portable receivers because of the

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added weight and size. One double-tuned transformer may be used in a receiver, between the mixer and the first IF amplifier, to provide a greater degree of isolation between the oscillator and the first IF stage than a single-tuned transformer will provide.
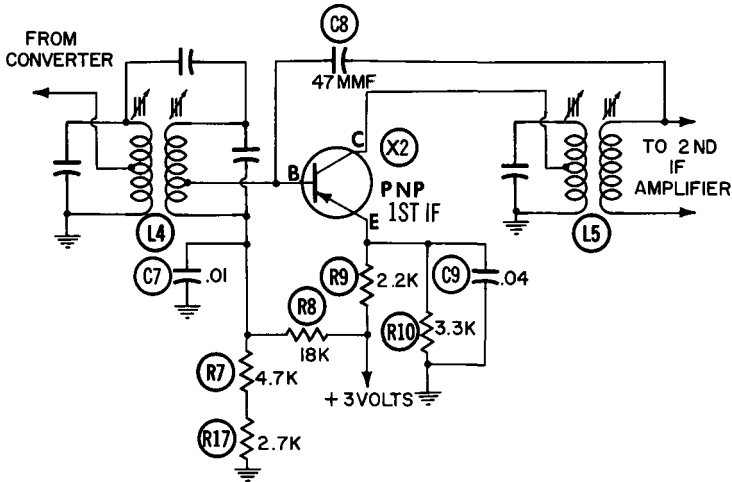

Fig. 4-11. An IF amplifier with double-tuned transformers.

Neutralization

In the circuits in Fig. 4-10 and Fig. 4-11, a small-value capacitor C8 is connected from the output of transistor X2 to the input circuit of the same transistor. Capacitor C8 is a neutralizing capacitor and cancels the effect of base-to-collector capacitance. The principle is identical to the neutralizing of a triode vacuum tube in a tuned RF amplifier.

The transistor is a three-element device that operates like a vacuum tube. When both the input and output of a transistor amplifier stage are tuned to the same frequency, voltages and currents are built up across the tuned circuits. The phases of these voltages and currents at resonance are such that a positive feedback occurs from the collector to the base through the base-to-collector capacitance.

Capacitor C8 couples a signal, which is nearly 180 degrees out of phase with the signal on the collector, from the output

circuit back to the base of the transistor. Cancellation is not complete. The feedback is only enough to keep the stage from oscillating when the input and output circuits are tuned to resonance at the intermediate frequency.

A circuit designed to operate with a neutralizing network will break into oscillation if the capacitor is open or missing. The IF strip of such a receiver cannot be aligned until the correct neutralizing capacitor is inserted.

Automatic Volume Control (AVC)

The audio output of a receiver can be controlled by affecting the gain of the IF amplifiers. In a transistor receiver, the
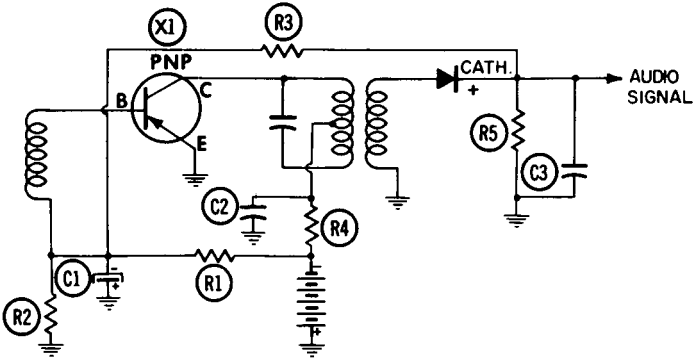
(A) System with a PNP transistor.
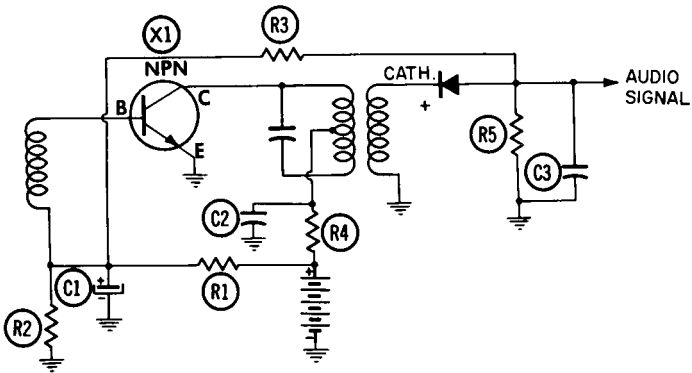
(B) System with an NPN transistor.

Fig. 4-12. Simplified versions of an AVC system.

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gain of the IF amplifier depends upon (1) the gain of the individual transistor and (2) the impedance match between each stage. Both can be changed by varying the voltage applied to the transistor and the current through it.

When the bias current of a transistor is reduced, the gain of the transistor drops and the output and input impedances rise. The impedance rises because of the change in collector voltage due to the reduced current through the transistor. (Refer to Forward and Reverse Bias in Chapter 1.) The impedance change causes a mismatch between stages and lowers the IF amplifier gain.

The current necessary to produce this lower gain is derived from the detection of the IF signal. The detector is generally a diode that serves as an AVC diode and as an audio detector. The circuits in Fig. 4-12 show a simplified version of an IF stage, an AVC detector, and the AVC path to the transistor base. In Fig. 4-12A the rectified current from the cathode (+) of the diode changes the potential on the transistor base. The base of the PNP transistor normally is negative. A positive potential will reduce the current flow or will move the base potential nearer to that of the emitter.

An NPN transistor stage is shown in Fig. 4-12B. The voltage and current are the reverse of the PNP circuit. Current from the anode of the detector moves the base potential in a negative direction.

An increase in signal level will increase the detector output, and the increased detector potential will reduce the current in the base circuit. Two actions result: (1) the current through the transistor is reduced and (2) because the IR drop across R4 is reduced, the voltage rises at the collector terminal.

Resistor R4 and capacitor C2 in Fig. 4-12 isolate this IF stage from the other stages and from the common supply line.

As previously stated, the change in output impedance affects the gain of the stage. The output impedance of transistor X1 in Fig. 4-12 will be determined by the current through the transistor and by the voltage between emitter and collector.

The collector current is controlled by the AVC current from the detector. This collector current must flow through
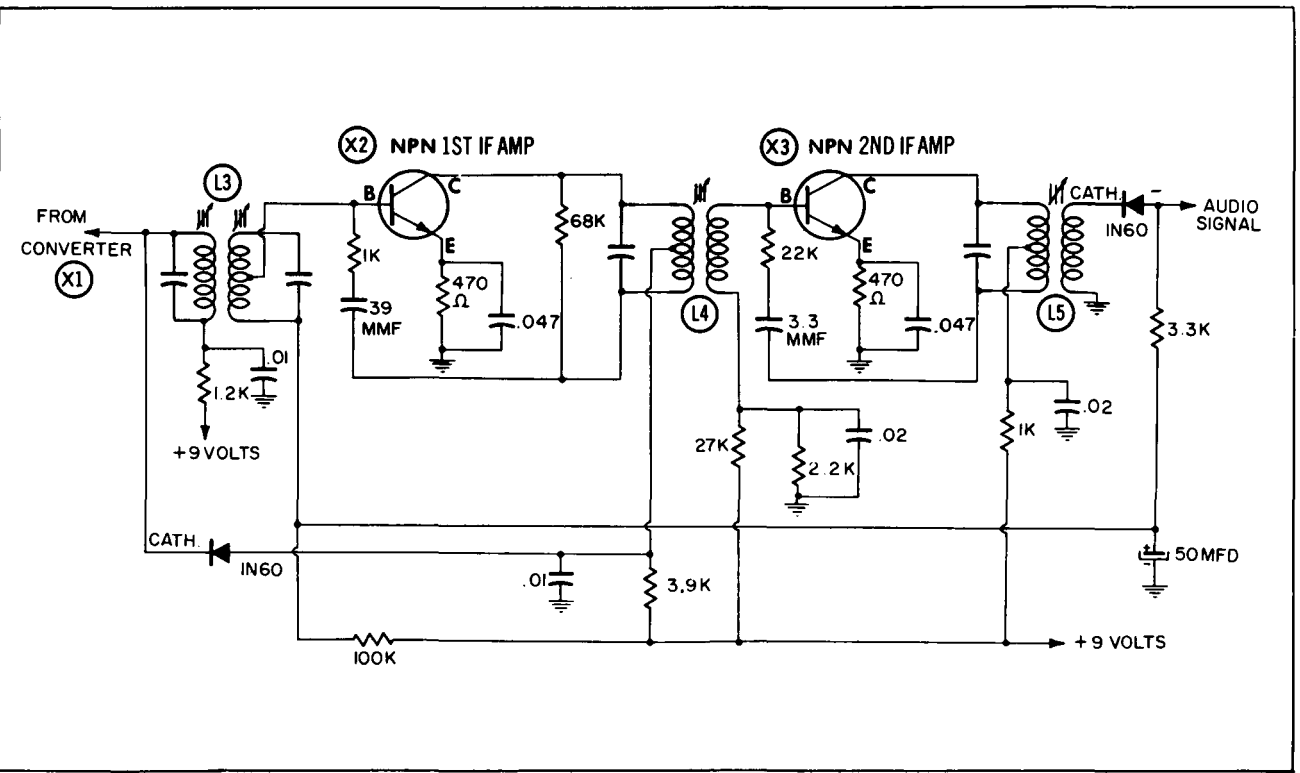
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Fig. 4-13. An AVC system with extended range.

resistor R4; as the transistor current is reduced, the collector potential rises and the output impedance of transistor X1 therefore increases.

The range of AVC action is extended by placing a diode across the primary of an IF transformer. Fig. 4-13 is the IF portion of a receiver that contains a 1N60 diode as part of the AVC circuitry.

The cathode of the 1N60 is connected to the high side of the first IF (converter IF) transformer L3. The anode terminal of the diode is connected to the tap on the second IF transformer L4. This tap is at RF ground potential and, therefore, the diode is, in effect, across the primary terminals of L3.

When no signal is present at the receiver input, the potential across the diode is equal to the difference between the collector voltages of X1 (+8 volts) and X2 (+7 volts) or 1 volt of reverse bias. When biased in reverse, a diode has an extremely high resistance, but this high resistance across the primary of the transformer does not greatly affect the Q of the tuned circuit.

