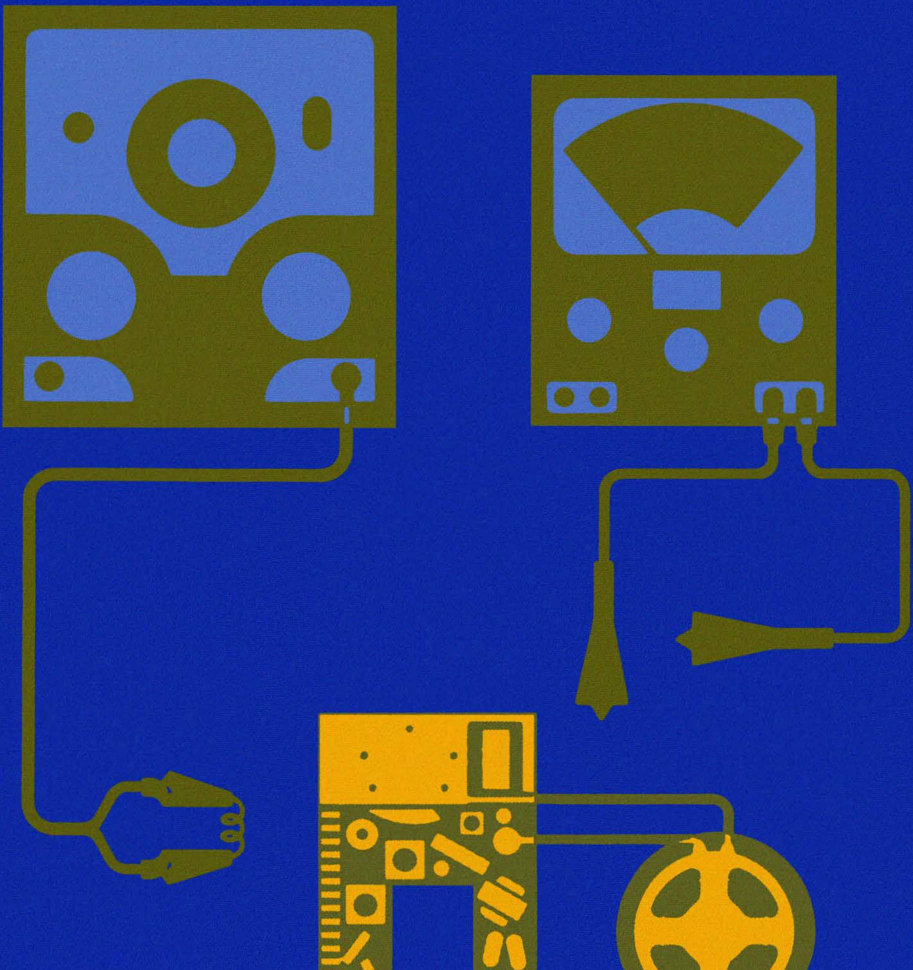
Repairing Transistor Radios

Sol Libes

Revised Second Edition



HAYDEN

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preface

The transistor has, within a decade, caused a major revolution within the electronics industry. The once all-supreme vacuum tube is, day by day, disappearing from many types of equipment. The transistor has put us in the era of miniaturization, low power consumption, and high reliability—the long-desired goals in electronic design.

At present the widest application of transistors in consumer products is in the portable radio. Today, every portable radio made in the United States, and elsewhere for that matter, is a transistor radio. This radical change has occurred with such swiftness that it has created a vast problem in servicing these radios.

The service technician who is in the forefront in learning the operation and servicing of new developments is the man who will profit most in this new area of electronics. It is to this man that this book is dedicated.

The introduction of transistorized equipment has brought to service technicians the realization that they must revise many of their concepts and attitudes toward circuit theory and practice. Indeed, totally new methods and procedures must be devised to troubleshoot and repair transistorized equipment. It is the purpose of this undertaking to present these newly developed procedures.

This book is designed so that a reader may read it as a text, from cover to cover, and also as a reference when the solution to a particular problem is required. For use as a text to learn the operation of transistor circuits and receivers, it is recommended that the reader start with the first chapter and read each chapter in succession. However, when using this book as a reference guide in servicing, the technician should first read the chapters on troubleshooting techniques (Chapter 10) and on tools and test equipment (Chapter 11). Then he should refer to the servicing sections at the end of each chapter for the servicing procedures for the particular circuit in which the trouble exists.

Information on the operation and servicing of transistorized equipment other than portable AM receivers is also discussed in detail, providing up-to-date coverage on hybrid and all-transistor auto radios, public address and high-fidelity amplifiers, and FM and multiband receivers.

It can truly be said that this book was made possible only through the cooperation of many individuals and companies. The author wishes to acknowledge their assistance in furnishing illustrations and making available technical data, and personally to thank the following individuals for their efforts: Bob Tomer, CBS Hytron; Samuel Rabinovitz, Cleavite Corp.; C. E. Knapp, General Electric Co.; C. A. Meyers and S. F. Phillips, RCA; C. W. Martel, Raytheon Mfg. Co.; W. W. Lenz and W. W. Cook, RCA Service Co.; E. M. Manni, Sylvania Electric Products, Inc.; Stan Stack and Orvil Jordan, Westinghouse Electric Co.; Jack L. Jaques, Motorola Semiconductor Products, Inc.; El Mueller, Motorola Consumer Products; Mark Ehren, Eico Electronics Instrument Co.; and Laurie Anne Shufflebotham, Dynascan Corp.

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1. The Transistor

A transistor is a semiconductor solid-state device capable of performing many functions heretofore performed only by vacuum tubes. To understand better just how the transistor operates, we should first review some basic atomic physics.

ATOMIC STRUCTURE OF ELEMENTS

All elements are composed of atoms, which in turn consist of a nucleus (positive charge) with orbital electrons (negative charge) rotating around it. To some degree, the atom resembles our solar system.

The simplest of all atoms is the hydrogen atom. An atom of this element consists of a single proton in the nucleus and one electron rotating around the nucleus. This element is shown in Fig. 1-1. With one proton (positive charge) and one electron (negative charge) balancing each other, we say that this element is *neutral.*

An atom with a more complex structure is shown in Fig. 1-2. This is an atom of the element carbon. It has six protons in the nucleus, two electrons in its first orbit, and four electrons in its outer orbit. Carbon is a semiconductor since the electrons in its outer orbit can be dislodged easily and other electrons can take their places.

An element may be a conductor, an insulator, or a semiconductor. A *conductor* is an element in which the electrons of the outermost

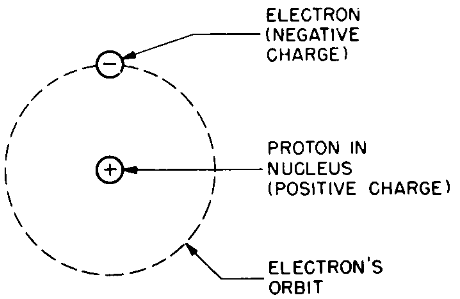


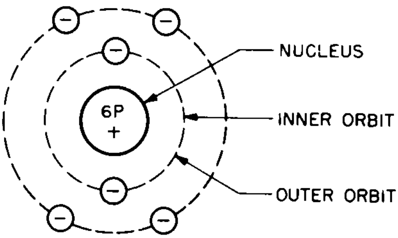
Fig. 1-1. The hydrogen atom is composed of a single proton in the nucleus and one electron orbiting around it. This is the simplest of all atoms.

orbit (called the valence electrons) may move from one atom to another in a free and haphazard manner. These electrons are called *free electrons.* For example, the aluminum atom is composed of thirteen protons in the nucleus and thirteen electrons revolving in orbit. The outermost orbit has three valence electrons which are not tightly bound to the nucleus and may move easily from one atom to another. Aluminum is therefore a good conductor. An *insulator* is composed of atoms that have few loosely held valence electrons and for all practical purposes has no movement of electrons from atom to atom. Between the extremes of good conductors and good insulators are the *semiconductors.* These elements are neither good conductors nor good insulators. Germanium and silicon fall into this category.

GERMANIUM AND SILICON ATOMS

Germanium and silicon are the basis elements currently used in the manufacture of transistors. The atomic structure of germanium is shown in Fig. 1-3. It has thirty-two protons in its nucleus and thirty-two electrons revolving in different orbits about the nucleus. The outermost orbit contains only four valence electrons. It might be thought that some of the four electrons in the valence ring of the germanium atom could easily be displaced and that this element would therefore be a reasonably good conductor. As a matter of fact, however, germanium is a very poor conductor.

Fig. 1-2. Atomic structure of carbon.



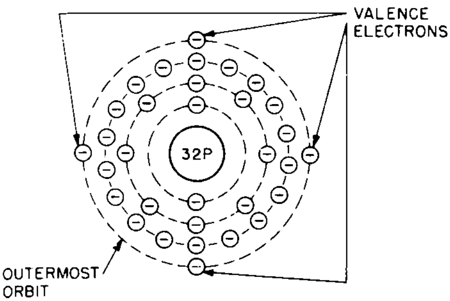


Fig. 1-3. A germanium atom is composed of 13 protons in the nucleus and 13 orbital electrons. Four valence electrons, in the outermost orbit, make this element a semiconductor.

When atoms of germanium are arranged in a crystal lattice structure, the valence electrons in the outer orbits of each germanium atom arrange themselves into covalent bonds (Fig. 1-4) with each atom. Here the outer orbits of each germanium atom contain eight electrons and are, therefore, complete. This is because the outer orbit electrons are shared (in a covalent state) by adjacent atoms. There are now no free electrons, and the pure germanium crystal is a good insulator.

Although the silicon atom contains only fourteen protons and electrons, it has the same number of valence electrons as germanium and behaves in the same way. The discussion for germanium semiconductors below thus applies to silicon semiconductors as well.

Making Germanium a Semiconductor. Germanium can be made a semiconductor in three different ways: adding minute quantities of impurities; applying heat energy; and applying light energy. Each of these actions increases the number of free electrons.

If a free electron could be added to pure germanium without destroying its crystal structure, the electron would move as freely as in a vacuum. It is possible to inject atoms of substances other than germanium into the crystal structure of germanium. These substances are called *impurities.*

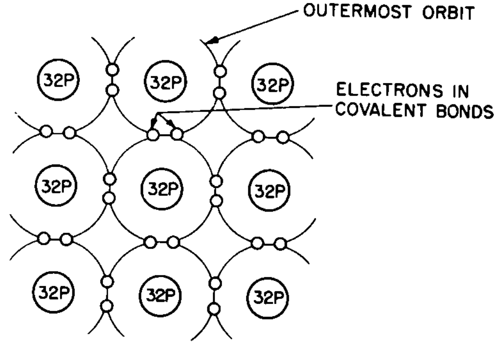


Fig. 1-4. A germanium crystal is composed of atoms in a covalent state. It is, therefore, a nonconductor.

Two groups of impurities exhibit the important characteristic of being able to join the lattice structure of germanium; one group is called *donors,* which have five valence electrons in their outer incomplete orbit; the other is called *acceptors,* which have three valence electrons in their outer incomplete orbits. Donor material is sometimes called *pentavalent* and consists of substances such as arsenic, phosphorous, and antimony. Acceptor material is sometimes called *trivalent* and consists of substances such as aluminum, gallium, and indium.

The amount of impurities added to germanium determines its conductivity. If the ratio of impurity added is on the order of 1 impurity atom to 100,000,000 germanium atoms, the conductivity increases 16 times. This form is adaptable for transistor use.

If the ratio of impurity, for example, were 1 atom of impurity to 10,000,000 germanium atoms, the conductivity increases 160 times. This form is excessive and would no longer be useful for transistor applications.

N-Type Germanium. When a small amount of donor type impurity (e.g., arsenic) is added to germanium, the impurity atom attempts to align itself (Fig. 1-5) into covalent bonds with the neighboring germanium atoms. Here, four of the arsenic atom's

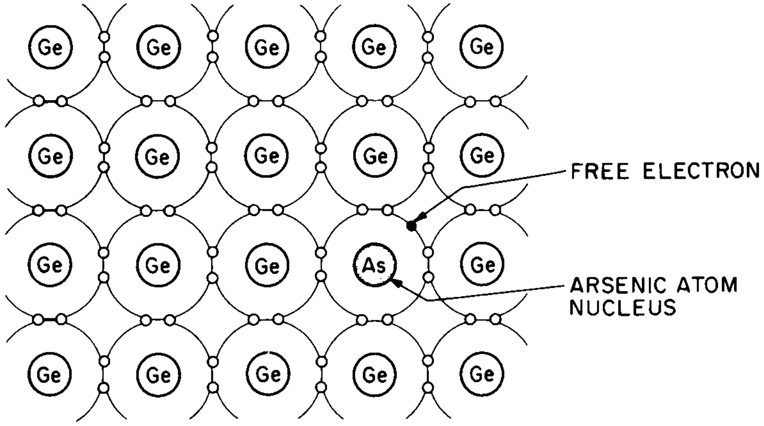


Fig. 1-5. When a germanium atom is replaced by an arsenic atom, a free electron remains. This is known as n-type donor germanium.

valence electrons form covalent bonds with the adjacent germanium atoms. However, the fifth electron has no adjacent germanium atom to form a covalent bond with and is, therefore, free to drift around.

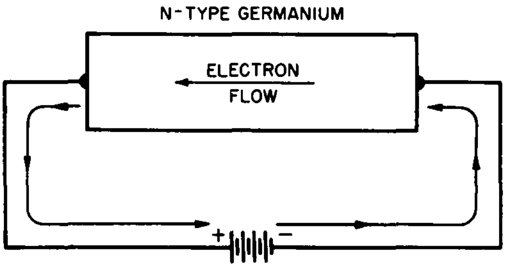


Fig. 1-6. Conduction in n-type germanium is by electron flow from the negative side of the battery to the positive side.

This germanium material is known as n-type germanium. It is a donor because it has an excess of electrons, which are able to move freely. If a battery were connected across the crystal lattice structure (Fig. 1-6), the electrons would drift over toward the positive terminal and enter the material from the negative side of the battery.

P-Type Germanium. Figure 1-7 illustrates a germanium crystal in which one of the germanium atoms has been replaced by an acceptor impurity. In this case, the impurity is indium which has three valence electrons in its outermost orbit. The three valence electrons align themselves into covalent bonds with the neighboring germanium atoms. The result is an electron-hole condition. The position that would normally be filled with an electron is termed a "hole." The indium atom robs, or borrows, an electron from one of the adjacent germanium atoms. The hole can thus change position, or move. This hole, experiments have shown, can

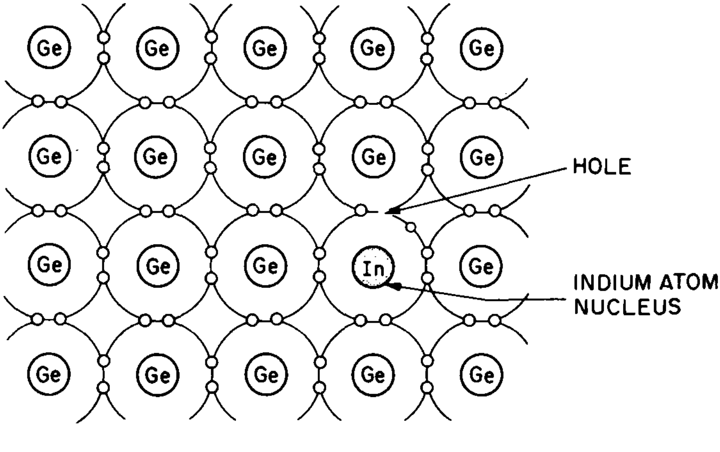


Fig. 1-7. The addition of an indium atom to the germanium lattice structure creates a hole (deficiency of electrons). This material is now known as p-type germanium.

move within the crystal in the same manner that a free electron moves within the crystal.

Holes may thus be defined as an incomplete covalent group of electrons having the properties of an electron, but possessing a positive charge.

With acceptor impurity atoms substituting for or replacing germanium atoms in the crystal structure, the germanium is known as p type. It is deficient in electrons and is known as an acceptor. It borrows electrons from the germanium crystal, and conduction is by positive charges.

If a battery were connected across the crystal structure, as shown in Fig. 1-8, the holes would drift toward the negative side of the battery. When they arrive near the battery's negative terminal, an electron would leave the negative terminal and enter the crystal structure, neutralizing the hole. At the same instant, a covalent bond near the positive battery terminal would break down, and an electron would enter the battery, leaving a hole. The new hole then drifts across the crystal toward the negative battery terminal, and so on. Thus, there is hole conduction within the crystal structure and electron flow in the direction indicated.

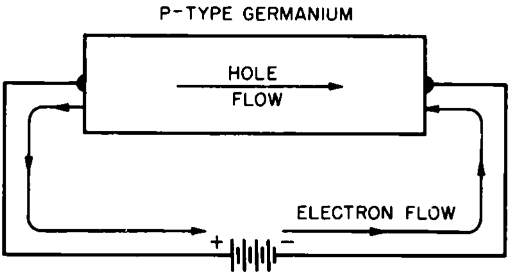


Fig. 1-8. Conduction in p-type germanium is by hole movement from the positive side of the battery to the negative side.

The PN Junction (Diode). Putting a piece of p-type and a piece of n-type germanium together forms a pn junction (Fig. 1-9). The first occurrence is that the electrons in the n region move over to the p region and vice-versa, with the electrons and holes combining at junction A-B. Because of the way the atoms are situated in the germanium material, a phenomenon takes place, and we find that the holes concentrate toward the left, away from the junction A-B. The electrons likewise concentrate toward the right.

This action could be shown as an imaginary battery [shown dashed in Fig. 1-10(A)], the negative potential attracting the holes and the positive potential attracting the electrons. This imaginary battery or potential existing between junctions A and B is known

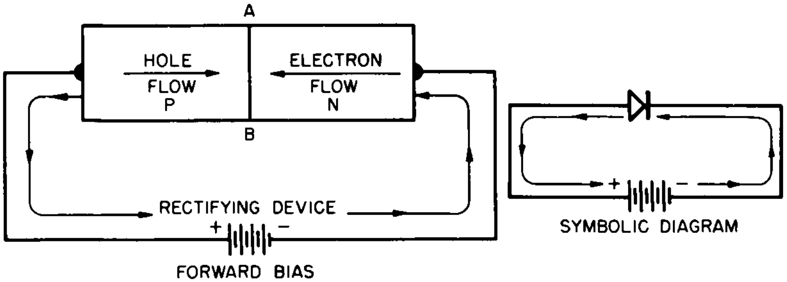


Fig. 1-9. Conduction in a pn junction occurs in one direction only (rectification) by hole movement in the p-type material, and by electron movement in the n-type material. The unit is "forward biased."

as a potential hill. If an external battery were connected [Fig. 1-10(B)], we would effectively increase the potential hill by attracting the holes and electrons further away from the junction A-B. This is referred to as *reverse bias.*

Taking the same pieces of p- and n-type germanium and reversing the battery results in a simple rectifying device. The positive potential of the battery now repels the holes in the p region toward junction A-B. The negative potential of the battery repels the electrons in the n region toward junction A-B.

At the junction A-B, an electron and a hole combine. For every electron and hole recombination at A and B, the battery gives up an electron. This electron enters the n region on the right, where the battery is connected to the n-type germanium. At the same instant, a covalent bond breaks down in the vicinity of the positive battery terminal connection to the p material, and an electron enters the positive battery terminal creating another hole. This hole in turn drifts toward junction A-B and recombines with another electron, and the process continues.

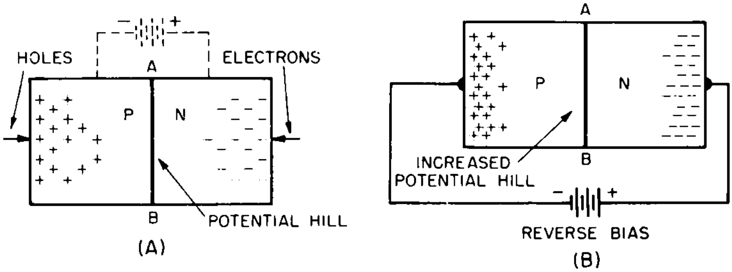


Fig. 1-10. If the battery is reversed, the potential hill is increased and conduction ceases. The unit is "reverse biased."

In this arrangement, then, holes from the left-hand portion of the p material drift toward junction A-B, and electrons in the n material drift also toward junction A-B. With this arrangement of hole flow, electron flow, and the eventual recombination of hole and electron, current flows in the external circuit, as shown in Fig. 1-9. The battery connected in this manner is known as *forward bias.* With the application of an external battery as shown, the potential hill has been effectively decreased.

JUNCTION TRANSISTORS

Junction transistors are the result of the combination of n- and p-type germanium. An npn junction transistor consists of a small piece of p-type germanium sandwiched between two pieces of n-type material [Fig. 1-11(A)]. A pnp junction transistor consists of a small piece of n-type germanium sandwiched between two pieces of p material [Fig. 1-11(B)].