The diode resistance decreases as the forward current increases. The resistance change of a 1N60 with respect to bias voltage is shown in Fig. 4-14. The resistance has been calculated from the voltage and current readings taken by using the circuit at the top of the chart. A strong signal arriving at the detector (refer to Fig. 4-13) produces a negative AVC potential that is applied to the base of transistor X2. The reduced current in the collector circuit will increase the collector voltage. When this voltage exceeds eight volts, the diode will be forward biased and will act as a low resistance.

When a resistance is placed across a tuned transformer, the transformer becomes less efficient. The diode in this circuit is a variable resistance that increases when the signal is weak and decreases when the signal is strong. The first IF transformer efficiency is varied by the shunting effect of the 1N60 diode.

The diode reduces the gain of the receiver by lowering the gain of the IF transformer; thus, the total range of the AVC is extended beyond the range attainable if only the gain of the transistor were reduced.

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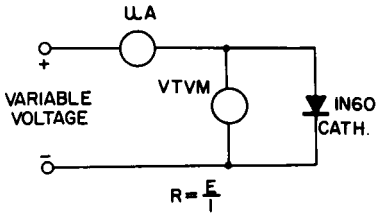
VOLTAGE	MICROAMPERES	RESISTANCE
.02	.5	40K
.04	2.5	16K
.06	5.0	12K
.08	10.0	8K
.1	20.0	5K
.12	40.0	3K
.14	70.0	2K
.16	110	1450 Ω
.18	150	1200 Ω
.2	200	1000 Ω
.22	260	890 Ω
.24	330	760 Ω
.26	400	650 Ω
.28	500	560 Ω
.3	600	500 Ω

Fig. 4-14. Resistance change of a 1N60 diode due to change of applied voltage.

AUDIO AMPLIFIERS

The last stage of an audio amplifier is the power output. Although this stage is an audio amplifier stage, it is different because the amplification is power gain. The output stage usually consumes more current than all the other stages. Power consumption is important, particularly to the customer, who has to purchase the batteries that supply this power.

Two output circuits serve as power stages: the single-ended (containing a single transistor) and the push-pull (containing two transistors). The single-transistor output must operate as a Class-A amplifier, whereas the push-pull arrangement can operate as Class-A, Class-B, or Class-AB (in which the operating point is somewhere between Class-A and Class-B).

Class-A operation takes place when the transistor bias sets the collector current at a point midway between design maximum and cutoff; the collector current flows at all times. Class-B operation takes place when the collector current flows for only half of the alternating cycle. Class-AB operation is at a point between A and B; the current flows for more than half the alternating cycle, but not for the full cycle.

Single-Ended Output

Fig. 4-15 shows a single transistor used as the ouput stage of a broadcast receiver. The transistor will be biased for Class-

A operation, and current will flow in the collector circuit at all times. An improper bias would distort the audio.

It is difficult to accurately measure the bias of a transistor amplifier stage directly. However, because the collector cur-
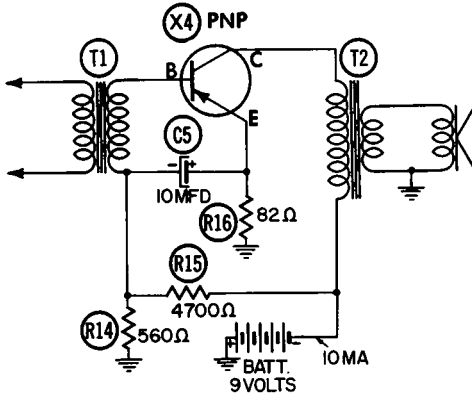

Fig. 4-15. A Class-A output stage.

rent is greatly affected by small changes in the bias current, the collector current can be measured and will provide an indirect measure of bias. Note in Fig. 4-15 that the total current from the battery is 10 ma and (from the preceding discussion) that the output stage of the receiver consumes a large portion of this current. A change in the bias current of the output transistor will measurably affect this current reading. The transistors in the preceding stages will have little effect upon the supply current.

Push-Pull Output

The push-pull circuit can be operated as Class-A, Class-B, or Class-AB. The Class-A, push-pull operation will provide only twice the power output of the single-ended, Class-A stage; and collector current will flow at all times. The Class-B operation is very economical because almost no current flows when no signal is applied. This no-current condition is due to the transistors being biased to cutoff. However, Class-B operation causes distortion at the crossover point (the point at which one transistor ceases conduction and the other begins).

The circuits in Fig. 4-16 and 4-17 are simple forms of a push-pull circuit; current waveforms for Class-B and Class-AB
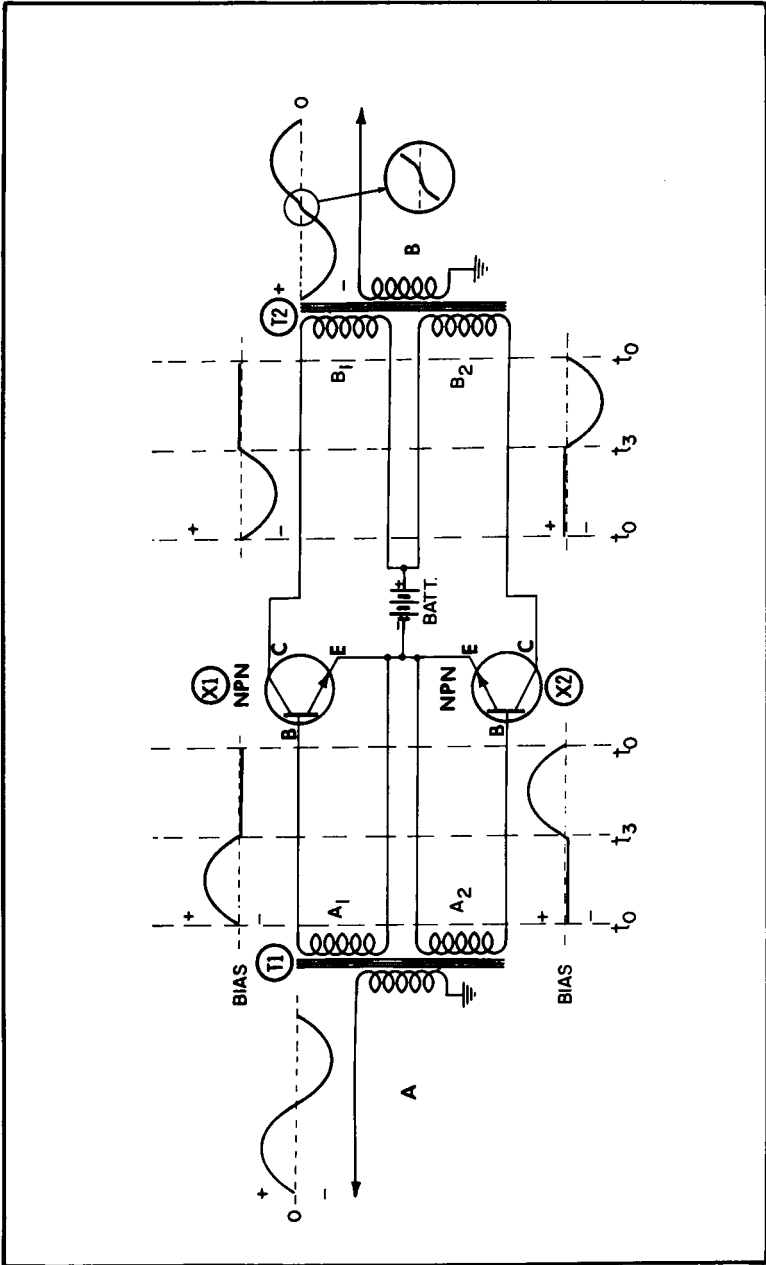
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Fig. 4-16. A Class-B push-pull output stage with current
waveforms. (Waveforms are not drawn to scale.)

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operation are shown. Transformer T1 is the input and T2 is the output. The secondary of T1 and the primary of T2 are shown as separate windings for each transistor in order for the reader to maintain the thought of two separate amplifiers. Signal coupling between them is accomplished by the mutual coupling of windings A, A1, and A2 in the input circuit and windings B, B1, and B2 in the output. The battery supplies power to both sides of the push-pull arrangement. The dotted horizontal line through each of the waveforms represents the current in the circuit when no signal is applied. No current flows in the input and output windings A and B when the signal is removed.

In the Class-B amplifier in Fig. 4-16, the transistors have zero bias. For a transistor, zero bias is equivalent to cutoff bias; and the collector current should be zero. However, because of leakage current, the collector current cannot be completely cut off. Current from winding A1 causes base-to-emitter conduction in transistor X1 on the positive half of the cycle, and current flows in the collector and in winding B1. During this half cycle, transistor X2 is not conducting. During the negative swing of the signal, X1 is cut off and X2 conducts through B2. The combined effect of current flow in B1 and B2 produces the output current in winding B. One of the main disadvantages of Class-B operation is crossover distortion which is produced by the switch in conduction from one transistor to the other. For this reason, the Class-B amplifier is seldom used for audio-output stages.

The arrangement shown in Fig. 4-17 is a Class-AB, push-pull amplifier that is biased to permit current to flow in the collector circuit when no signal is applied. The positive half of the input signal drives transistor X1 into conduction at time zero. Between t_0 and t_1, transistor X2 is also conducting. At t_1, transistor X2 reaches cutoff. During the time from t_1 to t_2, transistor X1 reaches maximum conduction and then decreases. At t_2, transistor X2 begins to conduct again. Both transistors are conducting between t_2 and t_3.