Transistor Symbols. The symbols and connections for junction transistors most often used are shown in Fig. 1-11. The elements

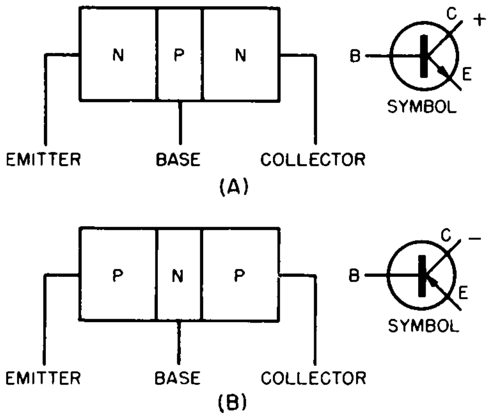


Fig. 1-11. (A) A junction-type npn transistor is constructed by sandwiching a piece of p-type material between two pieces of n-type. Symbol of an npn transistor is shown at the right. (B) A junction-type pnp transistor is constructed by sandwiching a piece of n-type material between two pieces of p-type. Symbol of a pnp transistor is shown at the right.

of a transistor can be compared quite easily with a simple triode vacuum tube circuit. The collector C is equivalent to the plate, the base B to the grid, and the emitter E to the cathode.

The arrow in the symbol can be used to determine the direction of the electron flow; it also designates the transistor as an npn or pnp type. The arrow can be thought of as an arrow on a weather vane, pointing in the direction from which the wind is coming. The same holds true of the arrow in the transistor symbol. It points in the direction from which the electrons are coming. Transistor

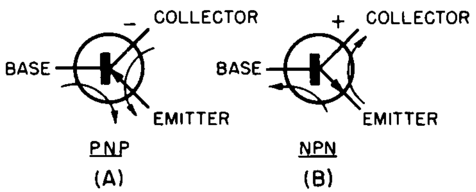


Fig. 1-12. (A) Conduction in a pnp transistor is from base to emitter and from collector to emitter. (B) Conduction in an npn transistor is from emitter to base and from emitter to collector. The arrow in the emitter element is opposite in direction to the electron flow.

pnp and npn junctions are the same, except that the conduction directions are reversed.

A rule of thumb in determining the correct collector voltage polarity of transistors is, first, to determine whether it is a pnp or npn unit. The middle letter (Fig. 1-12) will then tell what the voltage polarity must be on the collector — p for positive or n for negative.

NPN Transistor Action. Correct voltage polarities for an npn junction transistor are shown in Fig. 1-13. The emitter, being of n-type germanium, has an excess of electrons; therefore, the emitter is biased negatively, with respect to the base, to repel electrons into the base region. The emitter-to-base bias is in a forward direction to reduce the potential hill. The base, being of p-type germanium, is made very thin so that most of the electrons, attracted by the high positive battery potential, will pass on through to the n material of the collector circuit.

Approximately 5% of the electrons passing through the p-type germanium base combine with holes. Collector bias, with respect to the base, is in a reverse direction. Thus the potential hill between base and collector is increased. Electrons flow in the direction indicated in Fig. 1-13.

PNP Transistor Action. Correct polarities in a pnp junction transistor are shown in Fig. 1-14. The emitter now is composed

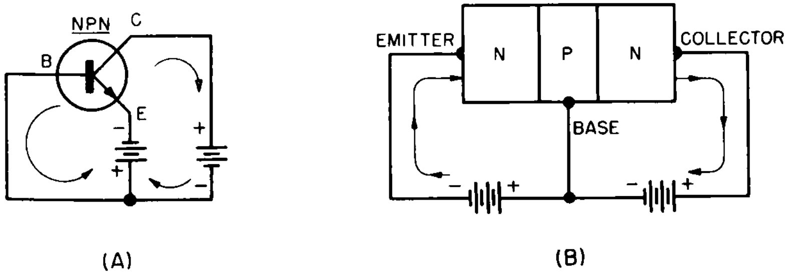


Fig. 1-13. The battery polarities shown here will forward bias the npn transistor, causing current to flow as indicated.

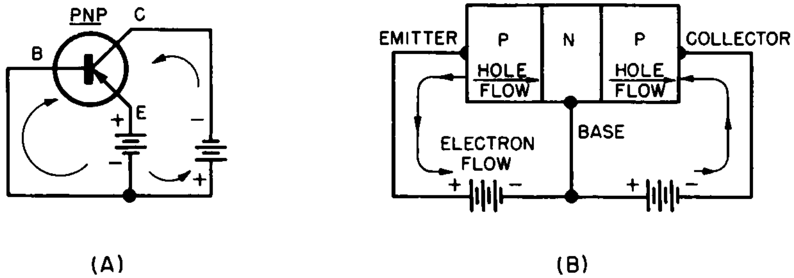


Fig. 1-14. A forward-biased pnp transistor with current flow shown.

of p-type germanium and contains holes (or is deficient in electrons). To repel the holes into the base region, some forward bias must be applied between the emitter and base. A positive voltage is thus applied to the emitter, whereas the polarity is reversed in the npn junction transistor.

Holes are repelled into the base region where approximately 5% combine with electrons. The rest go over into the p material of the collector, to which the high negative battery potential is applied. When a hole reaches the region where the battery wire is connected to the collector of p-type germanium, an electron leaves the battery and neutralizes the hole. At the same instant, a covalent group, adjacent to the positive battery wire connected to the p material of the emitter, breaks down and gives up an electron, which flows into the battery wire and to the battery.

This new hole is repelled toward the base region. Here, it is either neutralized with an electron or passes on through to the collector region and over to the battery wire, where the battery again will eject another electron. The collector in this case again is the opposite of the npn junction. To be biased in a reverse direction, the collector polarity, with respect to the base, must be negative. Therefore, for electrons to flow in the external circuit, as shown in Fig. 1-14, hole flow must be from emitter to collector inside the transistor, as indicated.

Amplification in a Junction Transistor. The current gain (or alpha gain) of a junction transistor is determined with the formula $a = I_c/I_e$, where I_c is the collector current, and I_e is the emitter current.

As mentioned earlier, in both the npn and pnp junction transistors, approximately 5% of the available current is lost because of the combination of holes and electrons in the base region. Hence, the emitter current must always be greater than the collector current. The alpha or current gain of a junction transistor can never be unity (1) or better, but must always be less than 1.

Assuming that there is 1.0 milliampere (ma) flowing in the emitter circuit, and 5% is lost because of electron and hole combination in the p region, the collector current will be 0.95 ma. Using the formula I_c/I_e to find current gain: 1 ma representing emitter (input) current I_e, divided into the collector (output) current I_c (0.95 ma), the current gain is 0.95.

According to the current gain, less is obtained than was put in. This does not seem advantageous, as far as functioning as an electrical device is concerned, but we must look further into the properties of a junction transistor before drawing any conclusions.

A vacuum tube generally has a high input resistance and a low output resistance. *A junction transistor is just the opposite.* It generally has a low input resistance (approximately 500 ohms) and a high output resistance, about 1 megohm). The *resistance gain* then would be the input resistance, divided into the output resistance. Thus, 500 ohms divided into 1 megohm gives a resistance gain of 2000.

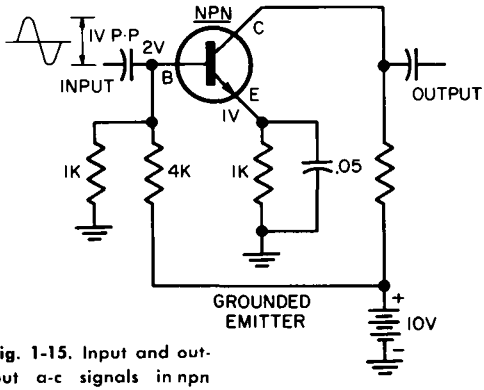
If the current gain and the resistance gain are known, the voltage gain can be computed. Voltage gain equals the current gain multiplied by the resistance gain. Thus, 0.95 $\times$ 2000 equals a voltage gain of 1900.

Since we know the voltage gain and the current gain, we can compute the power gain. The current gain squared, multiplied by the resistance gain (I^2R) yields a power gain equal to 1805.

Figure 1-15 is a simple transistor amplifier using an npn junction transistor in a grounded-emitter circuit. An emitter bias of approximately 1 volt is developed across the emitter resistor (1000 ohms) from emitter current. The base bias is developed from the battery voltage divider network (1000 ohms and 4000 ohms), and develops approximately 2 volts.

The emitter-to-base potential must be biased in a forward direction. Since the emitter is of n-type material, and the base is of p type, the emitter is 1-volt negative with respect to the base. Bias must be in the reverse direction from collector to base. The collector is of n-type material and the positive potential of the battery is applied to the collector through the collector load resistor.

Let us assume that a 1-volt, peak-to-peak sine wave is applied between emitter and base. If the sine wave can be stopped at its peak positive cycle point [Fig. 1-15(A)], the instantaneous voltage applied between emitter and base has increased. The forward bias between emitter and base has increased by 0.5 volt. This



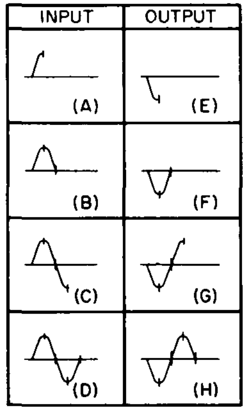


Fig. 1-15. Input and output a-c signals in npn grounded-emitter circuit.

means that the emitter is now 1.5 volts negative with respect to the base. More current now flows from emitter to collector and develops a negative voltage across the load resistor in the collector circuit [Fig. 1-15(E)].

In Fig. 1-15(B), the voltage between emitter and base is back to the static condition, where bias again is developed by the emitter current and battery voltage-divider current. The forward bias at this point is again 1 volt. Across the collector load resistor, there appeared a half-cycle of voltage which went in a negative direction, as shown in Fig. 1-15(F).

Stopping the input sine wave voltage [Fig. 1-15(C)], the bias between emitter and base is now less. The forward bias existing between emitter and base is 0.5 volt. Putting it another way, the emitter is 0.5 volt negative with respect to the base. With less forward bias, less current flows from emitter to collector. The a-c voltage coupled from the collector load resistor now appears, as shown in Fig. 1-15(G).

In Fig. 1-15(D), the input voltage is back at zero. The static bias condition exists and the output voltage appears as shown in Fig. 1-15(H).

In summary then, applying a sine wave of voltage between emitter and base increases or decreases the forward bias existing between the emitter and base. There will exist, across the output collector load resistor, a duplication of the input voltage, except that the signal phase is reversed by 180°.

TRANSISTOR CHARACTERISTICS

The manufacturer of each transistor supplies mechanical and electrical information (better known as characteristics) in the form of a specification sheet. Portions of a typical sheet (e.g., the RCA type 2N109 junction transistor) are illustrated here. The manufacturer has tabulated the specifications of transistor units in the following categories:

1. General Data
2. Maximum Ratings
3. Typical Operating Characteristics
4. Characteristic Curves

The "General Data" section is shown in Fig 1-16(A). The "Maximum Ratings" section includes those values of voltage, current, and temperature that must not be exceeded when operating the units. The values given are important not only to the electronic engineer, but also to the service technician. The maximum ratings for the RCA type 2N109 transistor are shown in Fig. 1-16(B). The *voltages* are generally given with respect to the base and the values indicated in *volts.* The *current* is given in *milliamperes* or *microamperes,* and the *power dissipation values* are given in *watts* or *milliwatts.*

The "Typical Operating Characteristics" are also given to serve as a guide to the engineer who may be designing equipment or the technician who is servicing equipment. The information given here is for the RCA type 2N109 transistor. This transistor is used primarily for class-B operation, and the operating characteristics are as shown in Fig. 1-16(C).

The "Characteristic Curves" section is also included as part of the specification sheet. These curves are similar to the curves furnished for vacuum tubes and serve a similar purpose. Typical curves are shown in Figs. 1-16(D) and (E).

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

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

GENERAL DATA

Electrical:

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

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

Mechanical:

Mounting Position.................... Any
Maximum Overall Length............ 0.697"
Maximum Seated Length............. 0.495"
Maximum Diameter.................. 0.260"
Dimensional Outline... See front of Section
Case.................... Metal, insulated
Envelope Seals................. Hermetic
Base......... Small-Round Linotetrar 3-Pin (JETEC No. E3-25)

Pin 1-Emitter   Pin 4-Collector

Pin 2-Base

(A)

AUDIO-FREQUENCY AMPLIFIER-Class B

Maximum Ratings, Absolute Values:

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

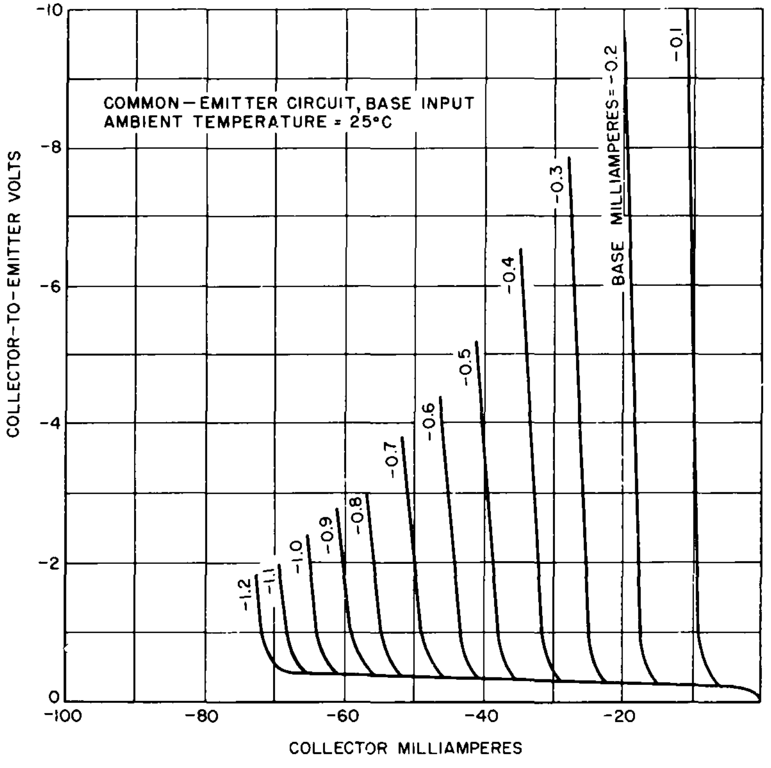
Characteristics, At Ambient Temperature of 25°C:

Common-Emitter Circuit, Base Input

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

(B)

(D)



TYPICAL PUSH-PULL OPERATION
At Ambient Temperature of 25°C:
Common-Emitter Circuit, Base Input
(Unless otherwise specified, values are for 2 transistors)

DC Collector-to-Emitter Supply Voltage.........	-4.5	-9	volts
DC Base-to-Emitter Voltage.........	-0.15	-0.15	volt
Peak Collector Current (Per transistor).....	-35	-46	ma
Zero-Signal DC Collector Current (Per transistor)..	-2	-2	ma
Max.-Signal DC Collector Current (Per transistor)	-11.5	-13	ma
Signal-Source Impedance (Base to base)..........	1500	1500	ohms
Load Impedance (Collector to collector)..	400	800	ohms
Signal Frequency.........	1	1	kc
Circuit Efficiency........	60	69	%
Power Gain..............	30	33	db
Total Harmonic Distortion.	7	7	%
Max.-Signal Power Output.	75	160	mw

OPERATING CONSIDERATIONS

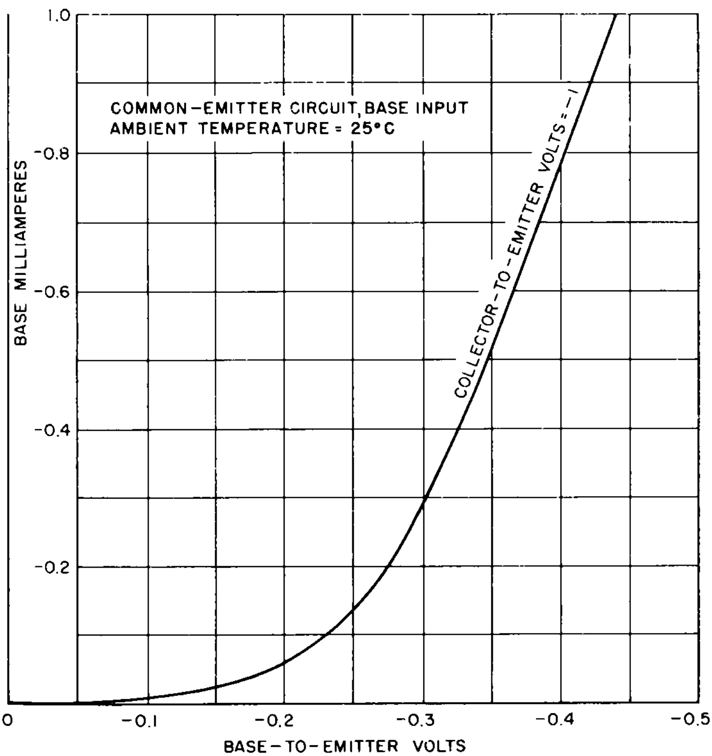
The 2N109 should not be connected into or disconnected from circuits with the power on because high transient currents may cause permanent damage to the transistor.

In class B service, when the 2N109 is operated at ambient temperatures other than 25°C, the base-to-emitter voltage should be reduced or increased by approximately 0.002 volt for each degree the ambient temperature is above or below 25°C, respectively. When this transistor is operated under varying ambient temperatures, some form of temperature compensation may be used in the base-to-emitter circuit to hold the operating point constant.

(C)

Fig. 1-16. Portions of a manufacturer's specification sheet for the 2N109 transistor. (A) General Data section. (B) Maximum Ratings section. (C) Typical Operating Characteristics section. (D) Average Collector Characteristics graph. (E) Average Base Characteristics graph. Courtesy RCA.

(E)



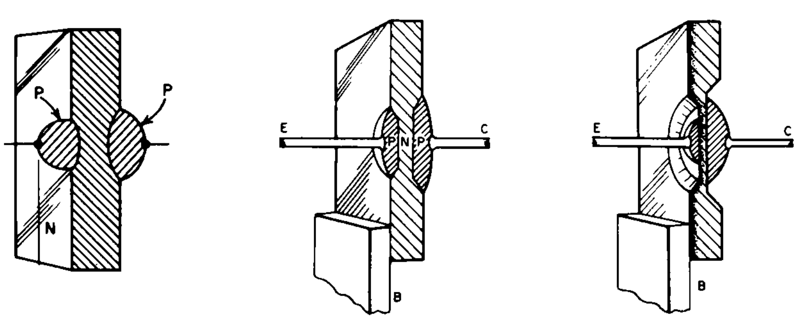
To obtain transistor performance which is equal to the vacuum tube, the maximum operating frequency should be about 20% of the frequency cutoff. Therefore, in applying this rule, it appears that the minimum cutoff frequency for a portable or home radio receiver, with an i-f frequency of 455 kc, is at least 2 to 2.5 mc. For a mixer operation of the broadcast band, a cutoff frequency of 8 mc is required. A television vhf r-f transistor amplifier operating at 200 mc would need a 1000-mc cutoff frequency.

TRANSISTOR TYPES

Since the invention of the transistor in the late 1940's, its construction, performance, and reliability have changed rapidly. The earliest devices were *point-contact* types, in which two pointed wires contacted a piece of semiconductor material to form p-n junctions. Because of its limited capabilities, this type has long been superseded by alloy, mesa, and epitaxial type transistors.

Alloy Transistors. This transistor [Fig. 1-17(A)] is formed from a small substrate section (1.8-in. square $\times$ 0.01-in. thick) of a semiconductor crystal. Depending on the type of crystal, two small dots of p-type material are melted against opposite surfaces of the substrate to form a pnp device, or two small dots of n-type to form an npn device. Such a device has a high current gain but is limited in frequency response because of the wideness of the base.

The frequency-handling capabilities are improved by etching pits into each surface of the substrate [Fig. 1-17(B)] to create an extremely thin base region. This structure is called the microalloy transistor (MAT). The improvement in frequency response, however, is gained at the expense of voltage-handling ability, which is limited by the narrow base region.



(A) (B) (C)

Fig. 1-17. Construction details of alloy-type transistors: (A) standard alloy type, (B) micro-alloy MAT type, and (C) alloy-diffused MADT type.

A further improvement of the alloy-type transistor is achieved by diffusing impurities into the base region to form a nonuniform concentration of impurities. This procedure reduces the gain of the transistor somewhat but extends its frequency range up to the 100-Mc region. A transistor of this type [Fig. 1-17(C)] is commonly referred to as a *drift* transistor or MADT (microalloy-diffused transistor).