The beginning of the negative half of the signal is at t_3. At this time, transistor X1 is decreasing conduction and X2 is
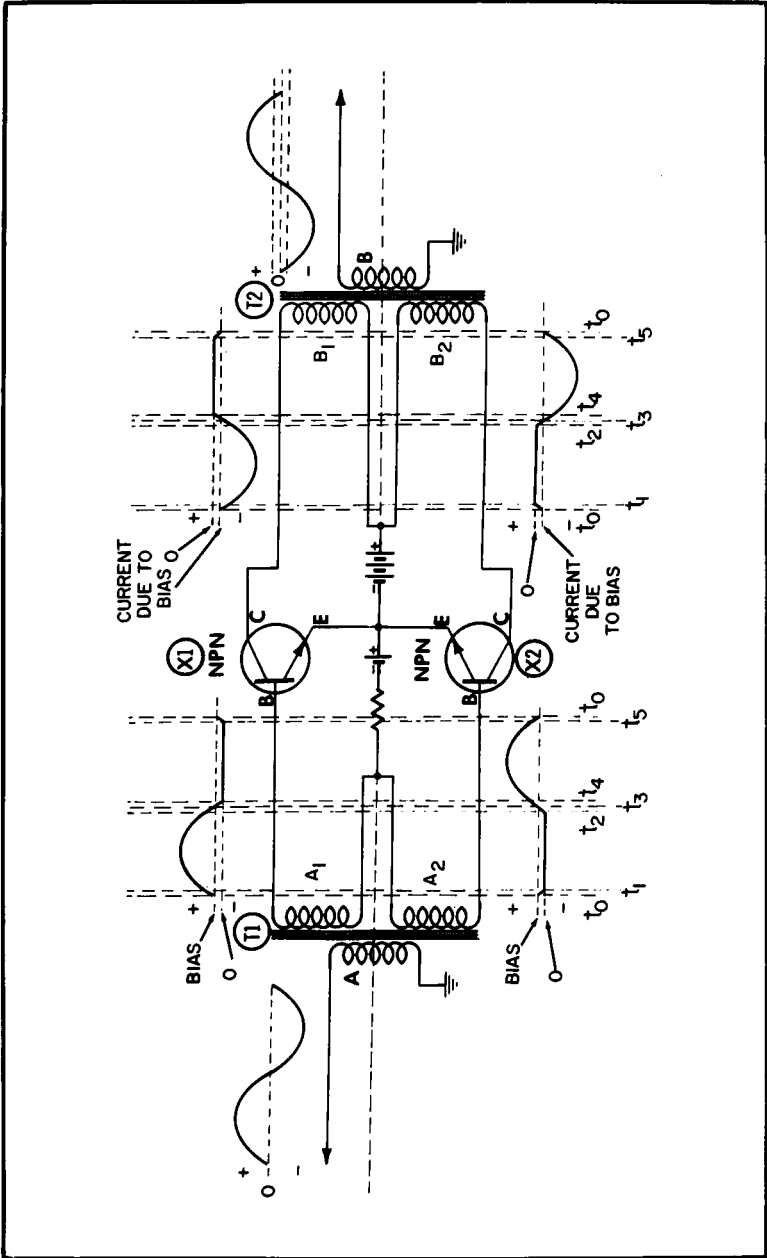
Fig. 4-17. A Class-AB push-pull output stage with current waveforms. (Waveforms are not drawn to scale.)

increasing. At t_4, transistor X1 reaches cutoff. During the time between t_4 and t_5, transistor X2 reaches maximum conduction, and then decreases. At t_5, transistor X1 begins to conduct again. Both transistors are conducting when t_0 is reached. The currents of windings B1 and B2 combine to form
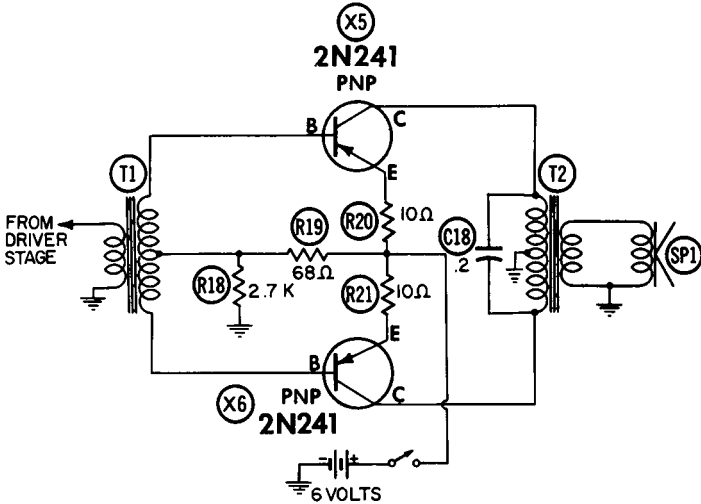
CURRENT DRAIN:
10 MA. WITH NO SIGNAL APPLIED AND VOLUME CONTROL AT MAXIMUM.

9 MA. WITH NO SIGNAL APPLIED AND VOLUME CONTROL AT MINIMUM.

18 MA. WITH SIGNAL APPLIED AND NORMAL VOLUME

Fig. 4-18. A push-pull output stage, showing current drain at various volume-control settings.

the output current in winding B. The dotted lines in the output waveform show the portion of the cycle during which both transistors were conducting. The change from the positive to the negative portion of the cycle is smooth, and crossover distortion is greatly reduced. This is the push-pull arrangement most used in power-output stages. The power dissipated by the transistors is very small during a no-signal condition, but increases as the signal increases.

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The output circuit of a broadcast receiver is shown in Fig. 4-18. This receiver, powered with a 6-volt battery, drains 9 ma when the volume control is turned to minimum. At a normal volume level, the current drain is about 18 ma. It is apparent that the volume at the speaker determines the power drain from the battery. The change in battery current will be greater for receivers that have the lowest battery voltage, and receivers with higher voltage batteries will have a smaller current change.

OSCILLATORS

The basic configurations for the three oscillator circuits were described and shown in Chapter 3. In this chapter we will discuss the practical circuits for each configuration and how they are used.

1. Common-emitter circuit—sometimes used in the converter stage of a superheterodyne receiver. However, this circuit is used almost exclusively in separate oscillators.

2. Common-base circuit—acts extensively as the oscillator portion of the converter in the superheterodyne receiver.

3. Common-collector circuit—seldom used as an oscillator in broadcast receivers, but is found in other equipment; for that reason the circuit will be discussed here.

Each of the three transistor oscillator circuits is shown in its basic form in Figs. 5-1, 5-2, and 5-3. The components needed to provide bias to the transistors have been deleted, and only the most basic elements are shown. Only capacitively- and inductively-tuned circuits are shown because no others are used in broadcast receivers.

If the input, output, or feedback circuits of an oscillator are frequency selective, the circuit will tend to oscillate at one particular frequency. A number of systems which produce a controlled frequency are listed:

1. The tuned circuit—composed of a capacitor and inductor which resonate at a particular frequency.

2. The RC or RL type—frequency is controlled by the length of time a capacitor or an inductor takes to discharge through a resistance.

3. Phase-shift type—the phase relationship of the input and output signals are controlled. The two signals are in phase at only one frequency. The Wien-bridge oscillator is an example of this system.

4. Crystal—frequency is controlled by the piezoelectric properties of certain crystals, such as quartz and Rochelle salt.

5. Electromechanical systems—a mechanical device such as a tuning fork is driven electrically, and the mechanical vibration rate controls the frequency of the oscillator.

6. Synchronizing systems—the oscillator is adjusted close to the desired frequency, and an external signal is applied in such a manner that the oscillator synchronizes itself to the incoming frequency.

An oscillator consists of the following: (1) an amplifying device (in our case, a transistor), (2) a power source to replace I^2R losses, (3) a feedback arrangement to cause oscillation, and (4) a frequency-selective system.

COMMON-EMITTER OSCILLATOR

A common-emitter oscillator is shown in Fig. 5-1A. The transformer (coils L1 and L2) transfers energy from the output to the input. The current change in the output, or coil L1, is transferred to coil L2 and, hence, to the base of the transistor.

Coil L1 in Fig. 5-1A is tuned by capacitor C1. Coils L1 and L2 are so designed that maximum feedback occurs at the resonant frequency of the tuned circuit. The impedances of coil L2 and of the tapped portion of the tuned circuit produce a reasonably good impedance match at the oscillating frequency.
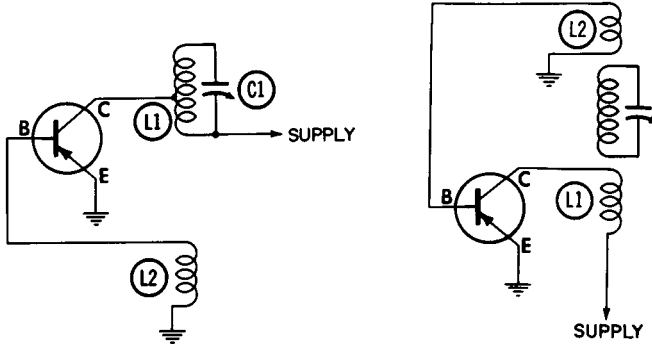
(A) Tuned circuit in supply lead.   (B) Separate tuned circuit.

Fig. 5-1. Common-emitter oscillator circuits.

The impedance match in a transistor circuit can vary a great deal without the proper operation of the oscillator being upset. This fact permits wide-tolerance components to be used for design and replacement.

The circuit in Fig. 5-1B shows a method of coupling coils L1 and L2 to a separate tuned circuit. The mutual coupling between the three windings makes the energy transfer from L1 to L2 greatest at the resonant frequency of the tuned circuit. The tuned circuit need not be directly connected to the circuit to effectively control the frequency.

COMMON-BASE OSCILLATOR

Fig. 5-2 shows two methods of connecting the common-base oscillator. The tuned circuit (L1 and C1) in Fig. 5-2A is in the output, or collector circuit; and the tap point on coil L1 goes to the supply voltage. The arrangement in Fig. 5-1A was quite similar, but both the direction of current in coil L1

and the phase of the feedback signal in coil L2 were reversed. If we assume that the coils in Figs. 5-1A and 5-2A are identical, then the phase reversal is proper, because the feedback is applied to the base in Fig. 5-1A and to the emitter in Fig. 5-2A.
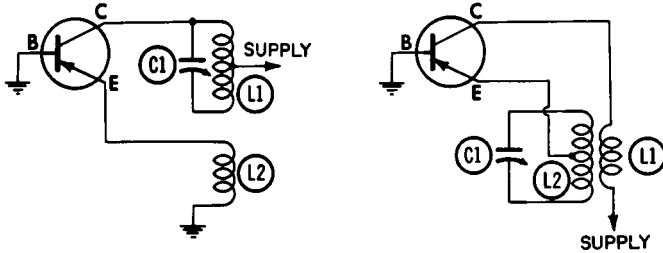
(A) Tuned circuit in supply lead.   (B) Separate tuned circuit.

Fig. 5-2. Common-base oscillator circuits.