Mesa Transistors. A major breakthrough in transistor design came with the development of the *mesa* structure. Using photolithographic and masking techniques for etching and diffusion, increased control was gained over junction spacing and impurity levels, thereby improving performance and reducing manufacturing costs at the same time.

The grown crystal is in the form of a rod *sliced* into very thin wafers (approximately 1 inch in diameter) that will serve as collectors for thousands of transistors [Fig. 1-18(A)]. An opposite polarity impurity is then diffused into the wafer to form a two layer pn (or np) junction. The diffusion, which will serve as the base region, is approximately 0.0001 inch in depth. The emitter junction is formed by the evaporation or diffusion of an impurity (the same as

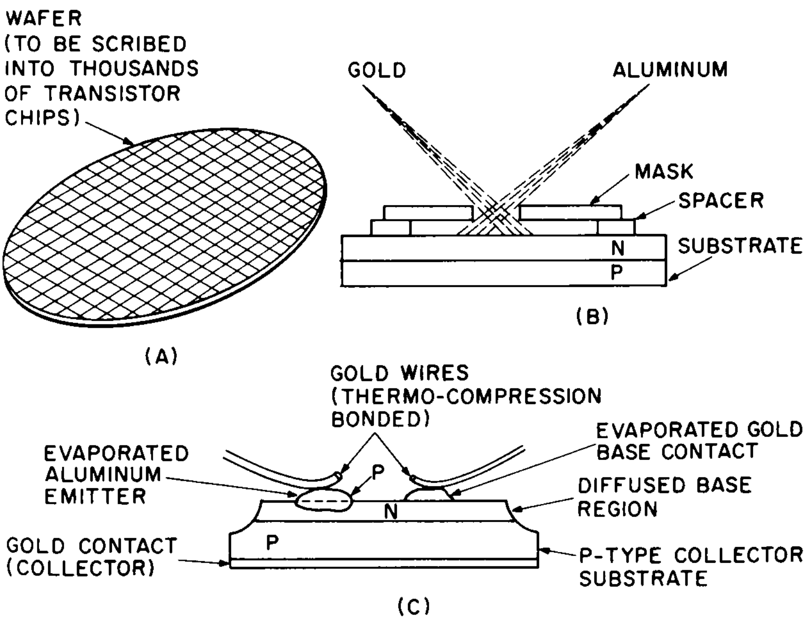


Fig. 1-18. Fabrication of diffused-case mesa transistor: (A) the wafer, (B) cross evaporation of emitter region and base contact, and (C) cross section.

that of the collector) through a metal mask into the base region [Fig. 1-18(B)].

The masking process is such that thousands of emitters are formed simultaneously and uniformly. The area between transistors is etched to form a plateau (mesa), and the wafer is now scribed and broken to obtain the individual chips. Mesa transistors can work at higher voltages than alloy types, are stronger, have very high gain, and can work at frequencies in the kilomegacycle spectrum.

Epitaxial Transistors. For the epitaxial transistor, a collector crystalline film of any desired impurity concentration and thickness is grown on top of a single crystal substrate, as shown in Fig. 1-19(A) and 1-19(B). On top of this is grown a very thin film of silicon di-

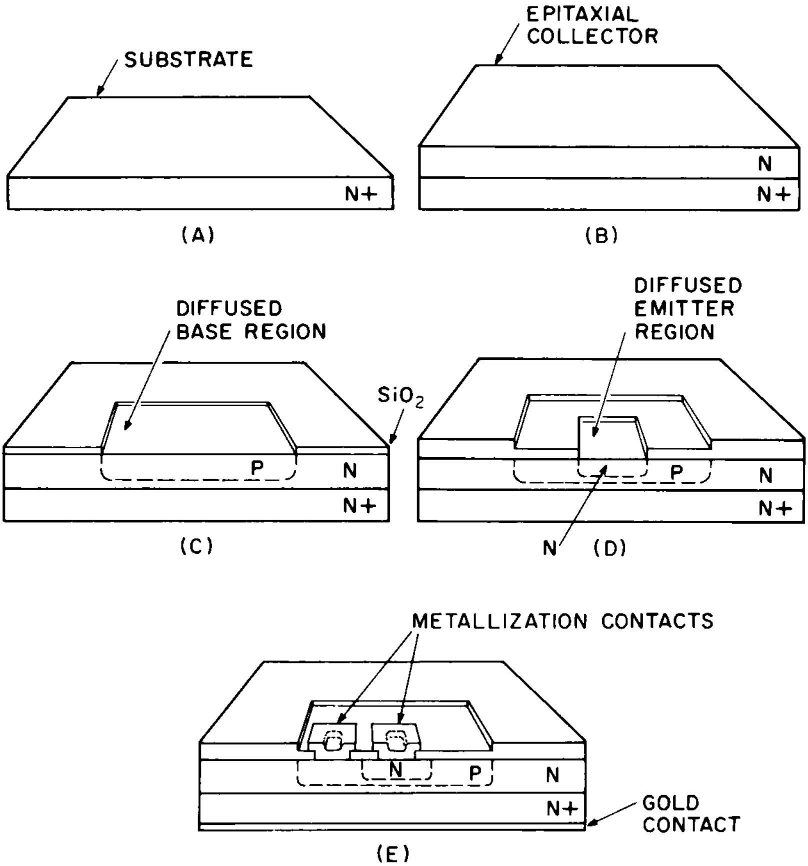


Fig. 1-19. Fabrication of an epitaxial type transmitter.

oxide (SiO_2), an insulating material that protects the epitaxial layer against penetration of impurities both during and after diffusion cycles. Using a masked photo-resist process, the SiO_2 is then removed from those areas where the base diffusion is to take place [Fig. 1-19(C)]. The mask used for the photo-resist contains multiple apertures so that thousands of bases may be formed during a single diffusion process.

The base regions are diffused into the collector's epitaxial layer. Another layer of SiO_2 is grown over the entire wafer to "passivate" the base-emitter junction, that is, to protect it against impurity penetration.

A second photo-resist diffusion and passivation process is now used to form the emitter regions [Fig. 1-19(D)]. Openings are etched in the SiO_2 over the base and emitter regions for contacts. A thin metallic film is then evaporated over the entire wafer and penetrates through the etched openings to contact the base and emitter areas. After this film is removed from the SiO_2 – it is permitted to remain in the base and emitter areas – it is then alloyed to the silicon, and connection wires are bonded to the metallized contacts [Fig. 1-19(E)].

Because its chip surface is completely covered with SiO_2, this type of transistor has lower leakage than the mesa transistor. Furthermore, resistors, diodes, other transistors, and like parts may be diffused into the same chip and interconnected by a metallization pattern on top of the SiO_2 to form an integrated circuit (IC).

FIELD-EFFECT TRANSISTORS

The development of photolithographic diffusion and metallization technologies have made possible a new type of transistor called the field-effect transistor, which is superior to the junction transistor in many applications. Because of its high input impedance, its characteristics more nearly approach those of a vacuum tube. Field-effect transistors are of two types: (1) the junction field-effect transistor (J-FET) and (2) the metal-oxide silicon field-effect transistor (MOS-FET).

Junction Field-Effect Transistor. The construction of a J-FET is shown in Fig. 1-20(A). A narrow channel of n- or p-type semiconductor material is created by diffusion between two materials of opposite type (p-type, in the example shown). In an n-type J-FET the carriers are the free electrons, and in a p-type J-FET the carriers are the free holes. When a potential is applied across the channel, the carriers move across the channel.

For example, in Fig. 1-21, a positive potential is applied to the drain and a negative potential is applied to the source, causing electrons to flow through the channel from source to drain. The amount of channel current flow and the resistance of the channel can now be decreased and increased, respectively, by applying a negative voltage to both p-region gates simultaneously. A depletion region is formed in the channel along the pn junction walls of the channel. The free electrons now have less area in which to move. Hence, the channel resistance increases, and the source-to-drain current decreases. If the gate voltage is made sufficiently negative, the depletion regions meet, and the channel current is zero (referred to as "pinch-off"). A relatively small change in gate voltage can cause a large change in source-to-drain current, and therefore the device acts as an amplifier.

The gate-to-channel resistance of the device is very high. Being a reverse-biased diode, its characteristics resemble those of a vacuum tube. The *source* terminal is the source of carriers, corresponding to the cathode of a tube. The *drain* terminal is where the carriers are drained from the device, corresponding to the plate of a tube. The *gate* opens and closes to control the channel current, corresponding to the grid of a tube.

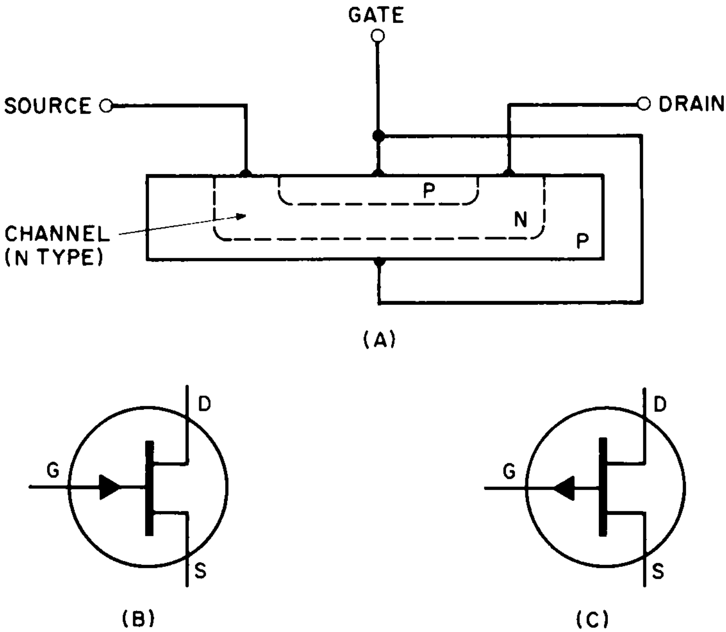
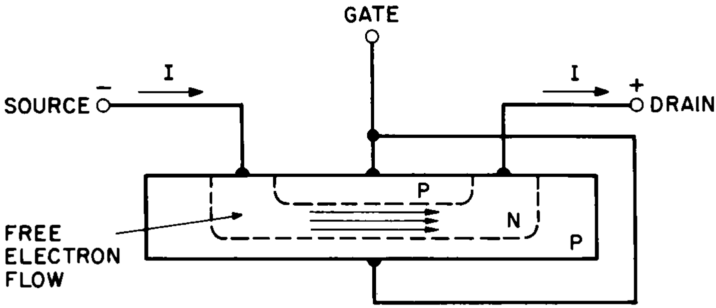
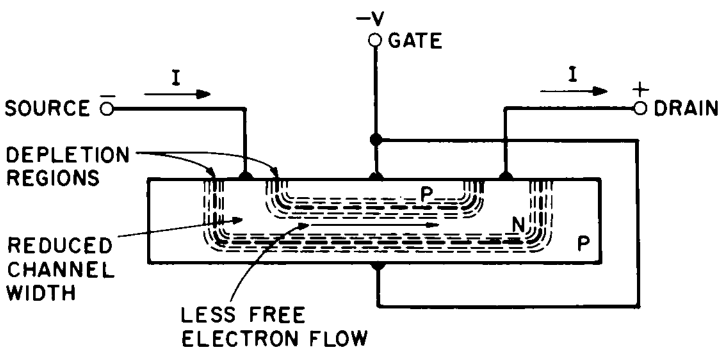


Fig. 1-20. Junction field-effect transistor (J-FET), n-channel type: (A) construction, (B) n-channel schematic symbol, and (C) p-channel schematic symbol.



(A)



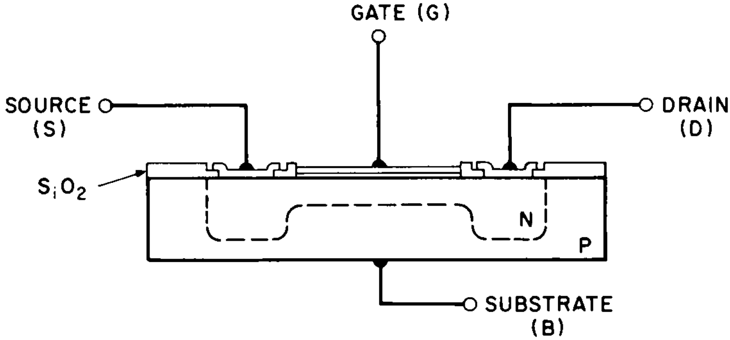
(B)

Fig. 1-21. J-FET operation: (A) Source-to-drain current high zero voltage on gate, and (B) source-to-drain current reduced by negative gate voltage, creating depletion regions in channel.

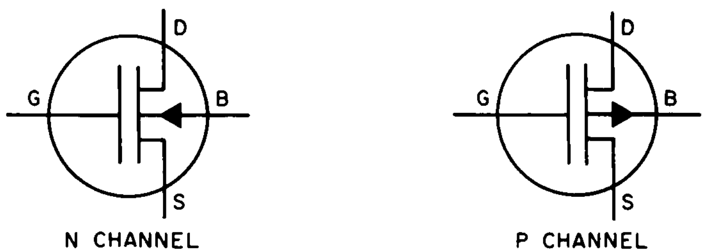
Metal-Oxide Silicon Field-Effect Transistor. The MOS-FET, sometimes called an insulated-gate field-effect transistor (IG-FET), can be of two types: (1) the depletion type, shown in Fig. 1-22, and (2) the enhancement type, shown in Fig. 1-23.

In the depletion type, a channel of semiconductor material exists between the source and drain. The gate terminal is connected to a metal plate insulated from the channel by a very thin layer of SiO_2. Carriers are present in the channel with no bias voltage applied to the gate. A reverse bias causes carriers to be attracted toward the plate. The result is a narrowing of the channel, increased resistance of the channel, and reduced source-to-drain current flow. When a forward bias voltage is applied, there is an opposite effect. The channel is made larger, resistance reduced, and current increased.

The enhancement type (Fig. 1-23) has only some minority carriers present in the channel with no bias voltage applied. A forward voltage (positive polarity on gate in the example shown in Fig. 1-23)



(A)



(B)

Fig. 1-22. MOS-FET transistor, depletion type: (A) construction, and (B) schematic symbols.

draws carriers into the channel, decreasing channel resistance and increasing source-to-drain current. When a negative voltage is applied to the gate, carriers are repelled from the channel with the opposite result.

The MOS-FET is different from the J-FET and standard junction transistors in that it can operate with forward and reverse bias voltages. Also, because the gate is insulated from the channel by the SiO_2 layer, the device has an extremely high input resistance; typical values are over a thousand megohms. An additional advantage is that mutiple-gate MOS-FET's can be easily made. These are particularly useful in mixer applications.

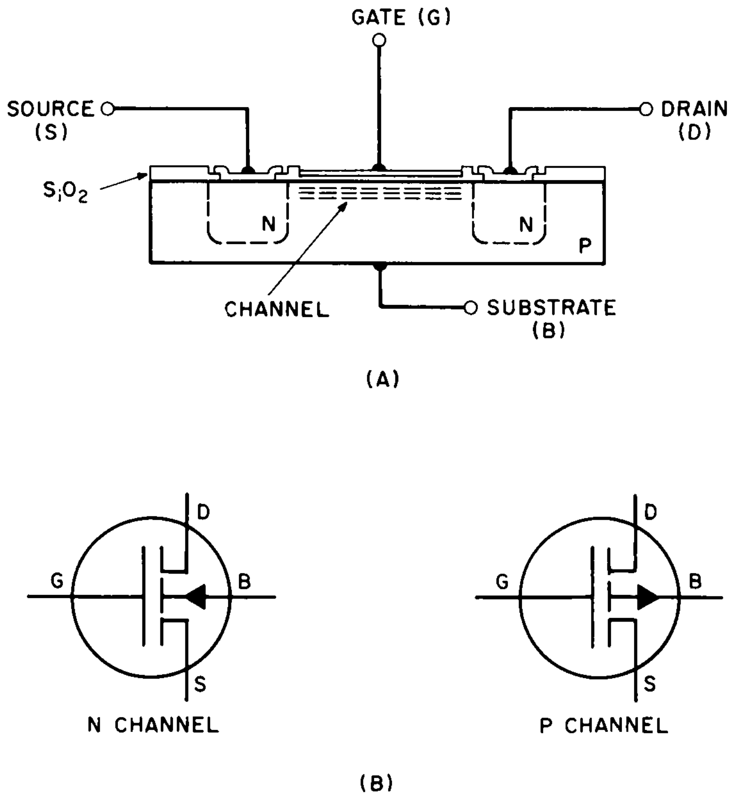


Fig. 1-23. MOS-FET transistor, enhancement type: (A) construction, and (B) schematic symbols.

INTEGRATED CIRCUITS

As the invention of the transistor ushered in a new era in radio communications, the integrated circuit is ushering in another era. Commonly referred to as IC's, these devices use the photolithographic and diffusion techniques developed for epitaxial transistors to create complete circuits on one semiconductor chip housed in one package. These techniques have reduced size, yielded closer tolerance characteristics, and decreased manufacturing costs.

IC's are now being manufactured containing hundreds of transistors with costs of less than a penny a transistor. In radios, IC's are being used that contain entire audio circuits or IF-amplifier-detector-preamplifier circuits in one package. A typical IC for use in radio receivers may contain over 10 transistors, 20 resistors (or transistors used as fixed resistors), several capacitors, and many diodes.

The IC is constructed on one silicon chip, as shown in Fig. 1-24. All devices on the chip are isolated from each other since each forms a reverse-biased np junction with the p-type substrate. The devices are interconnected by the metallization. The chip is then mounted in either a TO-5 type case, as shown in Fig. 1-25, or a flat-pack epoxy block. IC's used in radio receivers may have as many as 16 leads to connect them to the external circuitry.

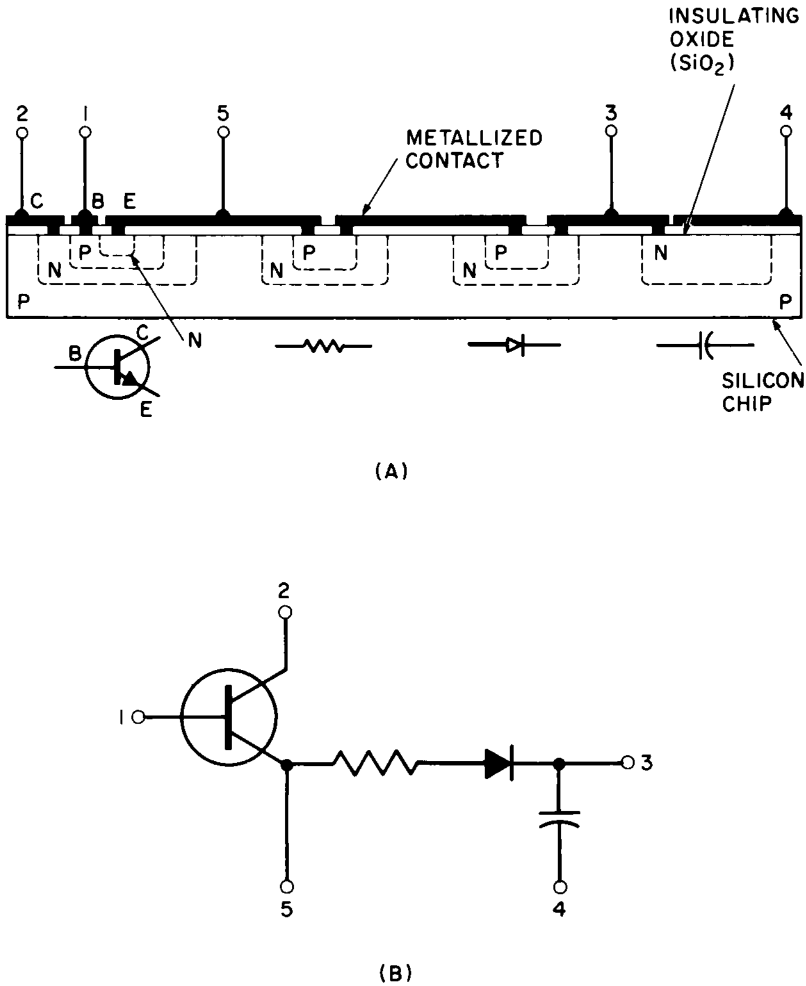


Fig. 1-24. Simple IC: (A) cross-sectional view, and (B) schematic of circuit.

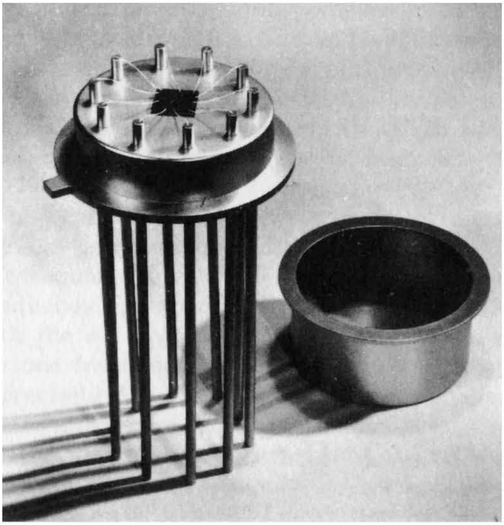


Fig. 1-25. IC chip mounted in a TO-type package (Courtesy *Motorola*).

2. The Superheterodyne Receiver

Without doubt, the superheterodyne principle reigns supreme in current receiver design. Superheterodyne radio receivers, often called "superhets," have been mass produced with great success for over thirty years. The superhet design offers the prime advantages of high selectivity and high sensitivity which remain fairly constant throughout the tuning range of a receiver. It was thus only natural that, from the very beginning, transistor radios should use the superheterodyne principle.

THE SUPERHETERODYNE PRINCIPLE

Figure 2-1 is a block diagram of a typical amplitude-modulated (AM) superheterodyne broadcast band receiver. Each block represents a stage. These will be discussed in the following chapters in detail. In some receivers, some of the stages shown may be omitted or additional stages added, according to the requirements of the particular receiver design. These variations will also be discussed.

The operation of the receiver shown in Fig. 2-1 is as follows: The modulated r-f signals, transmitted from radio stations in the areas, are picked up or intercepted by the *antenna* and fed to the first stage—the *r-f amplifier.* This circuit is tuned by the listener who rotates the receiver's tuning dial to the desired station's carrier frequency to accept and amplify the selected signal. In the standard broadcast band, this will be some frequency between 540 and 1600 kc. After the modulated r-f signal is selected and amplified, it is fed to the *mixer stage*. The r-f amplifier has thus provided a certain amount of selectivity and sensitivity. In some receivers, where less selectivity and sensitivity is required, this stage is omitted.

The mixer and oscillator stages perform the actual superheterodyne function. The *oscillator stage* is a generator of an unmodulated r-f signal, at a frequency about 455 kc above the desired incoming r-f signal's frequency. The oscillator stage is tuned simultaneously (ganged) with the r-f amplifier stage so that as the r-f amplifier is tuned from one frequency to another, the oscillator is tuned to a frequency precisely 455 kc above the radio frequency. Both the r-f and oscillator signals are fed to the mixer.

The mixer is also tuned to accept only the r-f and oscillator signals. In this stage, the two signals are heterodyned (beat together) to produce new signals. The output of the mixer stage consists of the incoming r-f signal, the oscillator signal, and two new signals—the sum and difference of the two input signals. As the receiver is tuned throughout the band, one of these signal's frequency remains constant. This is the difference signal, which is always 455 kc and contains the same audio modulation as the original r-f signal at the antenna. This signal is fed to the *i-f amplifier stage*.

The i-f amplifier is fixed-tuned to accept and amplify only the 455-kc difference signal (called the intermediate frequency). The gain provided by this stage remains constant over the entire broad-

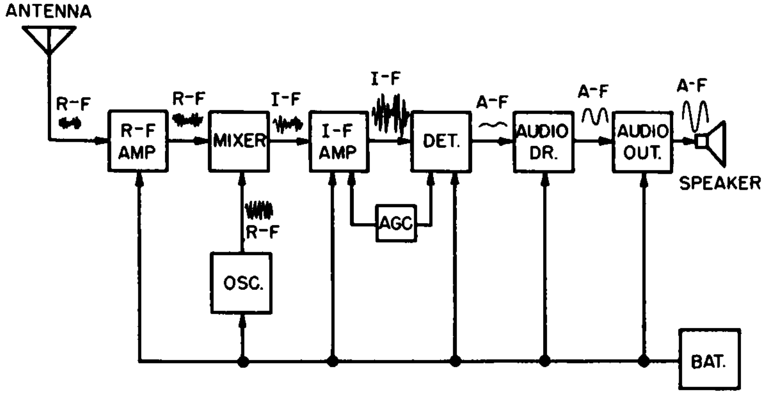


Fig. 2-1. Block diagram of a typical AM superheterodyne receiver. Signals at various points in receiver are shown.

cast band and provides high gain since amplification of a lower frequency signal is being performed. The gain of this stage may be controlled automatically by an agc (*automatic gain control*) circuit to compensate for variations in signal strength. The i-f signal is then fed to the *detector stage.*

The detector stage removes the audio component from the i-f signal and transfers it to the *audio driver stage.* The signal is recovered by rectifying and filtering the modulated i-f signal. The detector is also the source of agc voltage.

The audio drive stage amplifies the audio signal and feeds it to the *audio output stage.* The audio output stage further amplifies the audio signal, developing sufficient power to drive the *speaker.* The sound waves produced by the speaker are the same sound waves which were used to modulate the r-f carrier at the radio station's transmitter.

Power for the transistors to accomplish their many functions is most often supplied by a battery. The battery power is supplied to all stages, with the exception of the detector when a diode rectifier is used.

The block diagram shown in Fig. 2-1 should be kept uppermost in the mind of the reader throughout the following chapters so that each stage may be understood with respect to the superheterodyne principle.

Often a d-c power supply is included so that the receiver may be operated from the 115-volt, 60-cycle, a-c power line. It transforms the 115-volt a-c to a much lower d-c voltage (usually 9 to 15 volts).

MULTIBAND AM RECEIVERS

The multiband receiver, whether designed to operate on two or as many as eight bands, is still a superheterodyne receiver and basically the same as the receiver shown in Fig. 2-1. The prime difference lies in the receiver's *front end,* where the actual band selection is accomplished. This is shown in Fig. 2-2.

The front end of the multiband receiver employs the same r-f amplifier, mixer, and oscillator arrangement as in the single-band receiver. However, separate tuned circuits are employed in the various stages for each band. Hence, when the channel selector switch is turned to the *Hi Band* position, the following occurs: The r-f signal at the Hi Band antenna position is fed to the *r-f amplifier* through one position of the band selector switch. The amplified r-f signal from the amplifier is coupled, through a Hi Band tuned circuit, to the *mixer stage.* At the same time, the *oscillator* develops an r-f signal 455 kc above the r-f signal, using a Hi Band tuned circuit which has been selected by the band

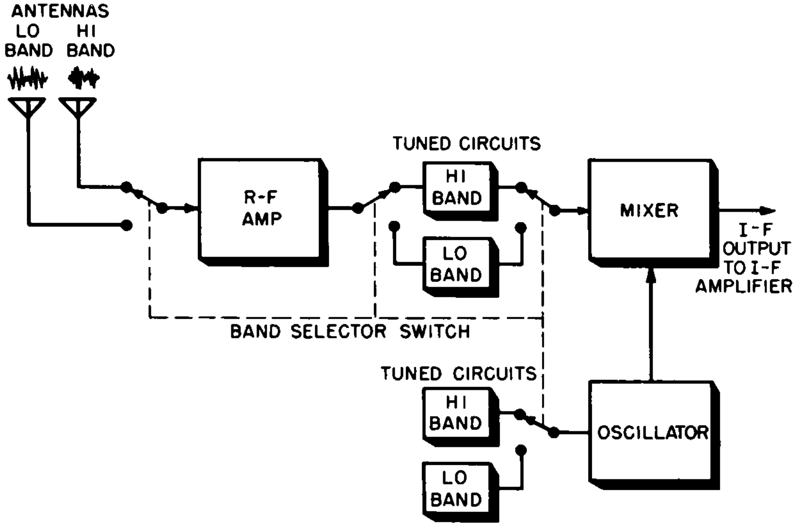


Fig. 2-2. Block diagram of a multiband receiver front end having two bands.

selector switch. The oscillator signal is fed to the *mixer*. The two signals are heterodyned in the mixer stage to produce the 455-kc i-f signal which is fed to the *i-f amplifier*.

When the band selector switch is moved to the *Lo Band* position, the Lo Band r-f antenna signal is fed to the *r-f amplifier*, where it is amplified and then fed to the *mixer stage* through the Lo Band tuned circuit. The *oscillator* is tuned 455 kc above the r-f signal, using the Lo Band tuned circuit.

The four switches, shown connected by a dashed line in Fig. 2-2, are manipulated together by having them connected mechan-

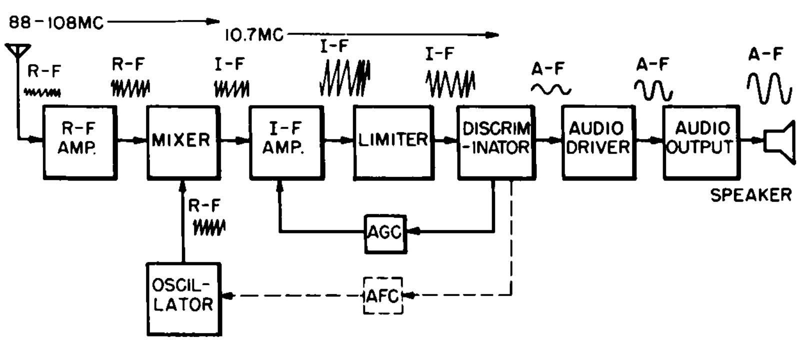


Fig. 2-3. Block diagram of a typical FM receiver (less power supply).

ically (ganged). Thus, when the band selector switch is moved from one position to another, all the switches move simultaneously.

FM RECEIVERS

A comparison of Figs. 2-1 and 2-3 shows that the only difference between an AM and FM receiver is that the detector in the AM receiver is replaced by a limiter-discriminator arrangement in the FM receiver. The limiter functions to remove all amplitude variations (AM) in the incoming signal introduced by atmospheric disturbances, electrical interference, etc., and to present to the discriminator a signal exclusively frequency modulated (FM). The discriminator changes the frequency variations into amplitude variations so that the resulting audio output signal can be amplified by the audio driver and audio output stages.

Although not illustrated by the block diagram (Fig. 2-3), an FM receiver operates at frequencies considerably higher (88 to 108 mc) than any of the AM bands. The operation of the oscillator at the vhf frequencies is affected by battery voltage and temperature, resulting in the shifting of the oscillator frequency and resultant "drift." To compensate for the effects of heat and battery voltage changes, an afc circuit is often included in the FM receiver to stabilize the oscillator and prevent drift.

3. Audio Amplifiers

Before undertaking the study of transistor amplifiers, it should be pointed out that the manner of amplification in a transistor differs from that of a vacuum tube. A vacuum tube is a *voltage-operated device.* An a-c voltage is applied to the grid-cathode circuit of the vacuum tube to control the current flow in the plate circuit. A transistor, however, is a *current-operated device.* The current flowing in the emitter-base circuit controls the current flowing in the collector circuit.

The symbols α (alpha) and/or β (beta) are used to indicate the current gain in a transistor, as compared to the symbol μ (mu) to indicate voltage gain in a vacuum tube. Other important factors are the transistor input and output resistances. It is the current flowing through these resistances that determines the voltage or power gain of a transistor amplifier.

BASIC TYPES

There are basically three types of transistor amplifiers: the common or grounded base, the common or grounded emitter, and the common or grounded collector. The word "grounded" is used throughout this chapter, since it has the greater usage in the field than the word "common."

The Grounded-Base Amplifier. The grounded-base amplifier is similar to the vacuum tube grounded-grid amplifier used exten-

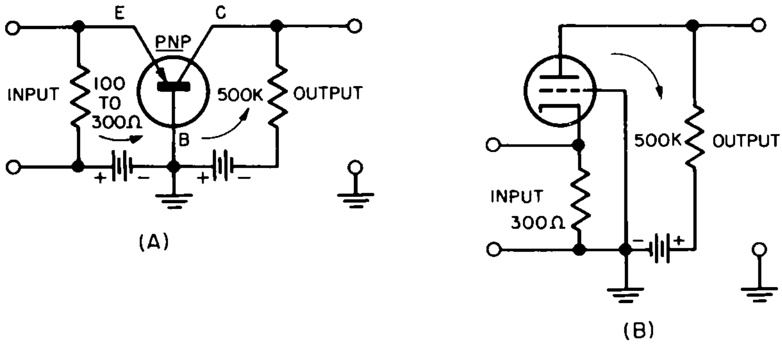


Fig. 3-1. (A) Grounded-base transistor amplifier compared to (B) conventional grounded-grid vacuum tube amplifier.

sively in r-f amplifiers in television tuners. A comparison of the two basic circuits is shown in Fig. 3-1.

As shown, the base of the transistor and the grid of the vacuum tube are grounded. The emitter is biased in the direction of greatest electron flow and the collector in the direction of least electron flow. With this bias arrangement, the input of the transistor has a low resistance, in the order of 20 to 50 ohms, and the output has a high resistance, approximately 0.1 to 1 megohm. The current gain (alpha) is always less than unity (1) in this type of circuit and is usually in the order of 0.98 to 0.99. (Alpha is the ratio of collector current I_c to emitter current I_e.) The resistance gain between input and output is very high. The voltage gain in this type of circuit may be in the order of 1500.

The characteristic curve of a grounded-base circuit (using a 2N105 type pnp transistor) is shown in Fig. 3-2. Note that the collector current never exceeds the emitter current. The maximum allowable power dissipation for the 2N105 is 35 milliwatts (mw). Therefore, it is very important to maintain the proper collector voltage and emitter current so as not to exceed the maximum dissipation of the transistor. This circuit is used when low input impedance and high output impedance are required.

A simplified biasing arrangement for the circuit is shown in Fig. 3-3. Only one battery is used. A resistor (R_b) is inserted between the negative side of the battery and the base in order to bias the emitter positive with respect to the base. Selecting the proper resistance obtains the desired emitter current. Capacitor C1 places the base at a-c ground and thereby prevents signal degeneration across R_b.

The Grounded-Emitter Amplifier. The grounded-emitter amplifier is similar to the conventional grounded-cathode vacuum tube

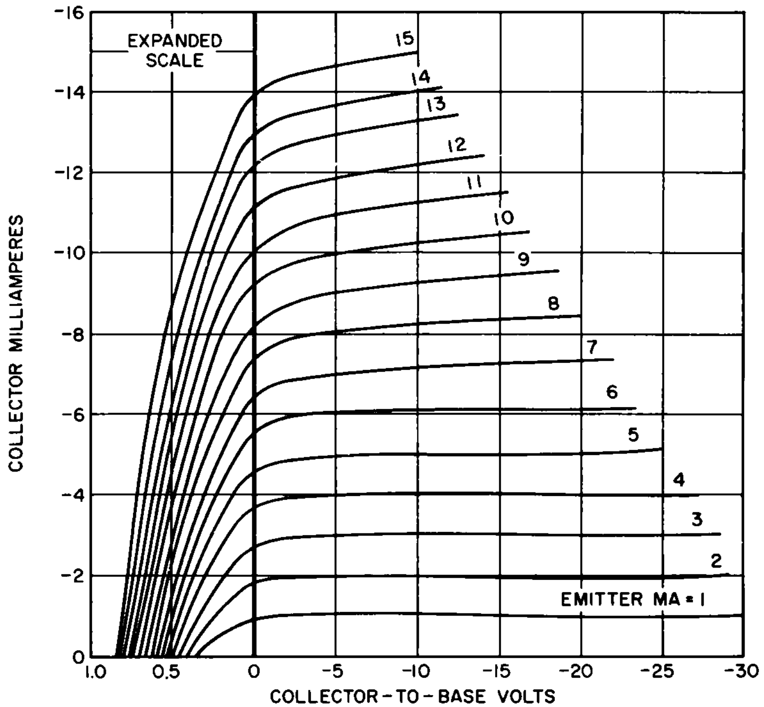


Fig. 3-2. The characteristic curve of a grounded-base circuit using a 2N105 pnp junction transistor. Courtesy RCA.

amplifier. The input signal is applied to the base-emitter circuit of the transistor, whereas the grid is the driven element in the vacuum tube circuit. This is shown in Fig. 3-4.

As in the grounded-base amplifier, the emitter is biased in the direction of greatest current flow and the collector is biased in the direction of least current flow. The input resistance is normally between 500 and 2000 ohms; however it may be as low as 100

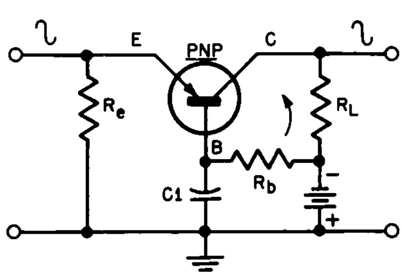


Fig. 3-3. Simplified biasing arrangement for the grounded-base circuit requiring only one battery.

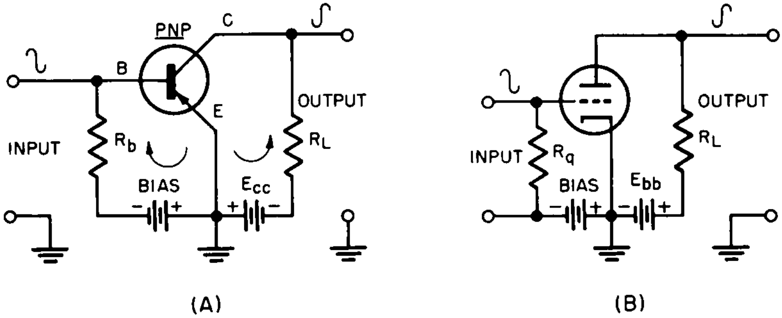


Fig. 3-4. (A) Grounded-emitter transistor amplifier circuit compared to (B) the conventional grounded-cathode vacuum tube amplifier circuit.

ohms or as high as 10,000 ohms. The output resistance is normally about 50,000 ohms; however it may be as low as 5000 ohms or as high as 500,000 ohms.

The characteristic curve of the grounded-emitter circuit is shown in Fig. 3-5. This curve is for the type 2N105 pnp junction transistor and is compared with the I_p-E_p curve of a type 6AG5 vacuum tube. The major difference lies in that, in a transistor, the collector current is controlled by the base-to-emitter current, whereas the vacuum tube plate current is controlled by the grid-to-cathode bias voltage. Aside from this, the curves are used in a similar manner.

From the characteristic curve shown in Fig. 3-5(A) it can be seen that, for a very small change in base current, a relatively large change in collector current is possible. For example, with a collector voltage of —4 volts, a change of base current from 20 to 30 microamperes (μa) produces a change of collector current from 1.1 to 1.7 ma. We can say then that a 10-μa change in base current produces a 600-μa change in collector current. Thus, a current gain is realized under these operating conditions for the 2N105 unit. This current gain is called the β gain between the base and collector currents as compared to the α gain between the emitter and collector currents in the grounded-base amplifier.

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

As with the grounded-cathode vacuum tube circuit, a voltage reversal takes place between base and collector. A positive signal at the base opposes the bias voltage, causing a smaller base cur-

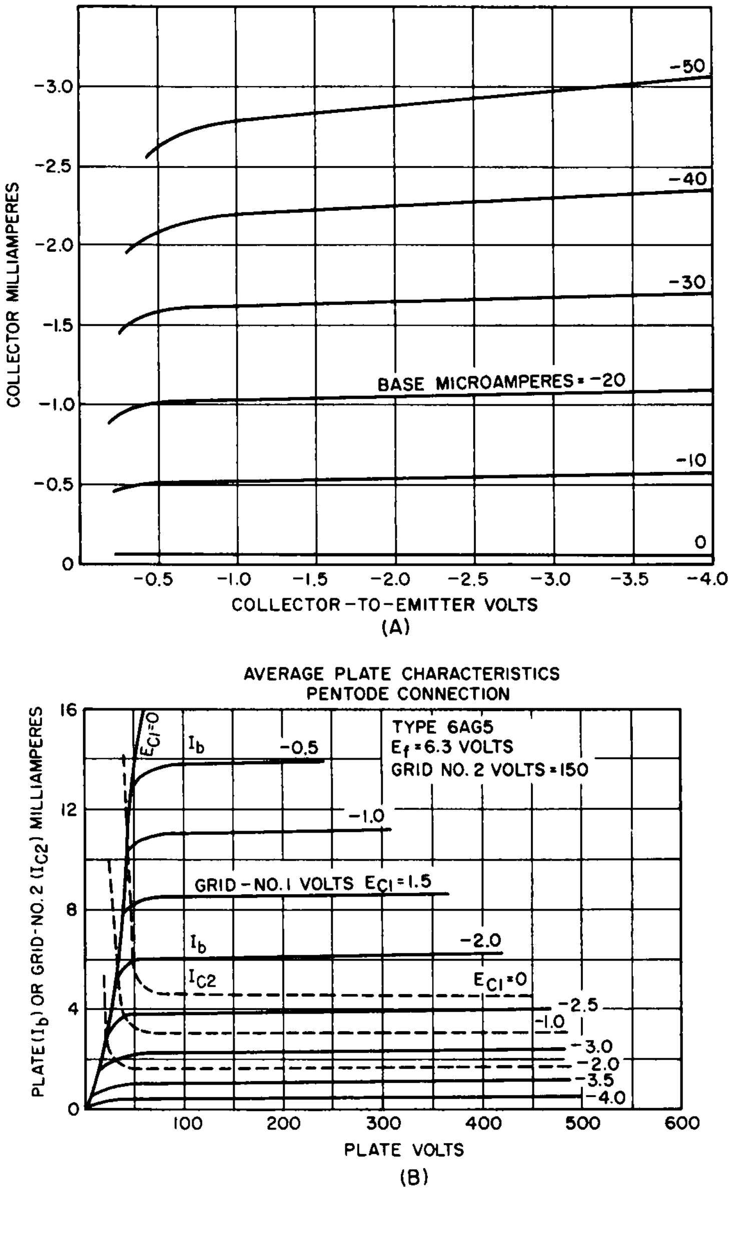


Fig. 3-5. Comparison between the operation characteristic curves for (A) a 2N105 pnp junction transistor and (B) a 6AG5 vacuum tube. Courtesy RCA.