Another arrangement of the common-base oscillator is shown in Fig. 5-2B. The input (emitter) is tuned and the collector is untuned. Operation of the oscillator follows the same line of reasoning as the previous ones. Circuits may differ because of such design considerations as keeping DC voltage off the tuning capacitor; thus, the stator of the tuning capacitor can be grounded.

COMMON-COLLECTOR OSCILLATOR

The common-collector circuit is seldom employed as the oscillator in broadcast receivers. One form of this oscillator is shown in Fig. 5-3. The output signal is developed in the tuned circuit of L1 and C1. Coil L2 receives a portion of this energy and supplies it to the base. The impedance of the winding from tap to ground of coil L1 and the impedance of coil L2 produce a reasonably good impedance match between the emitter and the base circuits.

An important use of the common-collector oscillator is in the inverter-type power supply. The common-collector configuration makes possible the connection of the collector or (if a push-pull oscillator) both collectors to ground. The transis-

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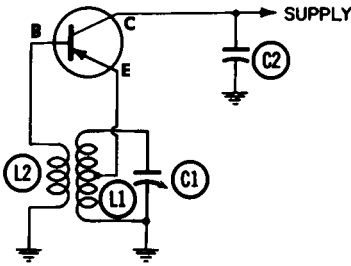tors can be electrically and mechanically connected to the chassis, so that the chassis can act as a heat sink.

Fig. 5-3. A common-collector oscillator circuit.

C O N V E R T E R

The converter stage of a transistor broadcast receiver (as this book is being written) is a three-element device operating as a mixing amplifier and a local oscillator. When operating as a converter, the transistor is a nonlinear amplifier and, as such, performs a third function, that of mixing or heterodyning the received signal with the oscillator frequency. This mixing produces, among other frequencies, an intermediate frequency (IF) that contains all the information of the original signal.

Fig. 5-4 shows a converter stage of a broadcast receiver. Transistor X1 is used in two circuit configurations at the same time. The collector circuit is the output circuit for both con-
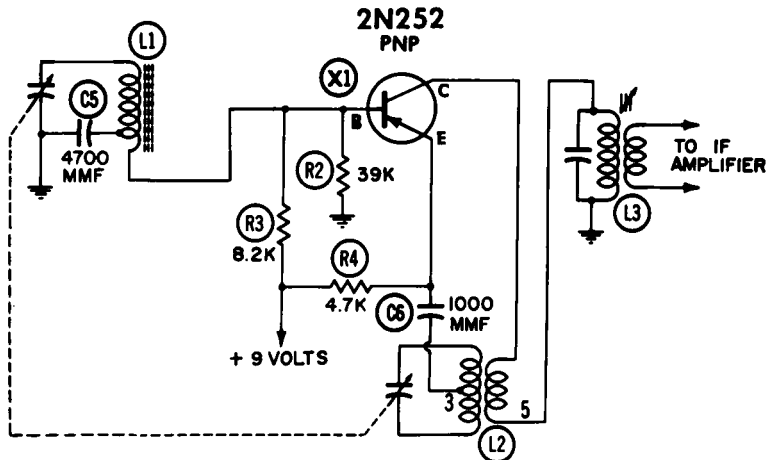

Fig. 5-4. A converter stage of a broadcast receiver.

figurations. The oscillator portion operates as a common-base circuit, and mixing amplification is accomplished by a common-emitter circuit.

This dual role of the transistor is practical because a parallel-tuned circuit presents a low impedance to the passage of frequencies that are different from the resonant frequency of the LC combination. The antenna circuit is virtually a short circuit to the oscillator frequency, and the oscillator tuned circuit acts as a short circuit to the incoming RF.

Oscillator

While referring to the schematic in Fig. 5-4, notice that the base of the transistor is connected to antenna coil L1. This tuned circuit has a very low impedance at the oscillator frequency; therefore, the base is grounded as far as the oscillator is concerned. Resistors R2 and R3 compose a divider to supply a DC bias to the base of transistor X1.

The input terminal for the oscillator is the emitter, and the output terminal is the collector. The transistor operates as a grounded-base oscillator. The feedback signal for the oscillator is obtained from the output circuit through tuned transformer L2. Tap #3 on the transformer is required to match the low impedance of the emitter or input circuit.

IF transformer L3 is in series with transformer L2, but the IF transformer is tuned to a much lower frequency than either the oscillator signal or the received signal. Therefore, the IF transformer presents very little impedance to the oscillator signal. Actually, terminal #5 on transformer L2 is effectively grounded by transformer L3. The oscillator in Fig. 5-4 is similar to the basic oscillator in Fig. 5-2B, the difference being in the addition of components necessary to set an operating bias for transistor X1.

Mixer Amplifier

By a line of reasoning similar to that used for the oscillator, we can consider the mixer-amplifier portion of the converter in Fig. 5-4 as being a grounded-emitter circuit. The tuned circuit of L2 in the emitter-to-ground path is tuned to

the frequency of the oscillator and therefore provides a good RF signal ground for the emitter.

Incoming signals are applied between the base and ground by antenna coil L1. Capacitor C5 acts as a DC blocking capacitor and maintains an operating bias on the transistor. Blocking capacitor C6 places the emitter at signal ground for received signals, but blocks the flow of DC current to ground.

Output

A great many frequencies are present in the output of the converter, but only two of them are important in the operation of the superheterodyne receiver. These are the oscillator frequency and the difference, or intermediate, frequency.

The oscillator-frequency energy is coupled back to the input by transformer L2 of Fig. 5-4. This transformer offers very little resistance to the passage of the 455-kc IF frequency. Transformer L3 is tuned to 455 kc and reacts to the IF energy in the collector circuit.
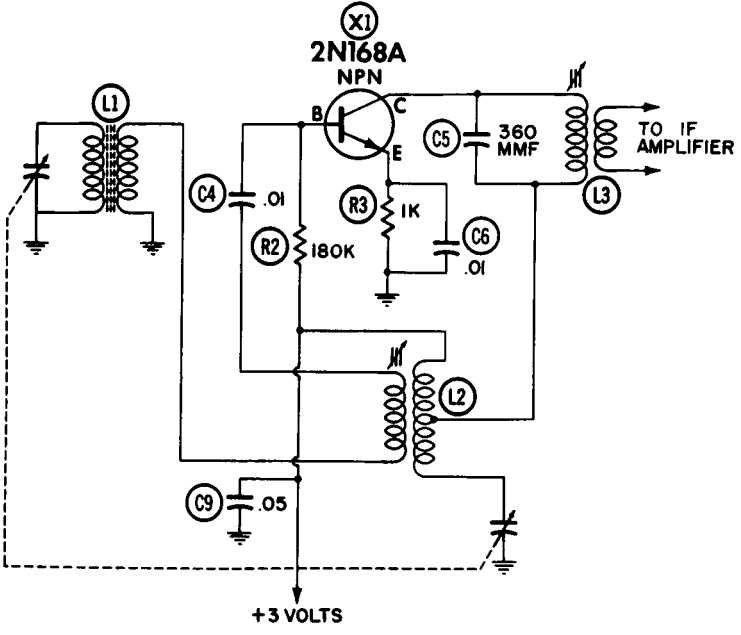

Fig. 5-5. Converter stage using the common-emitter configuration.

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Transformers L2 and L3 react to the oscillator frequency and the IF frequency only, and the output or collector circuit is effectively grounded to all other frequencies.

Common-Emitter Converter

The circuit in Fig. 5-5 is a converter that functions as a common emitter for both the RF amplifier and the oscillator. In this circuit, the energy from the antenna tuned circuit L1 and from the oscillator tuned circuit L2 are picked up by separate windings. These two windings are connected in series, and the signals from both are impressed on the base of the transistor.

The output is also a series arrangement of the two tuned circuits L2 and L3. Energy at the oscillator frequency is returned to the base through transformer L2, and the IF energy is extracted by transformer L3.
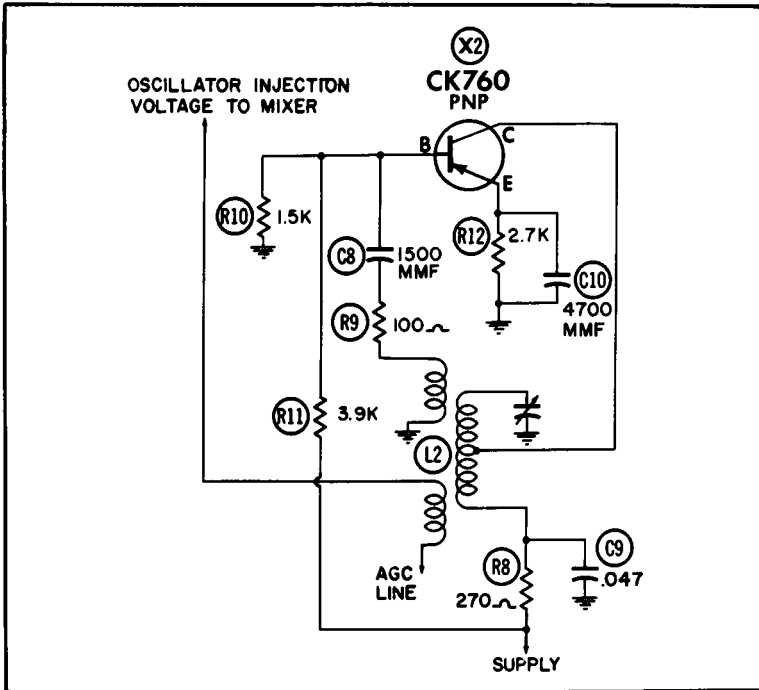

Fig. 5-6. A common-emitter oscillator circuit using a three-winding coil.

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The oscillator in Fig. 5-5 operates much like the oscillator circuit in Fig. 5-1A.