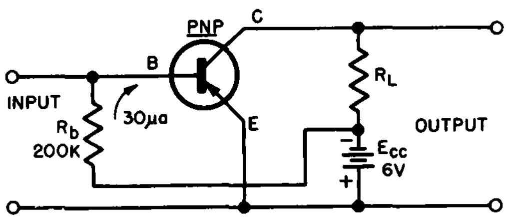


Fig. 3-6. Fixed bias system for developing the proper base bias in a grounded-emitter amplifier circuit.

rent. This decreases the collector current. The decrease in collector current causes the collector to become more negative. Therefore, a positive signal at the base develops a negative signal at the collector.

Various methods have been established for biasing the base in the grounded-emitter circuit. A simplified biasing arrangement, requiring only one battery is shown in Fig. 3-6. This method can be called "fixed bias."

The base current can be established by varying the resistance of R_b, according to the following formula:

$$R_b = \frac{E_{cc}}{I_b}.$$

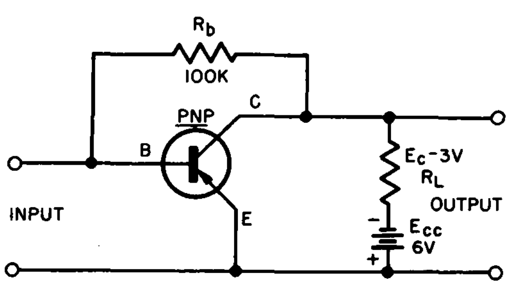
For example, if a base current of 30 μa is desired:

$$R_b = \frac{6 \text{ volts}}{30 \times 10^{-6} \text{ amp}} = \frac{6}{0.00003}$$

$$= 200{,}000 \text{ ohms.}$$

Fixed bias is not the most satisfactory method of biasing the base. Owing to variations between transistors and their sensitivity to temperature changes, it is difficult to maintain a critical base current. One method of partially overcoming this problem is to tie the base resistor directly to the collector as shown in Fig. 3-7. This arrangement provides degeneration in the form of "automatic control" of the base bias and can be called *self-bias*. To determine the value of R_b, the supply votage E_{cc} is replaced by the collector

Fig. 3-7. Self-bias R_b reduces the transistor's sensitivity to temperature changes.



voltage E_c in the previous formula:

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

Hence:

$$R_b = \frac{3 \text{ volts}}{30 \times 10^{-6} \text{amp}} = \frac{3}{0.00003} = 100{,}000 \text{ ohms.}$$

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

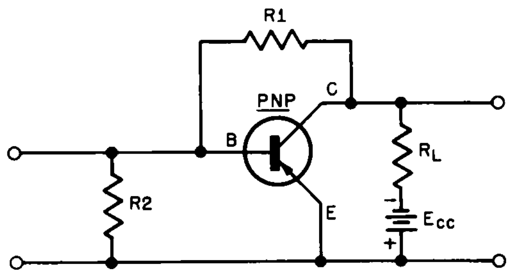


Fig. 3-8. Both fixed and self-bias can be used to provide even better circuit stability.

Both the fixed and self-bias can be used to provide even better circuit stability. This method is illustrated in Fig. 3-8. Here a voltage divider composed of R1 and R2 biases the base negative with respect to the emitter. Bleeder current through the voltage divider fixes a bias at the base. However, any change in collector voltage, due to a change in emitter current, will automatically change the base bias. This circuit is commonly used because of its inherent stability.

To minimize loss of gain, either of the two circuits shown in Fig. 3-9 may be used. In Fig. 3-9(A), a resistor is added to the emitter circuit and R2 is returned to the negative terminal of the battery instead of to the collector. The emitter resistor R_e provides additional stability and is usually 1/5 to 1/10 the value of R1. To prevent emitter degeneration, capacitor C_e is added. The value of this capacitor is usually about 50 μf; however, the value may be much higher depending, among other things, upon the lowest frequency to be amplified. The emitter resistor, in this case, is similar to the cathode resistor in a vacuum tube circuit.

Another biasing method is shown in Fig. 3-9(B). Here the voltage divider is split and all a-c variations are bypassed by capacitor C1. The value of R3 is usually 5 to 10 times the value of R2. The total resistance of R2 and R3 should equal the resistance of R1, shown in Fig. 3-8. In some circuit applications a combination of Figs. 3-9(A) and (B) may be used. In other

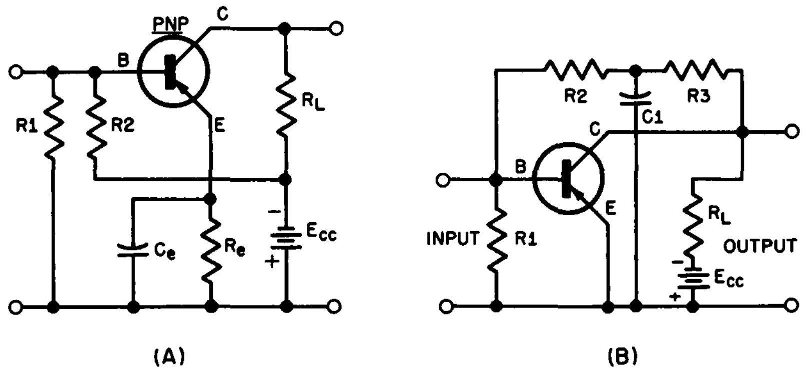


Fig. 3-9. (A) When an emitter resistor R_e is used to stabilize the circuit, it requires a bypass capacitor C_e to minimize losses due to degeneration. (B) Another method of bypassing is by splitting the voltage divider (R2 — R3) and inserting C1 to bypass a-c variations.

cases, a bypassed emitter resistor may be added to the circuit in Fig. 3-8. Voltage gain and circuit stability are usually the determining factors when selecting the proper circuit.

The Grounded-Collector Amplifier. The grounded-collector amplifier is similar to the vacuum tube cathode-follower circuit. Both circuits are shown in Fig. 3-10. The input impedance (resistance and reactance) of this transistor circuit is high, and the output impedance is low, being similar to the vacuum tube circuit. The voltage gain is less than unity and the power gain of the stage is usually lower than either the grounded-emitter or grounded-base

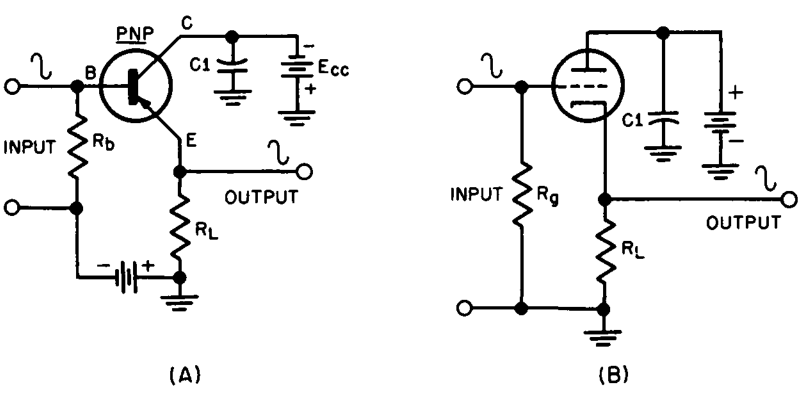


Fig. 3-10. (A) Grounded-collector transistor amplifier circuit compared to (B) cathode-follower vacuum tube amplifier circuit.

stages. The circuit is used mainly as an impedance matching device.

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

COUPLING METHODS

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

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

Transformer Coupling. Transformer coupling between transistor amplifier stages is shown in Fig. 3-11. This grounded-emitter circuit employs fixed and self-bias, and emitter resistor R_e for stabilization. The biggest advantage of this circuit is that the input and output impedance of the transistor can be matched for maximum power gain. A stepdown transformer T1 is used. It would

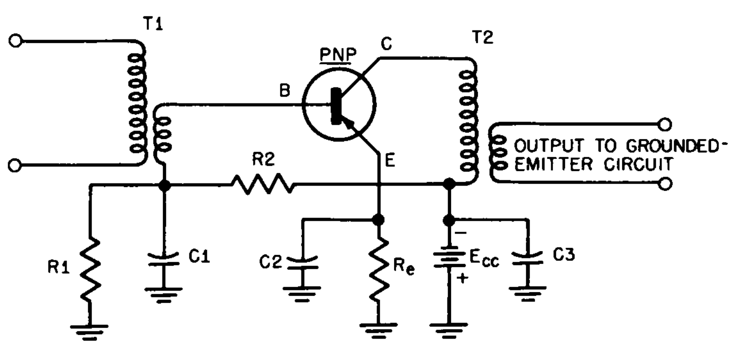


Fig. 3-11. A basic transformer-coupled amplifier.

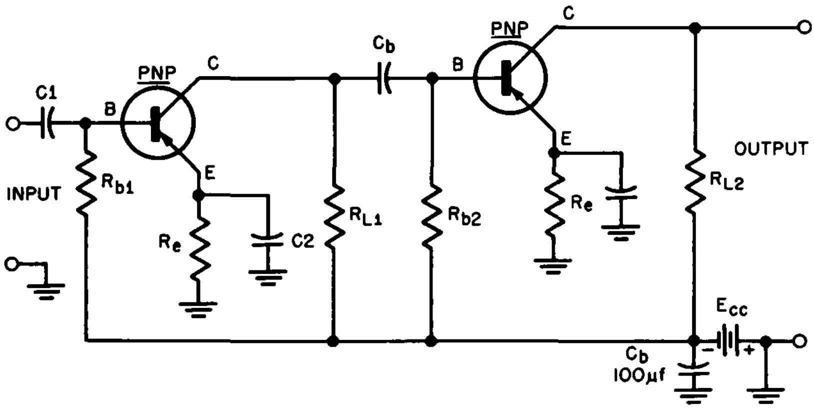


Fig. 3-12. A typical R-C coupled amplifier circuit.

seem that a voltage loss appears across the secondary, defeating the purpose. However, it must be remembered that a transistor is a current-operated device, not a voltage-operated device such as the vacuum tube. This stepdown then provides the best transfer of power through impedance matching. The change in base current, due to the presence of signal, causes transistor action, and a power gain can be measured across the transformer primary. This stepdown can be compared to the audio power output transformer in an audio amplifier. Here, a stepdown transformer is required to drive a low-impedance loudspeaker, which is a current-operated device. The transformer thus provides maximum transfer of power by matching the high plate impedance to the low speaker impedance.

The circuit shown in Fig. 3-11 includes a voltage divider (R1 and R2) which provides the proper bias. The voltage divider is bypassed by C1 to avoid signal attenuation. Resistor R_e is the stabilizing resistor that allows variations in the transistor and circuit elements to be absorbed automatically without adverse effects. Resistor R_e is bypassed by C2 to prevent loss of gain due to degeneration. The battery E_{cc} is bypassed by C3 to prevent feedback and regeneration due to a-c signal voltages developed across the battery's internal resistance. Capacitors C1 and C2 may be replaced by a single capacitor connected between the emitter and the bottom of the secondary of T1.

R-C Coupling. R-C coupling is desirable where low-level audio signals are being amplified since transformers are more susceptible to hum pickup and also take up considerable space. Figure 3-12 illustrates a two-stage R-C coupled circuit. The method of bias is similar to that used in the transformer-coupled circuit. The major additions are R_{L1} (collector load) and C_c (coupling capacitor). The coupling capacitor must be made very large (2–10 μf) because of the small output and input resistances involved.

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

When cascading R-C coupled amplifiers as shown in Fig. 3-13, it is necessary to decouple one or more stages to prevent feedback. One method of decoupling is illustrated in Fig. 3-13. This is accomplished by inserting resistor R1 in series with the base resistor and bypassing R1 with capacitor C1. The R1C1 time constant should be adjusted to ensure that the lowest frequency to be amplified is adequately bypassed. Generally the value of R1 must be kept small so that the supply voltage is not drastically reduced to the previous stages. Therefore, the value of C1 must be very large, usually 100 μf or larger.

Direct Coupling. Direct coupling is used generally where cost is a factor. A direct-coupled amplifier is shown in Fig. 3-14. In cases where the d-c component must be retained in whole, the coupling capacitors must be eliminated. As can be seen in Fig. 3-14, resistor R1 serves as both the collector load of Q1 and the bias resistor of Q2.

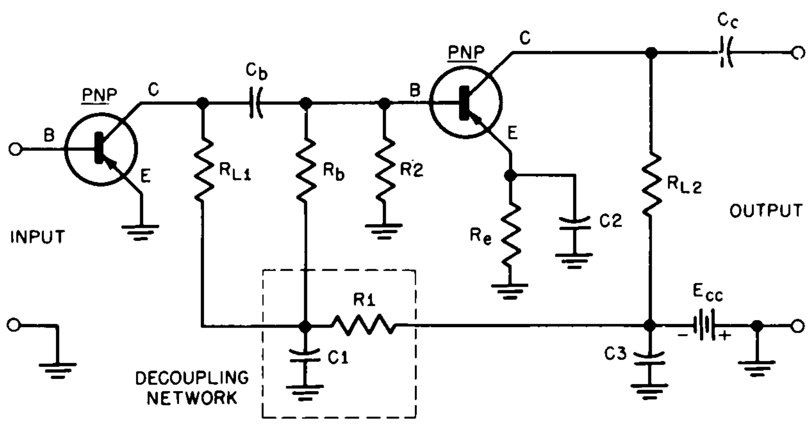


Fig. 3-13. Cascaded R-C coupled amplifiers require decoupling networks to prevent regenerative feedback.

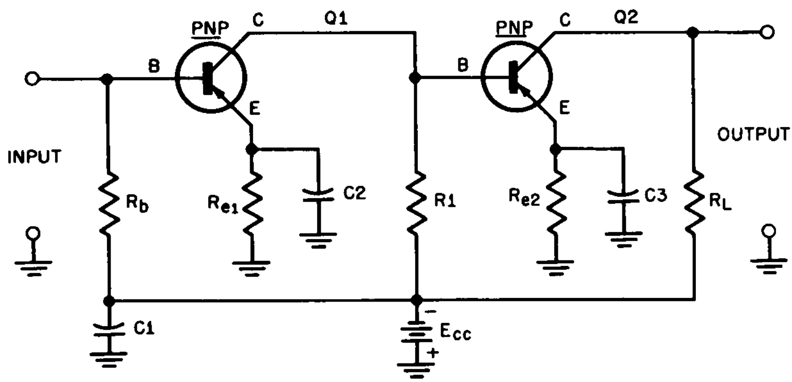


Fig. 3-14. A direct-coupled amplifier circuit. No coupling capacitor is used. R1 serves as both collector load for Q1 and bias resistor for Q2.

GAIN CONTROLS

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

A volume control circuit is illustrated in Fig. 3-15. The circuit includes the volume control and the first audio amplifier. Capacitor C2 prevents volume control R2 from changing the d-c operating point of the previous stages. Capacitor C3 prevents the base cur-

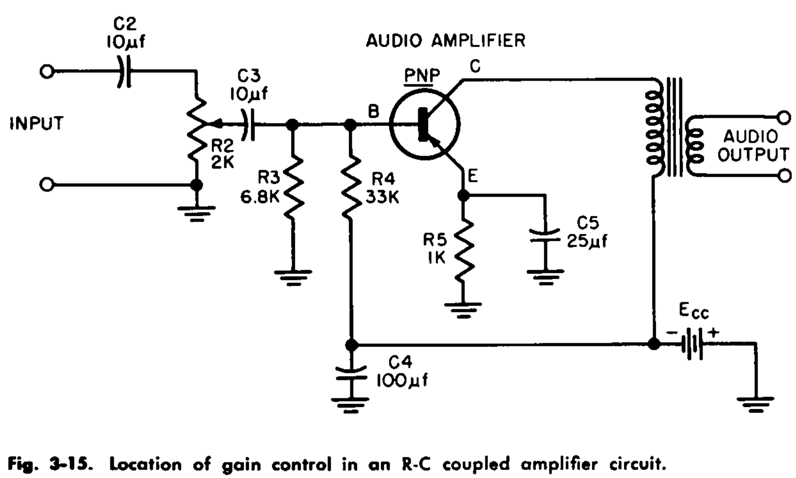


Fig. 3-15. Location of gain control in an R-C coupled amplifier circuit.

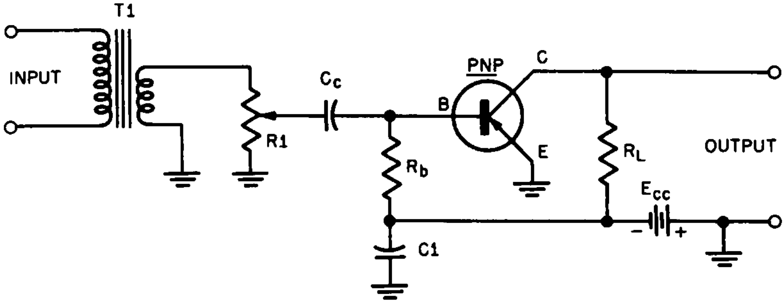


Fig. 3-16. The gain control in a transformer-coupled circuit is 2 to 3 times the impedance of the transformer secondary to prevent excessive loading.

rent from flowing through the volume control. Resistors R3 and R4 provide the necessary base bias. The base must be negative with respect to the emitter for pnp transistor operation. The coupling capacitors C2 and C3 must be large in value because of the low circuit impedance involved.

Where transformer coupling is involved, a circuit as shown in Fig. 3-16 may be used. The resistance of volume control R1 should be about 2 to 3 times the impedance of the secondary of the coupling transformer to prevent excessive loading.

TONE CONTROLS

Tone controls are often incorporated in the audio amplifier circuitry to permit manual adjustment of the frequency response of the amplifier. A *bass control* would consist of a suitable low-frequency compensating network. Hence the network composed of R1 and C1 in Fig. 3-17 provides bass boost as the value of R1 is decreased. The reactance of the network is low for high frequencies and high for low frequencies. The higher frequencies are thus shunted to ground (attenuated).

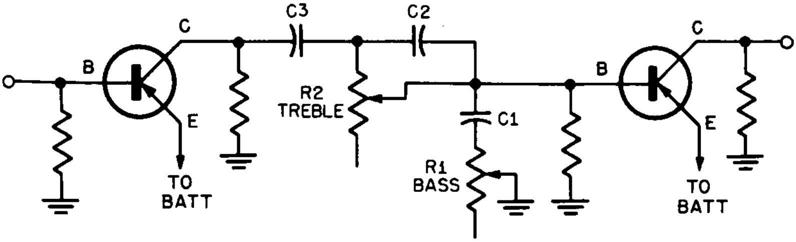


Fig. 3-17. Bass and treble tone control circuitry.

The network composed of R2 and C2 forms the *treble control.* Again the capacitor, because of its higher reactance at the lower frequencies, bypasses only the higher frequencies around the resistor R2. Capacitor C2 can be considered an open circuit at low frequencies. The low frequencies must therefore be passed through R2 and thus be attenuated, depending upon the resistance of R2. Capacitor C3 provides the necessary d-c blocking required to prevent shunting of bias voltages.

SERVICING AUDIO AMPLIFIERS

Quick Check. If a small positive voltage is momentarily injected at the collector of an audio driver transistor and then at the base, clicks will be heard from the speaker (provided the other circuits between this stage and the speaker are functioning properly). This check can be accomplished using a noise generator (which will be described in Chapter 10) as illustrated in Fig. 3-18. If the click is heard when the collector is touched, but not when the base is touched, the stage is defective. In a properly operating circuit, the

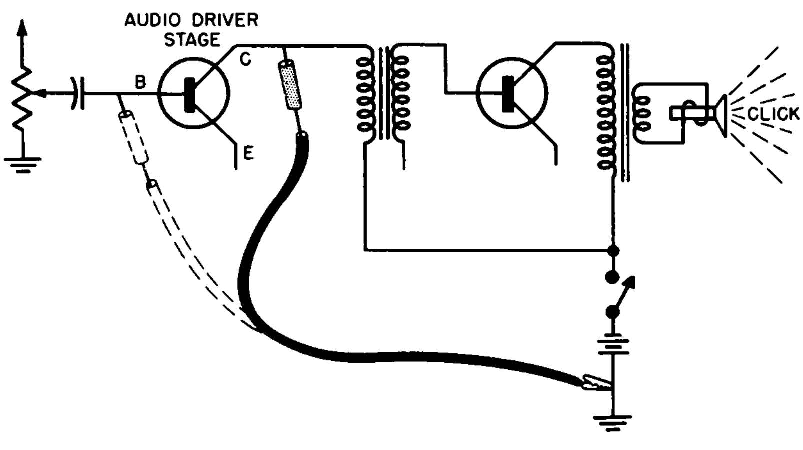


Fig. 3-18. Quick check of audio driver stage.

click heard when the base is touched will be louder than that when the collector is touched.