MIXER OSCILLATOR

Receivers employing a mixer and separate oscillator contain two transistors, one for the mixer and the other for the oscillator. The mixer is a nonlinear amplifier in which RF and oscillator signals are mixed to produce the difference, or IF, signal.
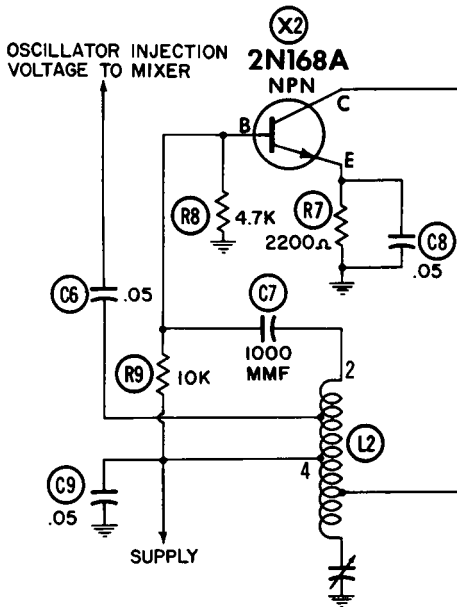

Fig. 5-7. A common-emitter oscillator circuit using a single coil.

The oscillator is nearly always a grounded-emitter type. The circuits in Figs. 5-6 and 5-7 show two oscillator-circuit arrangements. The circuit in Fig. 5-6 shows a common-emitter circuit which employs an oscillator transformer with three windings. The output (collector) winding is tuned. Two other windings provide oscillator feedback and mixer injection. The winding for oscillator injection to the mixer is connected directly to the mixer input, and the AGC voltage is supplied through this winding.

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The oscillator in Fig. 5-7 is also a common-emitter circuit, but with a tapped coil which provides feedback and injection signals. Note that tap #4 is grounded for signal frequencies by bypass capacitor C9. Grounding of this point causes a signal of the correct polarity to appear at tap #2 supplying the base of the oscillator. Capacitor C6 couples the oscillator signal to the mixer.

TEMPERATURE
CONSIDERATIONS

6

The operating characteristics of a transistor depend upon the temperature at which the transistor is operating. For most transistors and other semiconductors, this temperature is the same as that of the environment in which we live and work. This will average somewhere between seventy and eighty degrees Fahrenheit (about twenty-one to twenty-seven degrees centigrade).

Fig. 6-1 lists the degrees centigrade from zero to one-hundred and the corresponding Fahrenheit temperatures. The centigrade scale is used for nearly all measurements involving transistor characteristics. The Fahrenheit temperature scale is by far the more familiar, since it is used in everyday living. The table in Fig. 6-1 will be a help in correlating the two temperature scales.

Transistor characteristics are measured at a particular temperature because they change when the temperature changes. The effect of temperature on a transistor or other semiconductor junction can be shown by the following procedure.

First obtain a transistor and a fairly sensitive ohmmeter. Since the transistor can be damaged by overheating, it is best to use a low-cost unit. The voltage of the ohmmeter batteries should not exceed the maximum voltage rating of the transistor. Set the ohmmeter on one of the high scales ($\times 10K$ or $\times 100K$), and touch the ohmmeter leads to the base and col-

D E G R E E S									
C°	F°	C°	F°	C°	F°	C°	F°	C°	F°
0	32								
1	33.8	21	69.8	41	105.8	61	141.8	81	177.8
2	35.6	22	71.6	42	107.6	62	143.6	82	179.6
3	37.4	23	73.4	43	109.4	63	145.4	83	181.4
4	39.2	24	75.2	44	111.2	64	147.2	84	183.2
5	41.0	25	77.0	45	113.0	65	149.0	85	185.0
6	42.8	26	78.8	46	114.8	66	150.8	86	186.8
7	44.6	27	80.6	47	116.6	67	152.6	87	188.6
8	46.4	28	82.4	48	118.4	68	154.4	88	190.4
9	48.2	29	84.2	49	120.2	69	156.2	89	192.2
10	50	30	86	50	122.0	70	158.0	90	194.0
11	51.8	31	87.8	51	123.8	71	159.8	91	195.8
12	53.6	32	89.6	52	125.6	72	161.6	92	197.6
13	55.4	33	91.4	53	127.4	73	163.4	93	199.4
14	57.2	34	93.2	54	129.2	74	165.2	94	201.2
15	59	35	95.0	55	131.0	75	167.0	95	203.0
16	60.8	36	96.8	56	132.8	76	168.8	96	204.8
17	62.6	37	98.6	57	134.6	77	170.6	97	206.6
18	64.4	38	100.4	58	136.4	78	172.4	98	208.4
19	66.2	39	102.2	59	138.2	79	174.2	99	210.2
20	68	40	104.0	60	140.0	80	176.0	100	212.0

Fig. 6-1. Table showing degrees of temperature in centigrade and corresponding values in Fahrenheit.

lector terminals of the transistor; then reverse the leads. Attach the leads to the transistor in the position that gives the highest resistance reading, and set the multiplier switch of the ohmmeter to the scale that places the meter needle nearest the center.

Keep the ohmmeter leads connected to the transistor, and warm the transistor by holding it between your two fingers or by placing it near a heated soldering iron. As the transistor warms up, its resistance drops. When the temperature of the transistor changes, its characteristics also change.

A similar effect can be obtained by using a junction diode. In fact, diodes are used as temperature-compensating components in certain transistor circuits. The diode junction and the transistor junction are quite similar; therefore, the resistance change of a particular diode and transistor could be simi-

lar. The diode can be employed as a temperature-correcting device in the transistor circuit.

Amplifier stages such as RF, IF, and audio preamplifiers carry very small currents, and the usual temperature changes do not create current changes great enough to damage the transistors. The power-output stages of radios and amplifiers (particularly auto radios) control a relatively large current; and, if it were not for some form of temperature compensation, the ensuing temperature increase would cause a current increase that in turn would cause a further temperature increase. This runaway condition would almost always end in the destruction of the transistor or transistors.

TEMPERATURE COMPENSATION

The increase in current flow that accompanies a temperature rise can be reduced by controlling the bias to the transistor. The simplest form of this type of compensation was discussed in a previous chapter under biasing of the common-
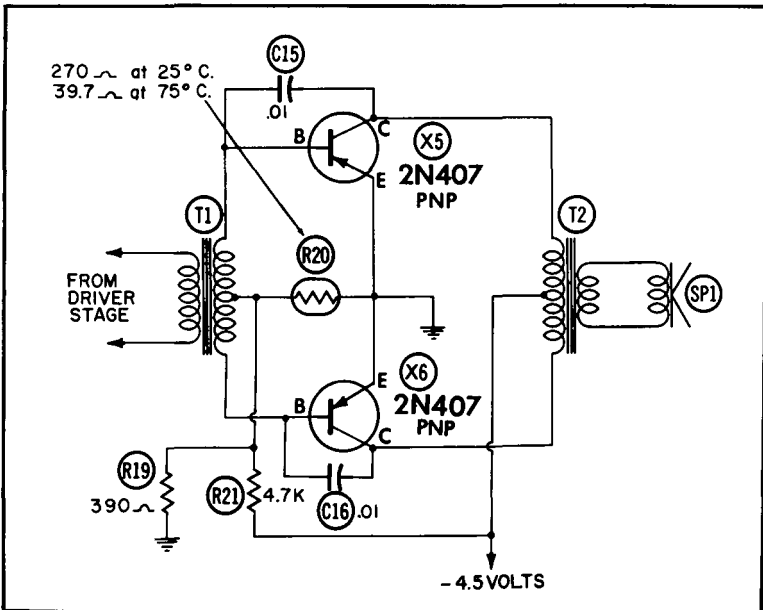

Fig. 6-2. Push-pull output stage using a temperature-sensitive resistor.

emitter configuration, in which a resistor is placed in series with the emitter to produce current feedback and to control the bias on the transistor. This method also produces some degeneration of the signal and increases the number of components in the circuit. Even so, many circuits do use this system of preventing runaway in a power-output stage.

In the circuit in Fig. 6-2, a temperature-sensitive resistor R20 is added to the biasing arrangement. This resistor, or thermistor, has a negative temperature coefficient (the resistance decreases as the temperature rises). The cold resistance of a thermistor is supposed to be measured at 25° centigrade. The hot resistance is seldom stated, since the resistance change between cold and hot is important only to the circuit designer.

Resistor R20 in Fig. 6-2 has both its hot and cold resistances given. These are 270 ohms at 25° centigrade and 39.7 ohms at 75° centigrade. This particular thermistor has a resistance-to-temperature relationship that is set during manufacture and cannot be changed later. The effect of R20 upon the circuit can be altered by adding parallel resistances (see R19 in Fig. 6-2), series resistances, and combinations of series and parallel resistances. When the circuit design and the transistors are different, the thermistor usually has entirely different characteristics.

The function of resistor R20 in Fig. 6-2 can be shown by the simplified circuit in Fig. 6-3. A single output transistor is used and the two resistors R21 and R20 make up a divider that supplies bias current to the base.

The collector current is controlled by the bias applied to the base of the transistor. An increase in temperature can increase the collector current beyond the safe limit. If the bias current is reduced, the collector current will be reduced and the transistor will return to its proper operating point.

In the circuit of Fig. 6-3, the values of resistors R21 and R20 determine the amount of transistor bias. Changing the value of either one will change the voltage on the base. Resistor R20 has a negative temperature coefficient, and the resistance decreases as the temperature rises.

There are two methods of describing the action of R21 and R20 in developing transistor bias—as a voltage divider or

as a current divider. This is a personal preference, and both methods are therefore given.

As a voltage divider, the two resistors can be considered a tapped bleeder with the base connected to the tap (Fig.
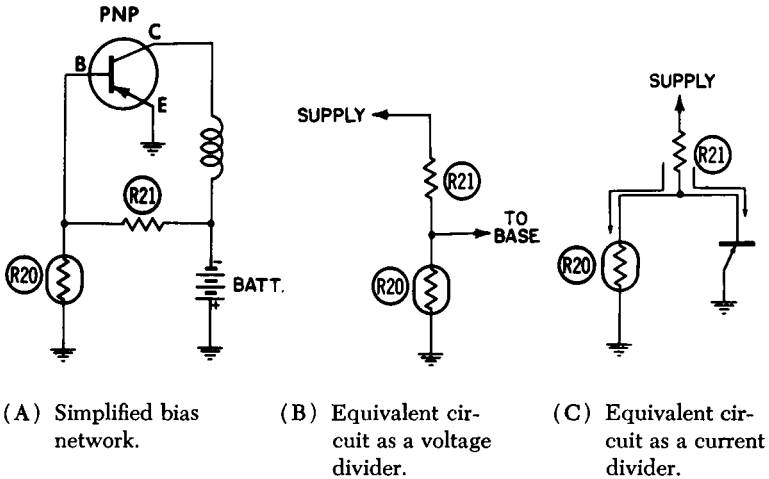

| (A) Simplified bias network. | (B) Equivalent circuit as a voltage divider. | (C) Equivalent circuit as a current divider. |

Fig. 6-3. Simplified versions of the bias network in Fig. 6-2.