If a noise generator were constructed, it might also be used to check the audio amplifier. This device provides a more conclusive check of audio amplifier circuits, since the generator frequency is at approximately 1 kc and harmonics of this fundamental. The noise signal is injected at the base and at the collector of the

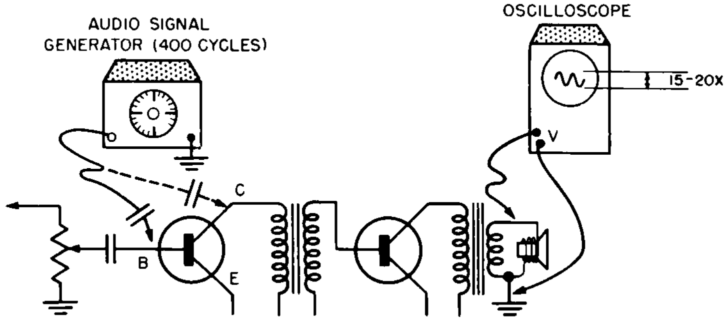


Fig. 3-19. Signal gain check of audio driver stage.

transistor. A significant increase in volume will be noted between base and collector injection points if the circuit under test is operative.

Gain Check. The gain of audio driver and preamp stages ranges from 15 to 20. This can be checked, roughly, using the method shown in Fig. 3-19. An oscilloscope is connected across the speaker terminals and used as an indicator. An audio signal (approximately 400 cycles) is injected alternately at the base and at the collector of the transistor through a 0.01- to 0.1-μf capacitor.

The signal output of the generator is kept just high enough to give a measurable indication. Too large a signal will overload the stage and not give a true indication of gain. Overloading appears as clipping of the sine wave on the oscilloscope screen. The pattern on the oscilloscope should be 15 to 20 times greater when the signal is injected at the base than when it is injected at the collector of the transistor.

SERVICING CHART FOR AUDIO DRIVER AND PREAMP STAGES

Trouble	*Possible Cause*	*Checks to be Made*
I. No sound	A. Dead battery	1. Replace battery. Check current drain. In a receiver using class-A audio output stages, the current drain should be 5—10 ma with no signal. If current drain is excessive, check power supply filter capacitor and bypass capacitors for shorts. Check for fused transistors (see I-B-1 below). If current drain is zero, check for open on-off switch.
(contd.)	B. Wrong transistor bias voltages	1. Check voltages at collector of transistor. If the transistor is fused, the voltage will be excessively high for pnp-type transistors and very low for npn types (provided base-to-emitter bias is correct). If collector voltage is zero, check for open transformer

SERVICING CHART FOR AUDIO DRIVER AND PREAMP STAGES (contd.)

Trouble	Possible Cause	Checks to be Made
		primary winding, shorted bypass capacitor, open earphone jack (if one is used), etc.
		2. Check voltage at base. If incorrect, check circuit resistances (should be within 10% of rating). Check for shorted or leaky coupling capacitors.
		3. Check voltage at emitter. If high, check for shorted transistor or open bypass capacitor. If low, check for open collector in transistor (see resistance check of transistors in Chapter 10), open in collector circuit, or shorted capacitors connected between emitter and B^+. If emitter voltage is zero, check for open emitter in transistor (see resistance check in Chapter 10), and open in emitter return circuit to ground.
	C. Defective coupling capacitor	1. Check coupling capacitor by shunting with known good capacitor (observe correct polarity).
	D. Defective coupling transformer	1. Resistance-check coupling transformer for open in primary winding. Remember to remove transistor from circuit when making resistance checks.
	E. Defective volume control	1. Check for open volume control. Sometimes the terminal rivets are not making good contact. Try soldering the terminals to the rivets.
II Low volume	A Weak battery	1. Replace battery. Check current drain (see I-B-1 above).
	B. Defective coupling capacitor	1. Check for change in capacitance of coupling capacitor which lowers amount of signal being coupled to transistor. Check by paralleling with known good capacitor (observe correct polarity).
	C. Defective emitter bypass capacitor	1. Check for open emitter bypass capacitor. Check by paralleling with known good capacitor (observe correct polarity).
	D. Wrong transistor bias voltage	1. Check as described in I-A-1, 2, and 3 above.
	E. Defective coupling transformer	1. Check for shorted turns in audio coupling transformer. Variation of 20% or more in the d-c resistance from that specified by the manufacturer indicates a partially shorted condition. This is most likely to happen in the primary winding. Remember to remove transistor from circuit when making resistance check.
	F. Defective volume control	1. Check as described in I-A-1 above.
III. Distortion	A. See II above.	1. Perform same checks as in II above.
IV. Oscillation	A Defective power supply filter	1. Check for open filter capacitor. Check by paralleling with known good capacitor (observe correct polarity).

4. Power Amplifiers

In terms of strictest definition, all transistor amplifiers are power amplifiers. In most cases, however, the amount of power handled is negligible. Therefore the term "power amplifier" is reserved for stages which drive electromechanical devices such as loudspeakers or solenoids, or which furnish a moderate-to-substantial amount of power.

THE POWER TRANSISTOR

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

Most of the heat dissipated in a transistor is generated at the collector junction. To simplify heat removal, the transistor chip is generally fastened directly to the heat sink (Fig. 4-1). Provision is

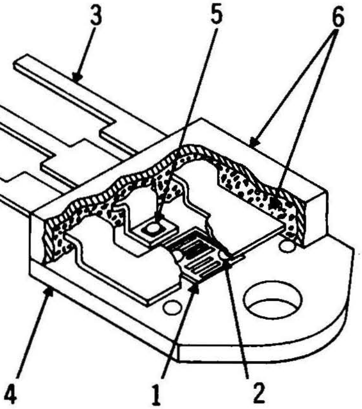


Fig. 4-1. Construction of a power transistor: (1) the chip, (2) contacts to chip, (3) leads, (4) heat sink, (5) collector lead, (6) plastic case with expoxy fill (Courtesy *Texas Instruments*).

made for the heat sink to be connected directly to a chassis or other heat-dispensing surface. Power transistors (Fig. 4-2) now available are capable of dissipating over 125 watts.

POWER AMPLIFIERS

Transistor power amplifiers can be divided into two basic types: single-ended and push-pull. Also, as in vacuum tube circuits, tran-

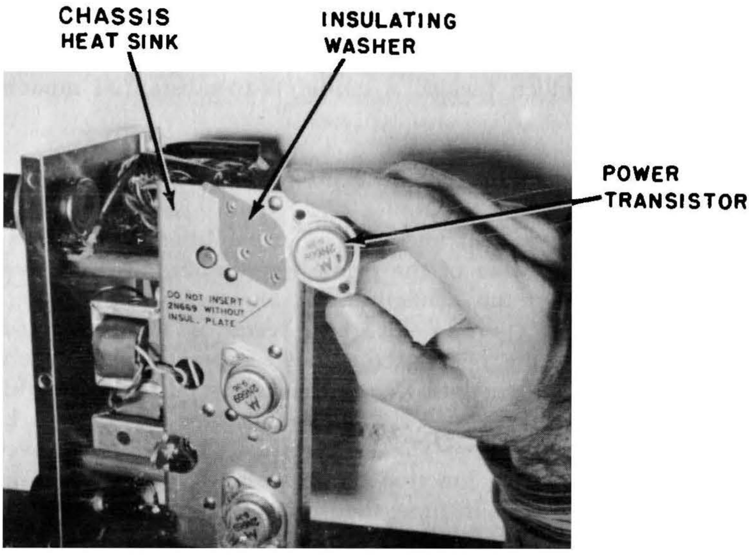


Fig. 4-2. When installing a power transistor, be sure that the insulating washer is placed between the transistor and chassis heat sink.

sistor power amplifiers can be classified by their modes of operation —class-A amplifiers, class-B amplifiers, etc.

The Class-A Power Amplifier. A typical class-A, single-ended power amplifier is shown in Fig. 4-3. The base-emitter circuit is biased in the direction of greater current flow by the bleeder arrangement of R1 and R2. This form of bias is better known as

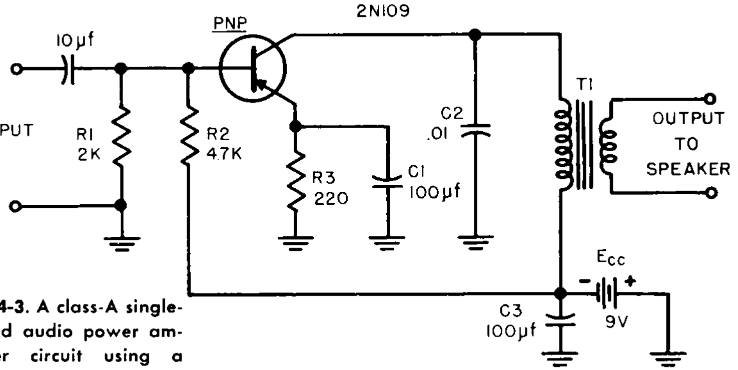


Fig. 4-3. A class-A single-ended audio power amplifier circuit using a 2N109 junction transistor.

forward bias, and causes the emitter to be positive with respect to the base. The emitter current is stabilized by R3, and the a-c component is bypassed by C1. Since this amplifier is used to drive a loudspeaker, a matching transformer T1 must be used. Capacitor C2 limits the bandwidth to prevent high-frequency distortion.

The type of circuit shown is limited as to power output. The circuit is arranged so that the collector current, with no signal, is 11 ma, and collector-to-emitter voltage is 6 volts. This means that the transistor is dissipating 66 milliwatts. Since this exceeds the maximum dissipation of a 2N109 transistor, a heat sink must be used to prevent transistor destruction. This is done by connecting the transistor case to some large metal surface (e.g., speaker frame) by a clamp or strap.

To provide a higher power output with less distortion, a push-pull circuit arrangement should be used. A class-A push-pull audio amplifier is illustrated in Fig. 4-4. A similarity can be noted between the single-ended and push-pull circuits. Actually, identical components are used; the difference is that the two transistors in the push-pull stage are driven 180° out of phase. The advantage of this circuit is less distortion at greater power outputs.

The Class-B Power Amplifier. One of the disadvantages of a transistor class-A amplifier is that collector current flows at all

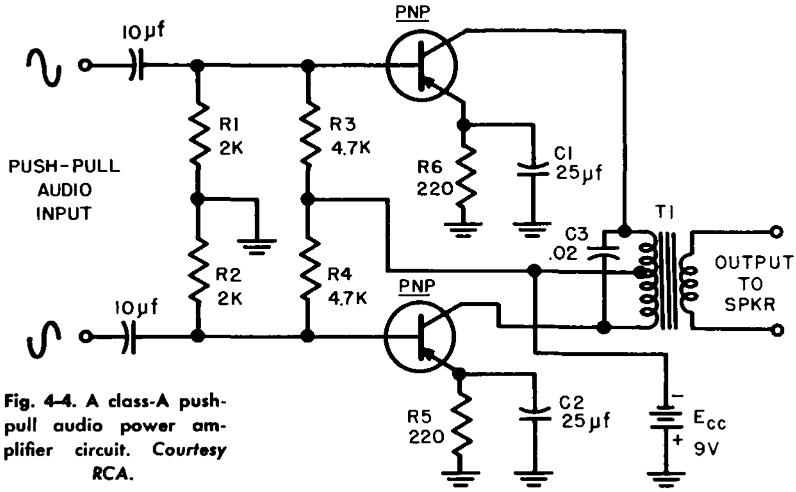


Fig. 4-4. A class-A push-pull audio power amplifier circuit. Courtesy RCA.

times. The transistor dissipation, therefore, is high even when no a-c signal is present. The dissipation can be greatly reduced by use of an emitter-base bias, such that very little collector current flows when no input signal is present (*reverse bias*). This type of operation is called class B. When pnp transistors are used, collector current flows only during positive signal excursions. The resulting distortion is minimized by two transistors connected in push-pull.

A class-B push-pull audio amplifier is illustrated in Fig. 4-5. The base-emitter circuit is biased near collector cutoff so that very little collector power is dissipated under no-signal conditions. Ideally, the transistors would be biased to cutoff, and no power would be dissipated under no-signal conditions. However, at low signal inputs, the resulting signal would be distorted as shown in Fig. 4-6(A). This is known as *crossover distortion.* By biasing the transistor so that a small collector current flows at all times (class AB), the greater portion of this distortion can be eliminated. Figure 4-6(B) shows how the coincidence of the projected cutoff points corrects this distortion. Any residual distortion can be minimized by the use of negative feedback. In Fig. 4-5, this feedback is provided by resistor R4.

Resistors R1, R2, and R3 form a bleeder network which provides proper bias for the transistors. To minimize distortion at low signal levels and prevent thermal destruction of the transistors, the characteristics of this network must be very carefully chosen. It was pointed out earlier that the collector current, collector dissipation, and d-c operating point of a transistor vary with the ambient temperature. To minimize the effects of these variations, a

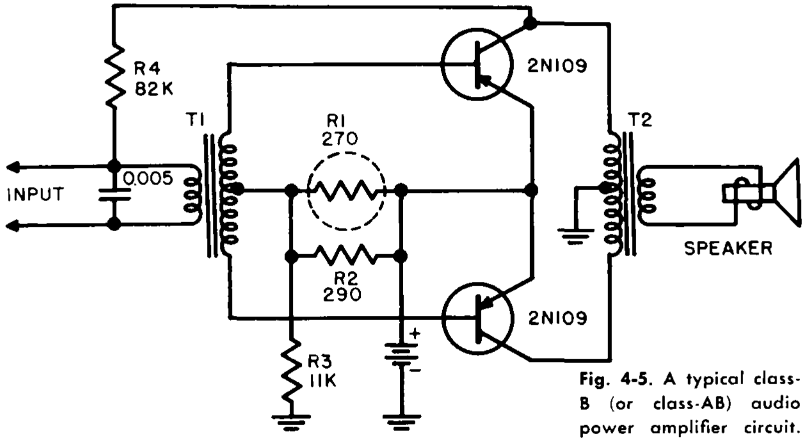


Fig. 4-5. A typical class-B (or class-AB) audio power amplifier circuit.

thermistor, R1, is used in the biasing network. When the ambient temperature increases, the resistance of the thermistor decreases, and vice versa. This maintains a constant voltage across the biasing network. Since the bias voltage controls the emitter and collector currents, the thermistor stabilizes the d-c operating level over a wide range of ambient temperature.

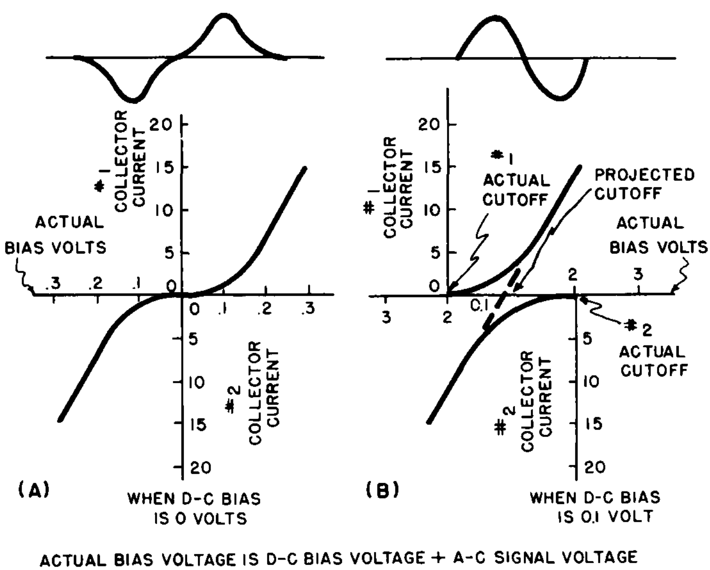


Fig. 4-6. (A) Crossover distortion as it appears in a push-pull class-B audio power amplifier. (B) Elimination of distortion by a small amount of forward bias (class-AB) operation. *Courtesy RCA.*

The Transformerless Audio Power Output Amplifier. The use of an audio output transformer has been so traditional in audio output stages that it is hard to conceive how an output amplifier can operate without one. Transformerless audio output circuitry using vacuum tubes presents many problems. However, the transistor, being basically a current device rather than a voltage device, lends itself very nicely to the development of a transformerless power amplifier. The transformerless circuit offers the prime advantages of lower inherent audio distortion and cost.

A single-ended transformerless circuit is shown in Fig. 4-7. This circuit is a simple grounded-emitter, class-A power amplifier. The speaker voice coil is the collector load. The transistor works directly into the low impedance of the speaker.

The low base-to-emitter current in the transistor controls the high collector-to-emitter current which flows through the speaker

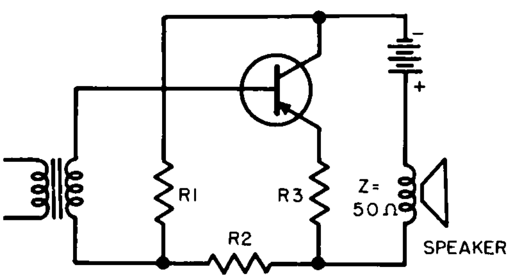


Fig. 4-7. A class-A grounded emitter transformerless power amplifier.

voice coil. The transistor is biased in a forward direction (emitter more positive than base) so that it will conduct during the entire input signal (class-A operation). The base-to-emitter bias is created by the current flowing from the negative side of the battery, through R1 and R2, through the speaker voice coil, to the positive side of the battery.

Figure 4-8 is a variation of the circuit shown in Fig. 4-7. Here the low signal current flowing between base and collector controls

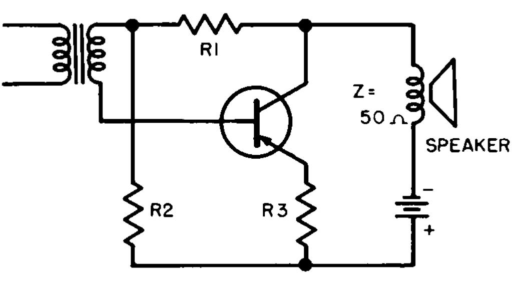


Fig. 4-8. A variation of the circuit shown in Fig. 4-7.

the high current between the collector and emitter. The speaker has been moved to the collector side of the battery.

The circuit used in many commercial portable radios is shown in Fig. 4-9. The circuits shown in Figs. 4-7 and 4-8 have been combined to increase the circuit power output and efficiency. The transistors are now operating in push-pull with each conducting for approximately 60% of each cycle (class AB). The operation of each transistor is similar to that of the circuits shown in Figs. 4-7 and 4-8 over the portion of the cycle that each is conducting.

Both transistors (Fig. 4-9) are biased close to cutoff so that, with no a-c signal received, both are effectively not conducting. Out-of-phase audio signals are fed to the base of each transistor from the secondaries of the audio driver transformer T4. Each transistor

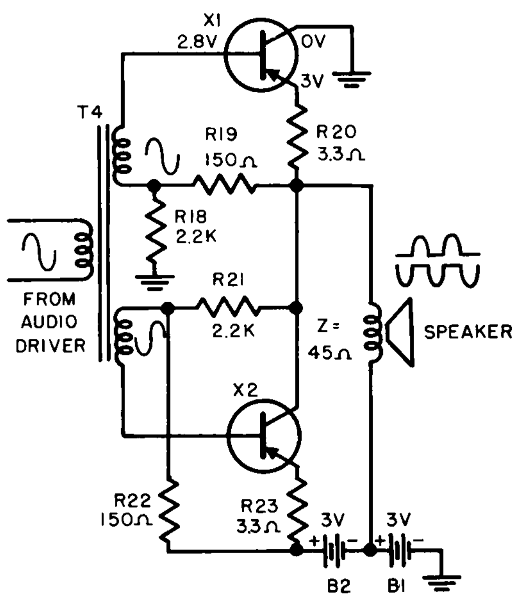


Fig. 4-9. The push-pull transformerless audio power circuit used in many commercial portable radios.

now conducts on alternate half-cycles of the incoming signal. The collector-to-emitter a-c currents of each transistor flow alternately through the speaker voice coil.