6-3B). Changing the value of resistor R20 will change the voltage at the tap. This voltage is applied to the base of the transistor. A rise in temperature will lower the resistance of R20, and the voltage applied to the base will decrease. The temperature rise that can cause an increase in collector current can also cause a decrease of the transistor bias, and the collector current will remain fairly constant.

As a current divider, the two resistors plus the junction are arranged as shown in Fig. 6-3C. The current passes through resistor R21 and splits into two paths. A rise in temperature will reduce the resistance of R20: more current will flow through R20, and less current will flow through the junction. Bias on the transistor will be reduced whenever its temperature rises.

Occasionally, a diode is employed as the controlling component to prevent collector current rise. The circuit in Fig. 6-4 is an example. The characteristics of a diode and the emitter-

follower action together produce temperature compensation in a circuit. A single-transistor version of this circuit is shown in Fig. 6-5.
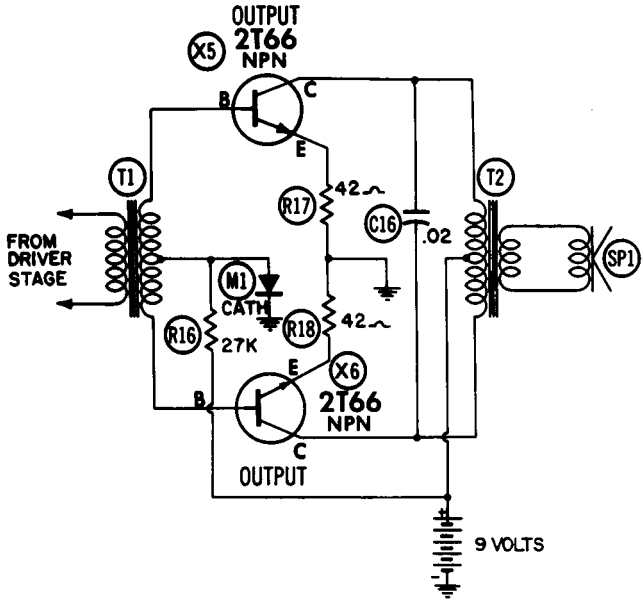

Fig. 6-4. Output circuit with diode employed for temperature compensation.

One-tenth or two-tenths of a volt applied to a diode in the forward direction will produce a relatively small current flow. The resistance is extremely high at very low voltages. As the voltage is further increased one-tenth of a volt, the current increases greatly. This change is nonlinear because the resistance of the diode decreases as the voltage rises. As a result, the diode can be used to obtain temperature compensation. This effect can be seen from the values given in the chart in Fig. 4-14.

In the circuit in Fig. 6-5, the voltage impressed upon diode M1 is the same voltage impressed upon the series combination of the base-to-emitter junction and emitter resistor R17. The bias current is determined by the combination of fixed resistor R16 and the resistance of the diode. The resist-

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ance of the diode is determined by the voltage impressed across it.

The current that will flow through the base-to-emitter junction of the transistor will be determined by the voltage be-
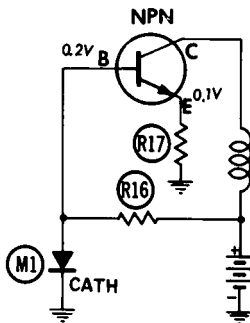
Fig. 6-5. Simplified circuit for temperature-compensating diode.

tween base and emitter. In Fig. 6-5 the voltage is shown as 0.2 volt on the base and 0.1 volt on the emitter, or an effective bias voltage of 0.1 volt on the transistor, whereas diode M1 has a voltage of 0.2 volt across it.

The 0.1 volt across resistor R17 is developed mainly by the output current flowing through it. A temperature rise will increase the collector or output current, and the voltage across R17 will increase. The potential at the emitter will rise, the difference in potential between base and emitter will be less, and the bias current will drop. For the circuits in Figs. 6-4 and 6-5, this is quite true because of the diode. Without the diode, the voltage at the base would rise because of the reduced current through R16. The current through R16 is constant because the changing resistance of the diode prevents the voltage at the base from increasing too greatly. The potential on the base of the transistor rises slightly, but this rise is smaller than the increase in emitter voltage, and the bias current is reduced. The transistor bias changes as the operating temperature changes, and prevents overheating of the transistor.
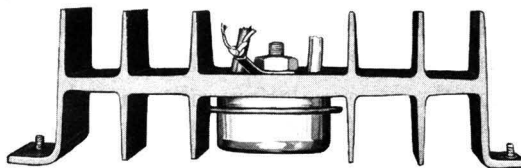
HEAT DISSIPATION

The current flowing through a transistor junction is converted into heat at a rate that can be determined by Ohm's law

for power. The junction of a transistor resists the flow of current, and the heat energy developed is determined by the quantity of this current. The heat produced at the junction must be conducted away to prevent destruction of the junction. The faster the heat is conducted away, the more efficient the transistor becomes.

Transistors used primarily for voltage amplification do not need to dissipate large quantities of heat; therefore, air is usually the only heat-conducting medium. On the other hand, the power transistor is so constructed that the metal of the junction electrically and mechanically contacts the case, and the case must be constructed of a good heat conductor, such as copper. The heat developed at the junction can be rapidly conducted away; thus, the junction can handle higher power without being damaged. The power-handling capabilities of transistors can be further improved by adding heat radiators to the transistor or by fastening the transistor to a heat sink.

RADIATOR AND HEAT SINK

The radiator and the heat sink are both descriptive of their functions. The radiator is usually a finned device, as shown in Fig. 6-6. The fins are vertical to take advantage of


Fig. 6-6. Finned radiator device used for heat dissipation.

the fact that hot air rises. As the air near the fins is warmed, it moves upward and is replaced by cooler air. This action is referred to as a "chimney" effect. Radiators of this type are shaped to provide a maximum of heat transfer with a minimum of material and space.

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The heat sink is just what the name implies, a large plate or block of metal into which a large quantity of heat can sink. The heat sink is usually constructed of a good heat conductor (such as aluminum) or of the metal in the equipment chassis.
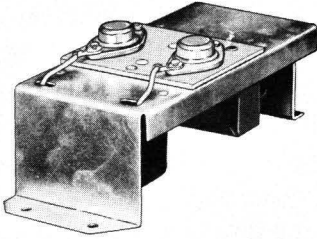
(A) Transistors mounted on plate which is fastened to chassis.
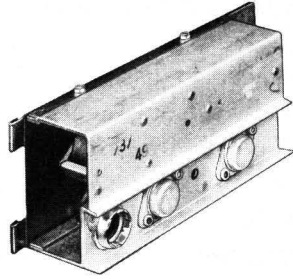
(B) Chassis used as a heat sink.

Fig. 6-7. Examples of heat sinks employed in automobile receivers.

Two examples of heat sinks employed in automobile receivers are shown in Fig. 6-7. The heat sinks are made of the chassis metal; but in Fig. 6-7A, the transistors are mounted on a small plate which is then fastened to the chassis. In Fig. 6-7B, the chassis is a heavy aluminum extrusion and functions as both chassis and heat sink.

The importance of heat dissipation should not be overlooked when a transistor fails. Heat sinks and heat radiators for power transistors should be located in free air. Obstructions that stop the air circulation will cause the transistors to overheat and to be damaged.

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MECHANICS OF
TRANSISTOR USAGE

One of the major advantages of a transistor is that it does not deteriorate and, by all rights, should last indefinitely; but this does not mean it will never fail. Transistors can fail because of excessive heat, current, voltage, and mechanical shock. Often, a transistor failure is precipitated by the failure of another component; this possibility should be investigated before a transistor is replaced. Another reason for transistor failure is improper installation of the transistor itself. This is important because another transistor has a good chance of failing if the same mistakes are repeated.
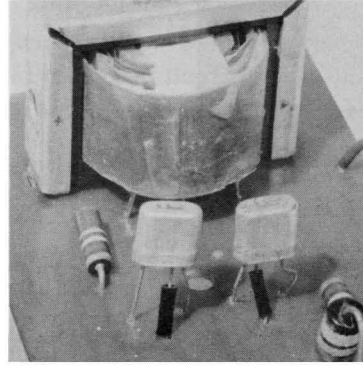
TRANSISTOR REPLACEMENT BY SOLDERING

Transistors used as low-power signal amplifiers in pre-amplifiers, RF and IF stages, etc., are connected into the circuit by inserting the leads or contacts into a socket or by directly soldering the leads into the equipment. Transistors that are plugged into the equipment (as in Fig. 7-1A) present few replacement problems, since the base and plug are usually matched. Transistors that are soldered into the equipment (as in Fig. 7-1B) require more consideration.

The terminals or lead wires of a transistor are fastened directly to the transistor junction and are good heat conductors. When a transistor must be removed or replaced, it

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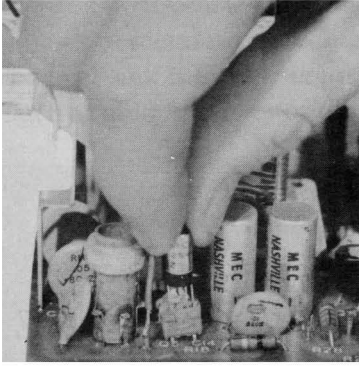
(A) Plugged into a socket.   (B) Soldered into the circuit.

Fig. 7-1. Two methods by which a transistor designed for low-power operation may be connected into a circuit.

should be isolated from the soldering iron by a heat sink. Fig. 7-2 shows two types of heat sinks; the long-nose pliers in Fig. 7-2 are more practical, since they are usually at hand. An alligator clip is also very useful, particularly when filled with solder, as shown in the inset in Fig. 7-2. This solder increases the area in contact with the wire and adds to the volume and efficiency of the heat sink.

The quantity of solder in the connection will also determine the amount of heat required to solder or unsolder a transistor lead. A large lump of solder takes more time to melt
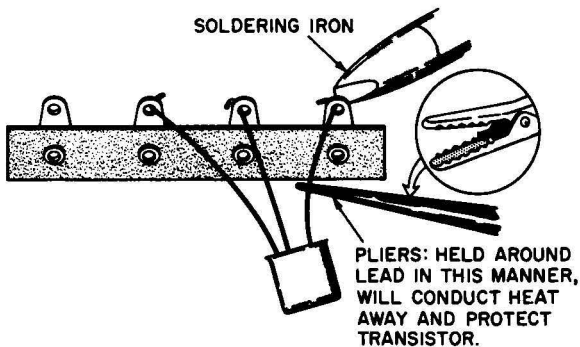
Fig. 7-2. Method by which a transistor is protected from excessive heat during installation.

than a smaller quantity; therefore, use as little solder as possible so that it will cool off more quickly. This leaves less chance for the transistor to heat up.

The leads of a soldered-in transistor will be flexed and bent while the transistor is being installed and removed. These leads will break, just as those on capacitors and resistors will; therefore, the transistor leads should not be moved excessively. Before removing a soldered-in transistor, make sure it actually is defective. (Suggested methods for checking the transistor are discussed in Chapter 8.) Chances are that another component is bad or that a component failure ruined the transistor. The defective component should be replaced first, and the circuit should be rechecked. A defective part can cause a good transistor to appear defective; thus, transistor replacement may be unnecessary.
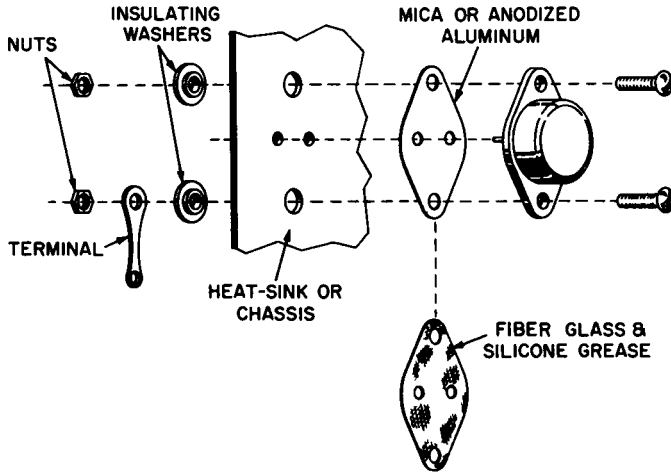
POWER TRANSISTORS

The power transistor usually is mounted on a heat sink or on a radiator in order to operate more efficiently. This heat sink or radiator normally is not part of the transistor, but is added while the transistor is mounted. Incidentally, power transistor installation is not complete, as far as power operation is concerned, until the power transistor is properly mounted.

The power transistor is so mounted to a heat sink or radiator that maximum heat is transferred away from the transistor case. One method of mounting the transistor for maximum heat transfer is directly to the heat sink (metal to metal); however, since the collector normally is connected directly to the case, an unwanted potential is placed on the heat sink. (Note: In a few circuits, the collector is grounded so that this method of transferring heat can be used.)

In most circuitry the collector must be kept above ground. Therefore, an insulator must be placed between the transistor and the heat sink. Fig. 7-3 shows a mounting arrangement for a power transistor.

In Fig. 7-3 the transistor is electrically insulated from the chassis or heat sink by a mica, fabric, or an anodized-aluminum

washer. Mica is a very good insulator of both heat and elec-
tricity, although heat will flow through thin sheets fairly well.
When installing a mica insulator, use only one sheet, because
more than one sheet will reduce the heat transferred to the


Fig. 7-3. Mounting arrangement for a power transistor.

heat sink and cause the transistor to overheat. Anodizing
aluminum produces a thin, tough film that is a good electrical
insulator, yet this film is so thin that heat is easily transmitted
through it.

The fabric insulator shown in Fig. 7-3 is made of glass
fiber. It is not a good heat conductor, although its heat-con-
ducting properties can be greatly improved by filling the
small openings with a silicone grease. Silicone grease, being
completely inert, does not react with the transistor or with the
metal of the heat sink and does not evaporate or become fluid
when heated. The glass fiber pad prevents electrical contact
between the heat sink and the transistor and acts as a gasket
to seal in the grease. The grease provides the heat conduction
necessary to cool the transistor.

Two flat surfaces placed together actually make physical
contact at only a few high points. If the seemingly smooth
surface were viewed under magnification, it would appear ex-
tremely rough; and two such surfaces facing each other will

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actually produce contact, as shown in Fig. 7-4. If the contact area can be increased, the efficiency of the heat transfer will increase. This is the purpose of the silicone grease—to fill the voids between the two surfaces.

Fig. 7-4. Two apparently smooth surfaces seen under a magnifying glass.
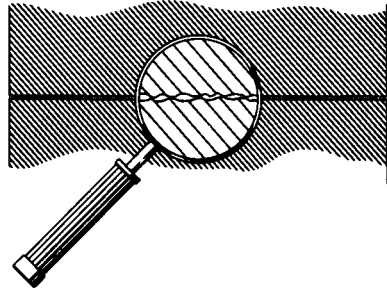
The grease should be spread evenly over all surfaces to be contacted, in much the same way that you spread glue on surfaces to be glued together. The mica or other insulating washer should be coated on both sides, and the excess grease will be pressed out by the normal tightening of the mounting bolts.

A further precaution when you are mounting a power transistor is to be sure both surfaces are free from any bits of metal or other abrasive particles. These can damage the insulator or short the transistor to the heat sink.

After the transistor is mounted, turn on the equipment and place your fingers on the transistors. A rapid build-up of heat indicates that something is wrong. Also check the equipment at high output to make sure the transistors do not overheat.

Overheating can be caused by:
1. Incorrect transistor bias.
2. High-frequency oscillation.
3. Blocked air circulation around the radiator.
4. Improper mounting to the heat sink or radiator.
5. Defective transistor.

EXCESS VOLTAGE

Voltage amplitude, voltage polarity, and voltage surges must all be considered when a transistor is placed into a cir-

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cuit. When the transistor breaks down, it is very much like an electrolytic capacitor. Too much voltage can puncture a transistor, and the wrong polarity will produce excessive current and subsequent overheating. Voltage surges will produce both puncturing and overheating, the damage taking place in just an instant.

The problem of too much voltage may be encountered when an unregulated power supply is used. The battery eliminator type of power source will change the voltage as the load changes. The voltage must be reduced when the load is removed. The output of a power supply intended for transistor equipment is usually bypassed with at least a 1000-mfd capacitor. When the load is removed, the voltage increases; when the load is then replaced, it will be connected to a higher-than-normal voltage. The voltage does not drop instantly because of the high-value capacitor, which must discharge first.

When a power supply is employed with transistor equipment, turn down or turn off the supply voltage, rather than disconnecting the receiver or switching it off.

POLARITY

One of the interesting aspects of transistors is that we must concern ourselves with both types of units, NPN and PNP; and both have similar envelopes, with only a number to point out the difference. If we guess at the type and guess wrong, we may well have a ruined unit. Therefore, give the same consideration to a transistor that you would give to an electrolytic capacitor. Observe the polarity, NPN or PNP. Remember this important fact—the *collector* of an NPN is Positive and the *collector* of a PNP is Negative.

High voltage or a voltage with potential great enough to break down a transistor junction seldom will be found in a transistor receiver powered by the correct batteries. If the wrong batteries have been placed in the receiver, high voltage may destroy a number of transistors, although chances are the filter capacitors will short first. The voltage of the batteries should be one of the first checks in a service procedure.

Another source of high voltage may be encountered in hybrid equipment containing both transistors and high-voltage

vacuum tubes. The transistors are often powered by B+ from a voltage divider. The voltages should be checked to reveal whether any excessive voltages are present.

Voltage surges are a common source of transistor failures. The surges are generally caused by making and breaking a current-carrying circuit. Resistive circuits can be broken and replaced with little trouble; but if the circuit contains high-value capacitors or inductors, the making or breaking of circuits can cause voltage transients that will damage a transistor. The power source should be turned off before any circuit breaks or connections are made.

EXCESS SHOCK

A great deal has been said about the shock resistance of the transistor. Transistors are highly shock resistant, but they can be damaged by a sharp blow or by being dropped. The statement "shock resistant" does not mean destruction-proof.

SUMMARY

When a transistor is to be removed or installed, the following considerations should be kept in mind.

Low-Power Transistors

Turn off the power source.

Observe the pin arrangement when a transistor is removed, and replace the new unit in the same manner.

When soldering transistor leads, use pliers or clips to clamp the leads and conduct the heat away from the transistor.

Make reasonably sure a transistor is defective before unsoldering it.

Power Transistors

Turn off the power source.

Use the recommended method for mounting, or mount the replacement the same way as the one removed.

Addition of silicone grease to any mounting system will improve the performance of any unit, and is required on many.

Check the operating temperature with the volume at a high setting. The heat rise should not be excessive.

TESTING TRANSISTORS

The transistor is the principal component in a transistor receiver; on this basis alone, one would be inclined to suspect it when a failure occurs. The transistor is, however, a very dependable component and generally fails no more, and probably less, than any other component. It is not practical to remove and test each transistor in the receiver, particularly when the transistors are probably good. Before making a wholesale attempt at testing transistors, you should check the normal operation of the transistors in the various circuits.

The servicing of transistor equipment should begin with an attempt to localize the general area of the trouble. This can be done in many ways, and each technician can apply his own particular methods. A general voltage check at various points in the equipment can sometimes locate discrepancies that may lead to the trouble. (An important point to remember is to check the battery voltage with the equipment turned on.) A signal-tracing check will also help determine the location of the trouble.