The base and emitter bias of transistor X1 is developed from current flow up from ground, through R18, R19, and the speaker voice coil to the positive side of B1. The base-to-emitter bias for transistor X2 is developed by current flow from the negative side of B2, through the speaker voice coil, and through resistors R21 and R22 to the positive side of the battery. A slight amount of forward bias is used to prevent crossover distortion and yet provide the efficiency of a class-B circuit. No capacitors are used, making troubleshooting easier and increasing reliability.

Resistors R20 and R23 provide the necessary d-c stabilization. Their values were chosen to establish the transistor's d-c operating point in such a way that it is less dependent on individual transistor characteristics and on changes due to fluctuations in ambient or in junction temperature.

The Complementary-Symmetry Amplifier. In one respect the transistor is unique as compared to a vacuum tube: units can be constructed to pass current in either of two directions. The vacuum tube can pass electrons from cathode to plate only, and not vice-versa. With transistors, however, units can be constructed which have identical characteristics with the exception that conduction is in opposite directions (pnp *versus* npn). It is this phenomenon that is used in the complementary-symmetry amplifier.

The circuit is shown in Fig. 4-10. The output transistors have identical characteristics but are electrically opposite types (complement each other symmetrically). Hence, when the same signal is fed to the base of each transistor, they produce output current flowing in opposite directions. The transistor input signals are in parallel, but the output currents are in push-pull. The economies of the circuit are readily apparent (see Fig. 4-10): no phase inverter component (transformer), or circuit or output transformer is required.

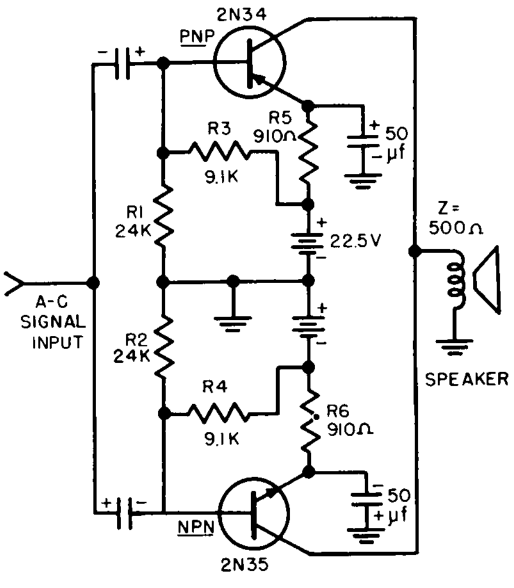


Fig. 4-10. A complementary-symmetry amplifier circuit.

SERVICING AUDIO POWER AMPLIFIERS

Quick Check. If a small positive voltage is injected momentarily at the collector of the audio power amplifier transistor and then at the base, clicks will be heard from the loudspeaker. This check is shown in Fig. 4-11. If the click is heard when the collector is touched, but not when the base is touched, the stage is defective. In a properly operating circuit, the click heard when the base is

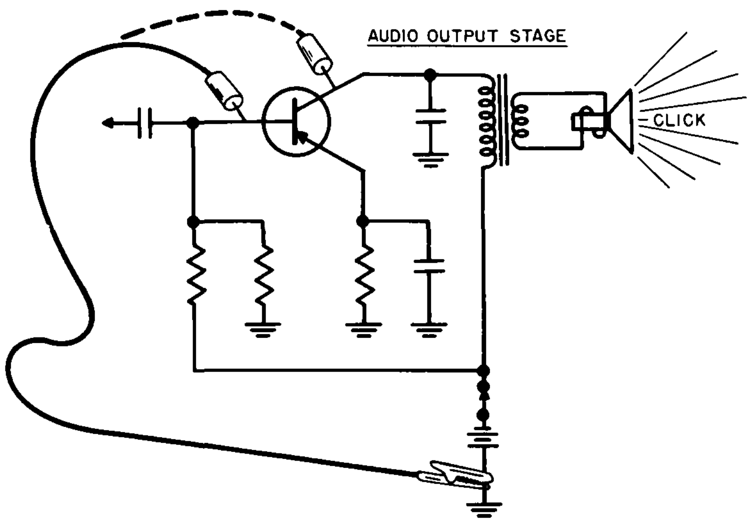


Fig. 4-11. A quick check of the audio driver stage.

touched will be louder than when the collector is touched. The coupling transformer (or capacitor, in some cases) can also be checked by touching the primary side of the component and listening for a click. No click would indicate an open circuit.

If a noise generator, such as will be described in Chapter 10, were constructed, it might also be used to check the audio output circuit. This device provides a more conclusive check of the circuit than the check described above. The noise signal is injected alternately at the base and collector of the transistor. A significant increase in volume will be noted between base and collector injection points if the circuit under test is operative.

The speaker can be checked by connecting the noise generator directly across the speaker terminals. A ground connection from the noise generator is an absolute necessity since the speaker is a power device requiring signal current.

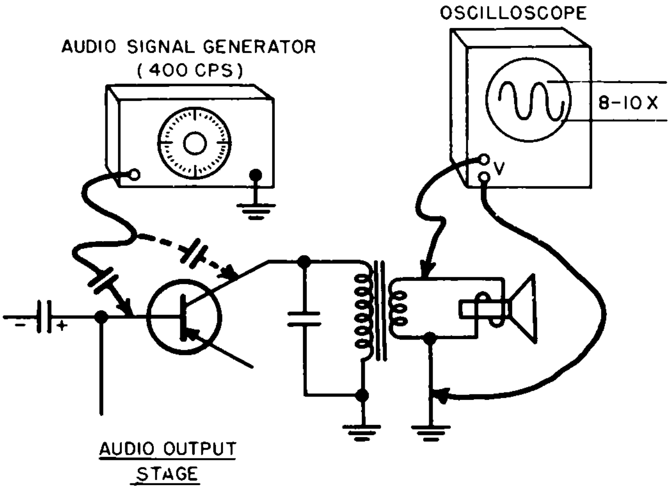


Fig. 4-12. Signal gain check of audio output stage.

Gain Check. The gain of an audio power amplifier generally ranges from 8 to 10. This can be checked, roughly, using the method shown in Fig. 4-12. An oscilloscope is connected across the speaker terminals and used as an indicator. An audio signal (approximately 400 cycles) is injected alternately at the base and collector of the transistor through a 0.01- to 0.1-μf capacitor. The signal output of the generator is kept just high enough to give a measurable indication. Too large a signal would overload the stage and not give a true indication of gain. Overloading appears as clipping of the sine wave on the oscilloscope screen.

The pattern on the oscilloscope should be 8 to 10 times greater when the signal is injected at the base than when it is injected at the collector of the transistor.

Audio Distortion Checks. Audio distortion occurs in audio power amplifier stages utilizing push-pull circuits when the characteristics of the two transistors used are not the same. This distortion appears as garbling of the sound sometimes at high volume levels only, sometimes at low volume levels only, and often over the entire range of the volume control.

To check for an imbalance in a push-pull audio amplifier, couple an audio signal (400 cycles) into the receiver at the primary of the input transformer of the stage. Connect the vertical input of an oscilloscope across the voice coil of the loudspeaker. Observe the pattern of the oscilloscope screen as the signal level of the audio generator is varied. As the level is increased, clipping of the sine wave should occur at equal amplitudes, above and below the zero reference, if the transistors are matched [see Fig. 4-13(A)]. If the transistors are not matched, one side of the sine wave signal will be clipped more than the other [see Fig. 4-13(B)].

If an oscilloscope and audio signal and generator are not available, a vtvm can be used. In this case, tune in a signal and turn

(A)

(B)

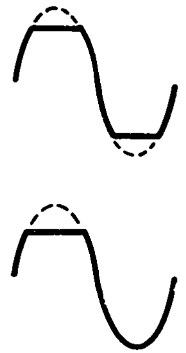


Fig. 4-13. (A) Equal clipping of sine wave signal indicates a balance of push-pull audio output transistors. (B) Unequal clipping of sine wave signal indicates an unbalance in the push-pull audio output stage.

up the volume to just under the distortion level. Measure the emitter voltage across the emitter resistors of the two transistors. The average value of fluctuations in voltage will be the same if the transistors are balanced.

These checks may also be used to select a pair of matched transistors. If one transistor in a matched pair becomes defective and has to be discarded, save the other transistor. It can usually be used as a replacement for the driver transistor.

SERVICING CHART FOR AUDIO POWER AMPLIFIERS

Trouble	*Possible Cause*	*Checks to Be Made*
1. No sound	A. Dead battery	1. See section 1-A-1, Chapter 3.
	B. Wrong transistor bias voltages	1. Check voltage at collector of transistor. If the transistor is fused, the voltage will be excessively high for pnp-type transistors and very low for npn types (provided base-to-emitter bias is correct). If collector voltage is zero, check for open transformer primary winding, shorted bypass capacitor, etc.
		2. Check voltage at base. If incorrect, check circuit resistances (should be within 10% of rating). Check for shorted or leaky coupling capacitors.
(contd.)		3. Check voltage at emitter. If high, check for shorted transistor or open bypass capacitor. If low, check for open collector in transistor (see resistance check of transistors in Chapter 10), open

SERVICING CHART FOR AUDIO POWER AMPLIFIERS (contd.)

Trouble	*Possible Cause*	*Checks to Be Made*
		in collector circuit, or shorted capacitors connected between emitter and B^+. If emitter voltage is zero, check for open emitter in transistor (see resistance check of transistors in Chapter 10), and open in emitter return circuit to ground.
	C. Defective coupling transformer	1. Check coupling transformer for open in primary winding. Remember to remove transistor from circuit when making resistance checks.
	D. Defective coupling capacitor	1. Check coupling capacitor for open by shunting with known good capacitor (observe correct polarity).
	E. Defective earphone jack	1. Check for open earphone jack.
II. Low volume	A. Weak battery	1. Replace battery. Check current drain (see I-A-1, Chapter 3).
	B. Defective coupling transformer	1. Check for shorted turns in coupling transformer. Variations of 20% or more in the d-c resistance from that specified by manufacturer indicates a partially shorted condition. This is most likely to happen in the primary winding. Remove transistor from circuit when making resistance check.
	C. Defective coupling capacitor	1. Check for change in capacitance of coupling capacitor which lowers amount of signal being coupled to transistor. Check by paralleling with known good capacitor (observe correct polarity).
	D. Wrong transistor bias voltages	1. Check as described in I-B-1, 2, and 3, above.
III. Distortion	A. Weak battery	1. Check by replacing with fresh battery.
	B Unbalance in push-pull transistor circuit	1. Check as described under "Audio Distortion Checks" (page 50). Check for one transistor defective, signal being applied to only one transistor, or incorrect forward bias.
	C. Incorrect bias	1. Check for correct bias voltages on emitter and base. Low voltages (emitter-to-base) create crossover distortion in push-pull stages. This appears as distortion occurring at low volume settings. If bias is incorrect, check resistance in divider circuits. Remove transistors from the circuit first. In addition, check the input and output transformers or capacitors for defects.

5. I-F and R-F Amplifiers

I-F AMPLIFIERS

The function of an i-f amplifier is to amplify the intermediate frequency produced by the mixer or converter stages. In addition, the i-f amplifier provides the selectivity needed at i-f frequencies to reject the r-f signal, oscillator signal, and sum signal produced by the beat between oscillator and r-f signals.

An i-f amplifier is similar to an audio amplifier except that the input and output loads are tuned circuits. Transformer coupling is most often used between converter (or mixer, as the case may be) and i-f amplifier, and between i-f amplifier and detector. The i-f amplifier tuned circuits are tuned precisely to the intermediate frequency by moveable iron cores in the coils. These cores vary the inductance of the transformer coils.

With only a few rare exceptions, all transistor radios employ two stages of i-f amplification. This provides increased gain and greater i-f selectivity than one stage could provide. Transformer coupling is used between the i-f amplifiers. The transformers may be double- or single-tuned. The double-tuned transformer has the advantage of greater selectivity.

Simple I-F Amplifier Circuit. A two-stage i-f amplifier system is shown in Fig. 5-1. The converter signal is coupled to the base of the first i-f transformer through T1. The agc voltage is present at the emitter of the first stage to decrease its gain as the signal level at the antenna increases. Transformer T2 couples the i-f signal to the base of the second i-f amplifier, and T3 couples the i-f signal to the detector. Decoupling networks (R2-C1, R4-C2, R5-C3, R6-C4, and R7-C5) provide the required interstage isolation. The capacitors provide a low-impedance path to ground for a-c signals, and the resistors offer opposition to the signal currents. The a-c signals are thus kept out of the power supply and cannot mix or beat with

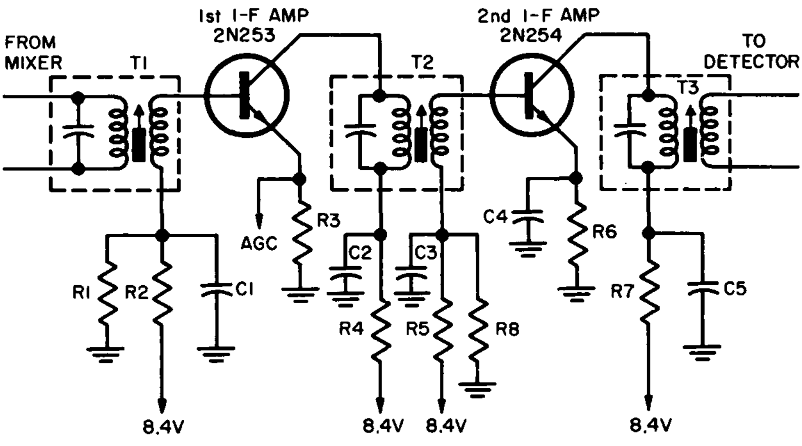


Fig. 5-1. Two-stage i-f strip used in many current AM standard broadcast receivers. The i-f frequency is 455 kc.

other signals in the receiver. The resistors also provide the necessary fixed and self-bias in the same manner as for an audio amplifier. In receivers not using r-f amplifiers, there is less chance of regeneration and therefore less necessity for decoupling. Some manufacturers have taken advantage of this to omit these capacitors sometimes.

Bandwidth Considerations. It is desirable that i-f amplifiers have a sharp response curve. As the bandwidth is increased, the gain is reduced. Transistors, being low-impedance devices, cause resistive loading of the resonant circuits, lowering their Q.

To obtain a narrow bandwidth, the tuned circuits are often tapped down at lower-impedance points to achieve closer impedance matching to the transistor. One such example is shown in Fig. 5-2. The primary of T2 is tapped to provide a better match between the low output impedance of the transistor and that of

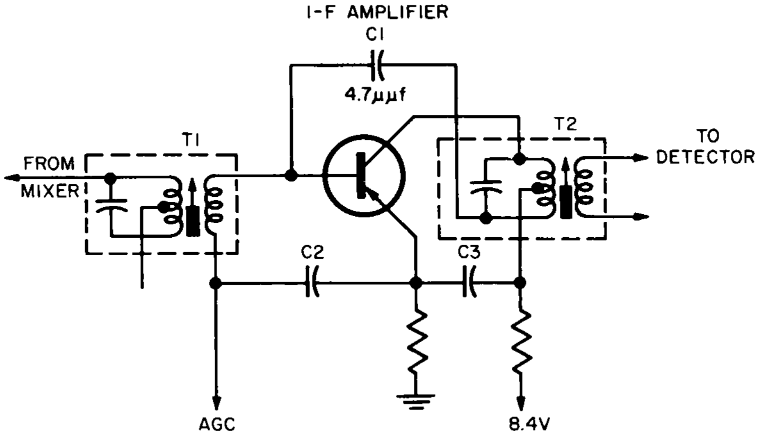


Fig. 5-2. A 455-kc i-f amplifier employing neutralization to increase circuit stability. The i-f transformers are tapped to provide an impedance match and increase the transfer of energy between stages.

the transformer. The primary of T1 is tapped to match the output impedance of the converter transistor.

Neutralization. The i-f amplifier shown in Fig. 5-2 also incorporates feedback from the primary of T2 to the base of the i-f amplifier transistor, through C1. This feedback neutralizes the capacitances existing within the transistor and associated circuitry. This tends to minimize circuit instability and provide better transistor interchangeability.

The feedback signal, for neutralization, is an out-of-phase signal of very small amplitude. This signal may also be obtained from the secondary of the output transformer (Fig. 5-3).

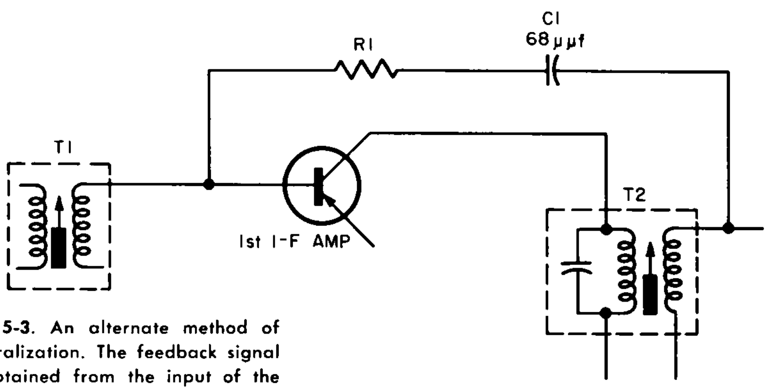


Fig. 5-3. An alternate method of neutralization. The feedback signal is obtained from the input of the following stage.

Reflexed I-F Amplifier. The reflexed i-f amplifier circuit is becoming more popular because of its economy (Fig. 5-4). Here the audio signal, recovered at the detector, is coupled back to the base of the second i-f amplifier transistor through R1. Hence the stage functions as both an i-f amplifier and audio amplifier simultaneously. No interaction between the two signals occurs because the i-f signal is developed across the tuned inductive load of the i-f

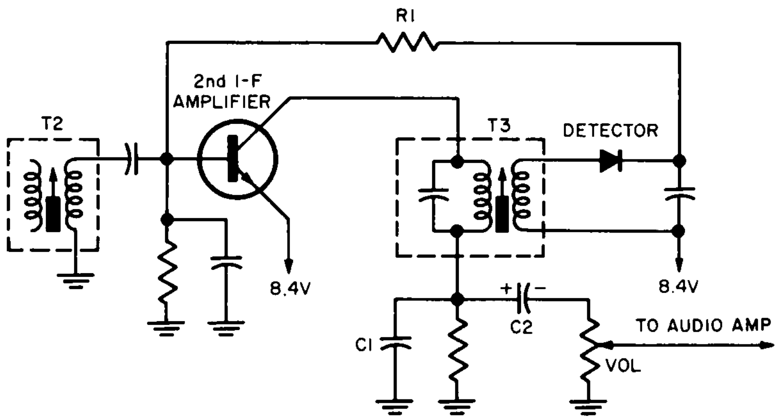


Fig. 5-4. A reflexed i-f audio amplifier. The circuit acts as both i-f and audio amplifier simultaneously with no interaction.

transformer and the audio signal is developed across the resistive load (volume control) in series with the i-f transformer. The i-f transformer offers practically no reactance at audio frequencies, while the i-f is bypassed to ground by C1.

R-F AMPLIFIERS

The r-f amplifier receives the incoming signal from the antenna, selects (tunes) the desired signal, amplifies it, and couples it to the mixer (or converter). The r-f amplifier thus provides additional sensitivity and selectivity to the radio receiver. In addition, it provides a reduction in noise level on weak signals and reduces the chances of overload distortion on strong signals (since the r-f amplifier stage is, in nearly every case, agc-controlled).

Another advantage of the r-f amplifier is the elimination of image-frequency interference, peculiar to superheterodyne receivers.

Image-frequency interference occurs when a frequency which is higher than the station frequency, by twice the i-f, is present. When this occurs, both signals — the desired signal 455 kc below the oscillator frequency and the image signal at 455 kc above the oscillator frequency — will both beat with the oscillator signal to produce 455-kc i-f signals. Since, in most cases, the signals are not exactly separated from the oscillator frequency by 455 kc, they will cause two slightly different i-f signals, which in turn will beat together to produce whistling (usually called tweets or birdies).

The r-f amplifier, since it provides selectivity of the r-f signal, selects only the desired signal frequency, thus preventing image-frequency interference. Naturally, an r-f amplifier with tuned input and tuned output will have a narrower bandwidth and hence increased selectivity.