CHECKING THE TRANSISTOR AMPLIFIER

The common-emitter configuration is found in nearly all transistor circuits. The voltage at the base will be just slightly different from the voltage at the emitter, but may be plus or minus in relation to the emitter. Fig. 8-1 shows two IF stages

from a receiver, one PNP and the other NPN. The collector of X2 measures zero volts, and the collector of X3 measures 5.1 volts. Without a schematic of this receiver, the service technician might be misled by this condition, since transistors used as IF amplifiers are usually of similar conduction types.
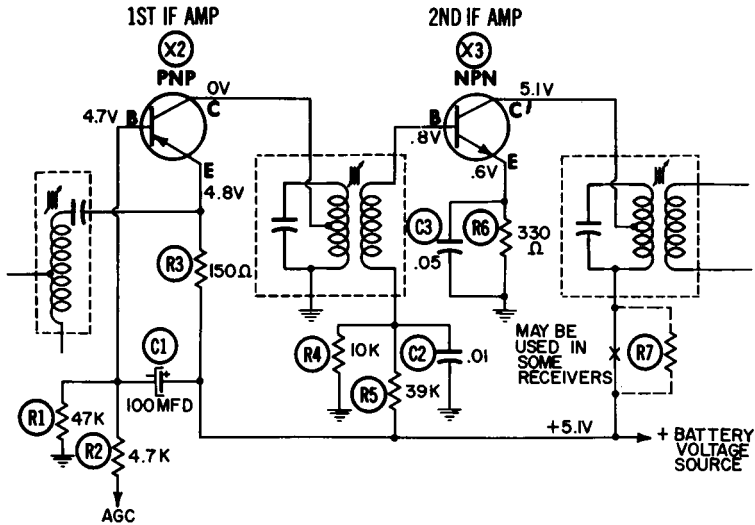

Fig. 8-1. An IF amplifier using both PNP and NPN transistors.

A measure of the base and emitter voltages in this receiver will reveal that the potential is less at the base of X2 than at the emitter, and the potential is higher at the base of X3 than at the emitter. Both biases are correct.

Collector current can be measured by checking the voltage drop across a known resistance in the emitter or collector circuit. For example, resistor R3 in the emitter of X2 in Fig. 8-1 is 150 ohms, and the voltage drop across R3 is 5.1 minus 4.8 or 0.3 volt. The current equals E/R, or .3/150, or 2 milliamperes. The current for transistor X3 can be figured by using resistor R6 in the emitter lead or a resistor such as R7 in the collector if the circuit contains one.

If the calculations place the current too high or too low, don't assume this is a true current until the resistor value has been checked and determined to be correct.

Improper transistor bias will produce an improper current flow in the emitter or collector circuit. The bias for transistor X3 in Fig. 8-1 is determined by R4 and R5. These resistors will seldom be off value because they carry very small currents; but when the bias is wrong, they should be checked.

TESTING TRANSISTOR CURRENT GAIN

The transistor must be able to control the current flow in the emitter and collector circuits. Current control can be checked without removing the transistor from the circuit. Before any suspected component is removed from the circuit, the current-gain tests should be performed. These tests are applicable to any transistor amplifier, whether in the oscillator, converter, IF, or audio circuits.

Test I

Locate a resistor in the emitter or collector circuit. In Fig. 8-1, resistor R6 can be used. The reading of 0.6 volt is due to the current flow through transistor X3. Short the base to the emitter. This will cut off the transistor and reduce the voltage across R6 to practically zero. A transistor that cannot be cut off is defective and should be replaced.

Test II

An additional test is to parallel one of the bias resistors with one of equal or nearly equal value. An example would be placing a 39K resistor in parallel with resistor R5 in Fig. 8-1. This would about double the emitter current, and the voltage across R6 should increase to 1 volt or more.

Test II is not as important as Test I, but does add useful information about the operation of the transistor.

CHECKING OSCILLATORS

The oscillator section of a receiver is shown in Fig. 8-2. The collector current in transistor X1 is approximately 0.4 ma. This is calculated by dividing the 0.4-volt drop across resistor R4 by 1,000.

When an oscillator is not operating, collector current will increase to about twice the operating value. In the circuit in Fig. 8-2, the collector current will rise to nearly 0.8 ma, and this will cause the voltage at the emitter to rise to about 1 volt.
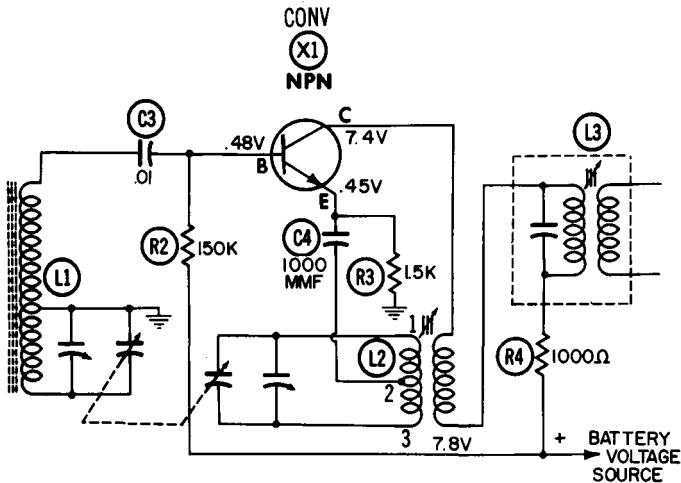
Fig. 8-2. A typical oscillator circuit in a broadcast receiver.

The oscillator can be checked by shorting the tuned section of L2 or by shorting any two of the terminals 1, 2, or 3. This will stop the oscillator and increase the collector and emitter current. If the oscillator is already inoperative, the current will be high and shorting the coil terminals will not change the current.

When an oscillator coil fails, it is either open or shorted. The open coil can be checked with an ohmmeter, but a short circuit may take place between two adjacent turns; therefore, no appreciable change in the resistance reading will be noted. Shorting two terminals of a good oscillator coil produces the same effect and can be used to check oscillator operation.

Remember that lack of transistor current gain will also prevent oscillation; therefore, check the current gain of the oscillator or of the converter transistor before changing other components.

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CHECKING CLASS-A AUDIO AMPLIFIERS

A single-ended audio amplifier is operated Class-A. This means the transistor is biased close to the center of the operating curve, or about halfway between design maximum and cutoff. Since most audio amplifiers have output or coupling transformers for collector loads, it is difficult to determine whether the transistor is actually biased for Class-A operation.

An audio amplifier that is improperly biased will cause the signal to be distorted at high volume levels, but at low output levels it will sound normal. The circuit should be checked for correct voltages, and the transistor should be checked for current control.

CHECKING PUSH-PULL OUTPUT

The push-pull output stage usually is biased near cutoff, and current drain increases when a signal is applied. A milliam-
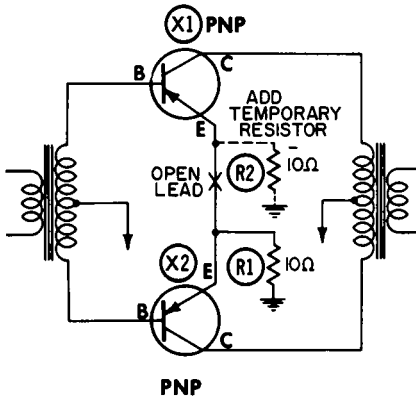
Fig. 8-3. An arrangement for checking the current balance in a push-pull output circuit.

meter in series with the supply will indicate how the stage is operating. Excessive current flow in either or both transistors will be indicated by a high meter reading.

The individual currents can be checked by measuring the voltage across each emitter resistor. When the emitter resistor is common to both units and one transistor is suspected of being defective, one emitter lead can be opened and another resistor of the same value placed in that lead (Fig. 8-3). The

original emitter resistor R1 is not touched. The emitter lead of transistor X1 is opened, and resistor R2 is temporarily clipped or tack soldered between the emitter terminal and ground. The current balance between the two transistors can now be checked both with and without a signal.

OUT-OF-CIRCUIT TESTS

A rapid check of a transistor can be made with an ohm-meter. Such a procedure is shown in Fig. 8-4. Be sure the battery voltage in the meter does not exceed the voltage rating of the transistor. Also be sure not to use the low meter scales for the low-power transistor. On the high meter scales, the current through the probes is limited by high internal resistances; but on the low scales, the current can become quite high and over-heat the transistor junction. Start by setting the ohmmeter on the highest scale, then reduce it to the scale that produces an appropriate reading.

The ×10,000 and ×100,000 scales on most meters are usually safe for checking low-power transistors. The ×1 and ×100 scales are almost correct for the high-power transistors.

Set the ohmmeter to the highest range, and connect the leads to the base and the collector terminals (Fig. 8-4A). Reverse the connections and note the direction that provides the highest reading (Fig. 8-4B). This is the reverse-bias direction. Connect the leads in this direction, observe the meter reading, and short the emitter and base terminals together as shown in Fig. 8-4C. The resistance reading should decrease.

Remove the ohmmeter lead from the base terminal and connect it to the emitter terminal. Observe the resistance reading, then short the base to the emitter (Fig. 8-4D). The resistance should increase.

A defective transistor will not perform in this way. A transistor that is weak or that has high leakage will not be detected by this test. This is strictly a good-bad test.

A number of transistor testers are available on the market. Some of these give a value reading; others give only a good-bad indication. Transistor testers are available either as separate

units or combined with other test instruments, such as tube testers. For most receiver repairs, a good-bad indication is all that is required. The most positive test, however, is direct substitution of the questionable transistor.
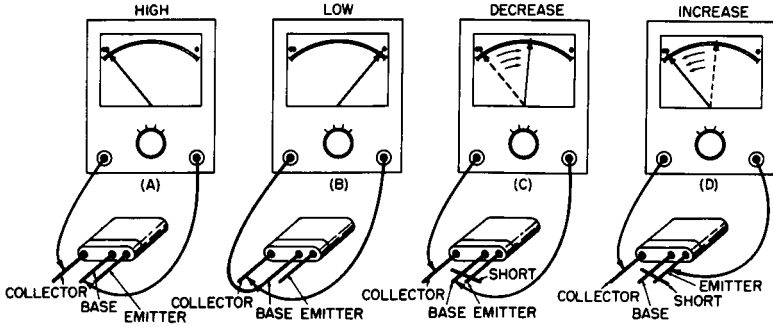
(A) Resistance measurement between collector and base. (B) Same resistance measurement as in (A), but with ohmmeter leads reversed. (C) Resistance measured between collector and base, with a short placed between base and emitter. (D) Resistance measured between collector and emitter, with a short placed between base and emitter.

Fig. 8-4. Procedure for checking a transistor with an ohmmeter.

SUBSTITUTION

A transistor can be temporarily substituted for checking circuit operation or for detecting a defective transistor. In such instances, any transistor with a similar rating can be used. Although this substitute may not work as well as the correct transistor, the fact that it does work indicates that the original transistor is defective. The defective transistor should then be replaced with one having the same type designation or a type recommended by the receiver or transistor manufacturer.

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