Basic R-F Amplifier Circuit. A typical r-f amplifier used to tune the standard AM broadcast band (535 to 1605 kc) is shown in Fig. 5-5. The ferrite-core antenna, L1, is tuned to the desired radio frequency by C1 (the tuning capacitor). The incoming signal is inductively coupled to the base of the r-f amplifier transistor by a small winding on L1. The output of the r-f amplifier is also tuned by another section of C1 across the primary of L2. The primary of L2 is tapped to provide a better impedance match to the col-

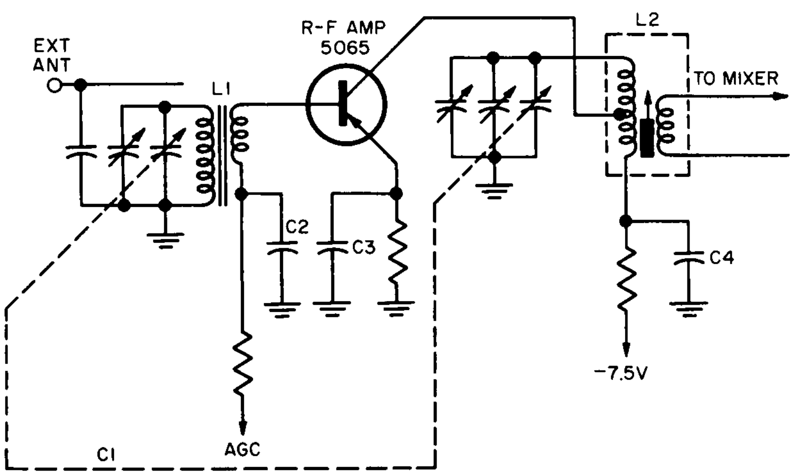


Fig. 5-5. A tuned r-f amplifier using a common-emitter circuit. This amplifier circuit is used to tune the standard broadcast band.

lector circuit of the transistor. Trimmer capacitors across the tuning capacitor are used to provide equal sensitivity across the entire band.

Capacitors C2, C3, and C4 provide the necessary decoupling as in the i-f amplifier circuits. An external antenna, when connected to the external antenna terminal, is capacitively coupled to the ferrite-core loop by a small length of wire cemented parallel to the loop.

SERVICING I-F AMPLIFIER STAGES

Quick Check. If a small positive voltage (negative voltage in the case of an npn transistor) is momentarily injected at the collector of the i-f amplifier transistor and then at its base terminal, clicks will be heard from the speaker (provided the other circuits between this stage and the speaker are functioning properly). This check is shown in Fig. 5-6.

If the click is heard when the collector is touched, but not when the base is touched, the stage is defective. In a properly operating circuit, the click heard when the base element is touched will be slightly louder than when the collector is touched. If two or more i-f amplifier stages are used, they should be checked in this same manner.

The noise generator may also be used here to check i-f and r-f amplifiers. It provides a more conclusive check of these circuits since the generator signal contains harmonic frequencies in the i-f and r-f range. (Refer to Chapter 10 for details on construction and use of noise-type signal generators.) The noise signal should be injected alternately at the base and collector of the i-f transistor.

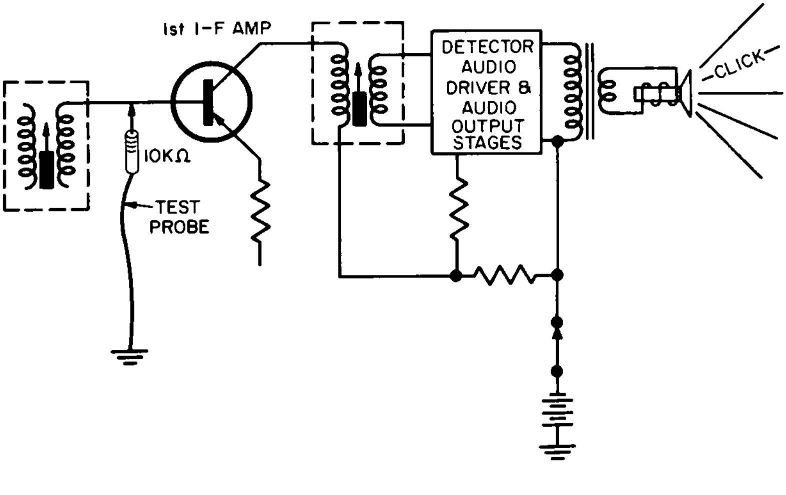


Fig. 5-6. Quick check of i-f amplifier stage.

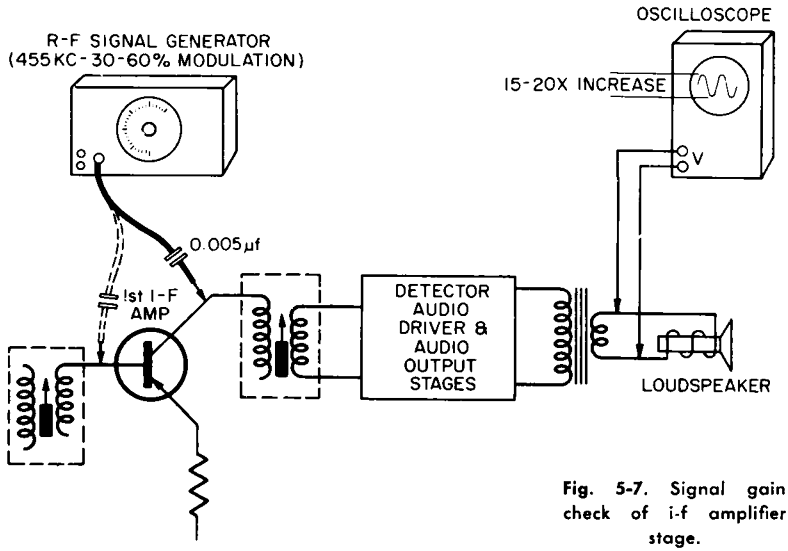


Fig. 5-7. Signal gain check of i-f amplifier stage.

A significant increase in volume will be noted between the base and collector injection points if the circuit under test is operative.

Injection to the r-f amplifier input circuit should be made as follows. Form a 6- to 8-turn coil of ordinary hookup wire, and connect it across the generator output. The diameter of the coil should be just large enough to fit over the antenna's ferrite core. As the coil is brought near the antenna (holding it parallel to or over one end of the ferrite core), the generator tone will be heard if the circuit is operative.

Gain Check. The gain of a typical i-f amplifier stage ranges from 15 to 20. This can be checked roughly, using the method shown in Fig. 5-7. An oscilloscope is connected across the speaker terminals and used as an indicator. An i-f signal (30–60% modulation) is injected alternately at the base and collector of the transistor through a 0.005-μf capacitor.

The signal output of the generator is kept just high enough to give a measureable indication. Too large a signal will overload the stage and not give a true indication of gain. Overloading appears as clipping or distortion of the sine wave signal on the oscilloscope screen. In some receivers, it will be necessary to leave the generator ground connection disconnected from the receiver chassis ground to prevent circuit loading.

The pattern observed on the oscilloscope screen should be 15 to 20 times greater when the signal is injected at the base connection than when it is injected at the collector connection of the transistor. If two i-f amplifiers are used, both should be checked in this manner, with an increase of gain, as this test is made from the second to the first i-f stage.

SERVICING CHART FOR I-F AMPLIFIERS

Trouble	*Possible Cause*	*Checks to be Made*
1. No sound	A. Defective i-f transformer	1. Check i-f transformer by removing transistor from circuit and measuring d-c resistance of transformer windings.
		2. Check that transformer is tuned to correct frequency. See the next section.
	B. Defective intermittent socket, if used	1. Check intermittent socket by replacement with known good unit.
	C. Defective transistor	1. Check, by replacement with known exact transistor, to assure that it is correct unit.
	D. Opens or shorts in circuit wiring	1. Frequent in receivers using printed wiring circuitry. Check locations of opens or shorts by continuity and resistance checks. Remove transistor from circuit first.
		2. Check for intermittently occurring opens or shorts; make resistance measurements while flexing printed wiring board and moving components. Flexing board over lighted 60-watt lamp may show opens in printed wiring.
(contd.)		3. Check for extra particles of solder forming "bridges" between two printed wires or in the hole of an i-f transformer terminal,

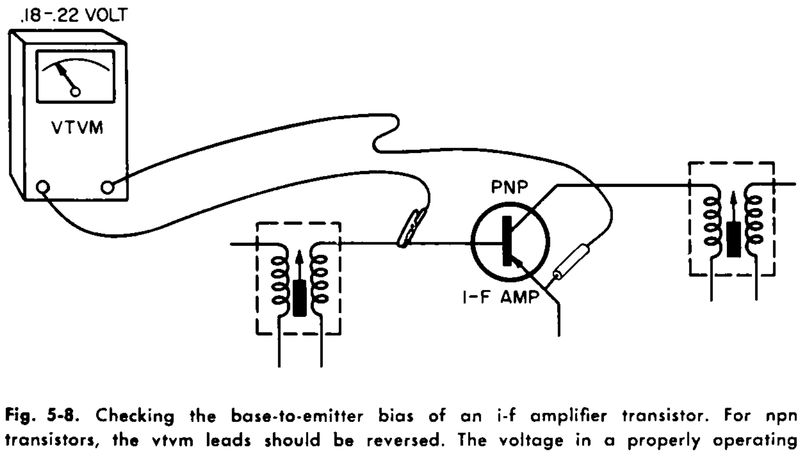


Fig. 5-8. Checking the base-to-emitter bias of an i-f amplifier transistor. For npn transistors, the vtvm leads should be reversed. The voltage in a properly operating circuit will be between 0.18 and 0.22 volt.

SERVICING CHART FOR I-F AMPLIFIERS (contd.)

Trouble	*Possible Cause*	*Checks to be Made*
		causing short between terminal and i-f transformer shield (which is usually grounded).
		4. If transistor sockets are used, check leads to board carefully.
II. Low gain or distortion (inability to receive distant stations).	A. Wrong transistor bias voltages	1. Check the base-to-emitter bias voltage, as shown in Fig. 5-8 (on pnp types, connect the vtvm ground lead to base of transistor, and to emitter on npn types). Voltage should be between 0.18 and 0.22 volt, so that transistor is biased in the forward direction. If voltage is high, transistor conducts heavily, lowering collector voltage. If low, or in opposite direction, transistor gain is low (or not conducting at all). If voltages are incorrect, check the base and emitter bias divider networks for correct resistance, and transformer windings and bypass capacitors for wrong values, shorts, leakage, or opens.
	B. Defective overload diode	1. If agc overload diode is used connected from the low side of the first i-f output transformer primary to the high side of the first i-f transformer primary, check the diode. An open diode causes distortion on strong signals. A reversed diode causes poor sensitivity (if the diode is fused, there is no sound).
	C. Unsatisfactory alignment	1. Check i-f alignment as described in the section at the end of this chart. If unsatisfactory peaking conditions exist, check for open bypass capacitor, shorted turns in i-f transformer, and other circuit defects.
	D. Defective agc filter capacitor	1. Check for open by paralleling with known good capacitor.
III. Oscillations (squeals)	A. High impedance in receiver ground circuit	This is more critical in transistor radios than in vacuum tube types because of the low impedances of transistor circuits as compared to tube circuits. A rosin connection can have a re-resistance as high as the impedance of the circuit and cause regeneration. The same applies to the internal a-c impedance of capacitors in transistorized equipment.
		1. Check all ground solder connections. Check for loose mounting lugs of the i-f transformer, causing high-resistance connections. Check the solder points at the i-f transformer shield, if used. In some cases, soldering jumpers between the different ground connections in the i-f amplifier circuits will eliminate oscillations.
		2. Check power supply filter capacitors. If low in capacitance, they may cause oscillations. Check by shunting with a known good capacitor. Sometimes helps if value of filter capacitor is increased. Check for poor solder connections at the leads.
(contd.)		3. Check the i-f transistors to be sure that they are the correct ones. If one transistor is "hot" it is sometimes desirable to substitute one with less gain. The condition is sometimes corrected by interchanging the two i-f transistors where the same type is used. Check neutralizing capacitor, if used, for correct capacitance.

SERVICING CHART FOR I-F AMPLIFIERS (contd.)

Trouble	Possible Cause	Checks to be Made
		4. Check for incorrect installation of i-f transformer. Also check transformer windings.
		5. Check i-f alignment.
		6. Check battery. If run down, high internal resistance results. Check for poorly riveted connections in battery holder. If this condition exists, causing high-resistance points, try soldering the leads to the rivets.
	B. Defective r-f amplifier	1. Check r-f amplifier (see information at the end of this chapter.)
	C. Defective converter stage	1. Check converter circuit (see information in Chapter 6).

I-F AND R-F ALIGNMENT TIPS

Although the alignment procedure of a transistor radio is a little different from that of a vacuum tube radio, the equipment used is the same. Before beginning alignment, be sure that the battery voltage is at its rated value (check under load) to achieve the best alignment possible. Also, be sure before beginning that the receiver is in good operating condition.

It is necessary on some transistor radios to remove the speaker and its mounting bracketry from the printed wiring board to allow access to the i-f transformer cores. In these cases, the speaker bracket is soldered to the printed board and should be unsoldered. *Caution:* Some models have their speaker frame mountings twisted and these must be straightened before removal. With the speaker mounting removed, a ground jumper lead must be connected between the speaker bracket and chassis ground. One such setup is shown in Fig. 5-9.

A fiber or plastic alignment tool that snugly fits the slot in the i-f transformer cores should be used to prevent chipping of the slot. Such a tool is shown in Fig. 5-10.

A typical i-f alignment setup is shown in Fig. 5-9. Here, the i-f transformers are exposed for adjustment (for r-f alignment, the speaker mounting bracket is remounted onto the printed wiring board).

The i-f test signal is injected by forming a 4- or 5-turn loop of wire, connecting it across the signal generator output cable, and placing it near the antenna loop. *The signal generator should never*

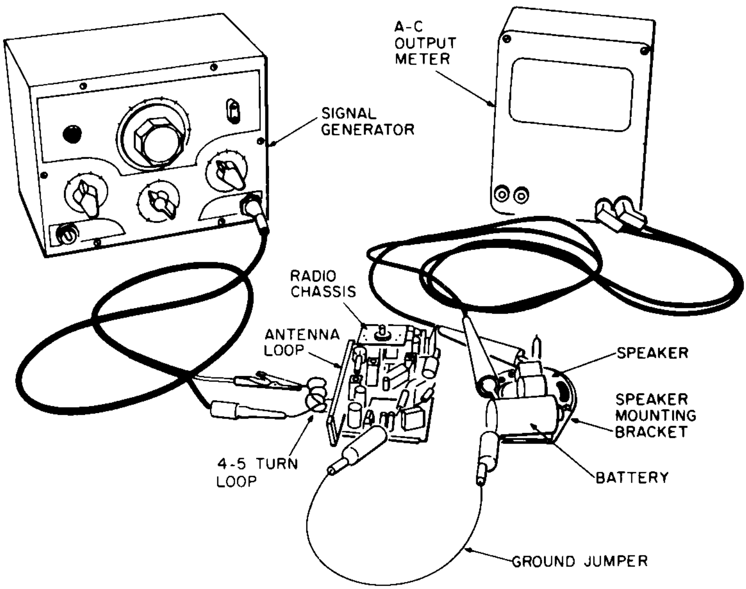


Fig. 5-9. I-F alignment setup for transistor radios. *Courtesy Westinghouse.*

be connected directly to the receiver. The output of the signal generator should be kept low enough to give only an indication on the vtvm or output meter. If, during alignment, the peak is found to be very broad or double peaks occur when rocking the i-f slug adjustment, the generator signal is excessive and should be reduced. To reduce the signal, either move the loop further away from the antenna, or decrease the generator output.

Be sure, during r-f alignment, that the hand or any metal objects on the bench do not come in close contact with the antenna loop, or detuning will occur and the alignment will be incorrect. If the work is done on a metal bench, make certain that the loop is at least 6 inches from the metal surface.

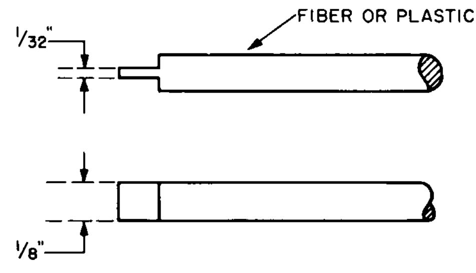


Fig. 5-10. Alignment tool.

For an indication, connect a vom, vtvm, or output meter (use a-c setting of meter) across the voice coil. The volume control should be set to maximum.

If the receiver tracking is not correct after the receiver has been installed in the receiver case, it means that the trimmers were disturbed during installation. To prevent this from happening, seal the trimmers after alignment with coil cement. (Do not get any cement in the trimmer.)

Needless to say, the receiver alignment should always be checked after replacement of an r-f oscillator, mixer, or i-f amplifier transistor, transformer, or coil.

I-F TRANSFORMER REPLACEMENT

I-F transformers may either open, short, or develop corrosion of the windings. An open i-f transformer causes loss of sound and can be detected by the absence of a normal voltage on the collector or base of the transistor (provided no bleeder bias network is used). A shorted transformer winding can cause loss of sound or very weak and distorted sound. Corrosion of the windings causes low gain and noisy operation. In this case, the d-c resistance of the transformer winding will be several times its normal value.

There is a large variation in the design of i-f transformers used in transistorized i-f amplifier circuits. An exact replacement should therefore be used for a defective unit. If it is impossible to obtain an exact replacement, choose a universal type which most closely matches the original transformer in size, type of core, i-f range (scope of core adjustment), and type (input and output impedances, taps, etc.).

Be sure that the replacement transformer is oriented correctly in the circuit so that its high-impedance winding goes to the collector of the preceding stage and the low-impedance winding goes to the base of the following stage. The d-c resistances of the i-f transformers range from 3 to 8 ohms for the primary and 0.25 to 2 ohms for the secondary. The transformer's terminals are either numbered, or a colored dot identifies the terminal connections.

Replacing a defective transformer incorrectly or with an incorrect replacement can cause oscillations, no sound, low volume, or distortion. Very often, the i-f transformer shield is part of the receiver ground circuit. Therefore, be sure that the replacement does not open the ground circuit. If it does, simply connect a jumper wire to complete the circuit.

After installing a new i-f transformer, always check the i-f alignment and oscillator tracking (if the transformer was the input unit).

SERVICING R-F AMPLIFIER STAGES

Circuit Check. Radiate an r-f signal (30–60% modulation) through a loop placed close to the receiver's antenna loop (see Fig. 5-9). Keep the generator output just high enough to obtain a reasonable volume output from the receiver's speaker. Adjust the radio receiver for maximum gain (volume turned all the way up, minimum tone control setting, etc.). If available, connect an output meter across the voice coil.

Tune the receiver dial through the portion of the band having the generator r-f frequency. If the generator modulation note is heard very strongly from the receiver's speaker, the r-f amplifier is operating normally. Random noise picked up by the receiver will be measured on the output meter when the tuning dial is off generator frequency. If this signal check does not show significant gain over this noise signal measurement, it may be assumed that the r-f amplifier stage is not functioning.

SERVICING CHART FOR R-F AMPLIFIERS

Trouble	*Possible Cause*	*Checks to be Made*
1. No signal	A. Open antenna loop	1. Check by injecting r-f signal (through a 250-$\mu\mu$f capacitor) at high end of antenna loop or at transistor element receiving the signal. Do not connect generator ground lead to radio receiver chassis. A continuity check will confirm this trouble. Remember to remove transistor from socket first.
	B. Shorted gang tuning capacitor	1. Usually caused by plates touching or by poor wiper contacts. Also, trimmer capacitor may be shorted (usually a crack in mica insulator).
	C. Shorted by-pass capacitors	1. Measure the bias on transistor elements. To make resistance check, first remove transistor from socket.
	D. Defective transistor	1. Check by substituting exact replacement transistor in circuit (check bias first to be sure that it is correct). Use transistor checker or procedure given in Chapter 10 to check for shorts, opens, or leakage. These checks, however, will not provide an indication of the transistor's gain at r-f frequencies, so exact replacement is essential.
		2. If no replacement is available, the following check works in many receivers: Remove r-f amplifier from socket and connect a jumper from the antenna to collector terminal of the transistor socket (see Fig. 5-11). Tune the receiver through the band. If a weak signal is heard where no signal was heard before, it can be assumed that the transistor is defective.
(contd.)		

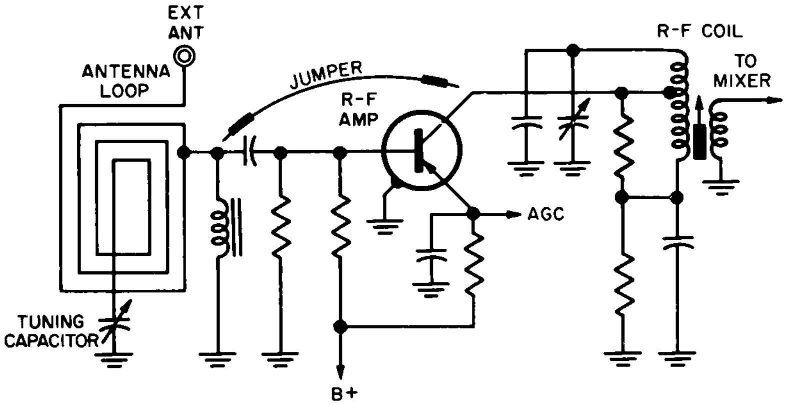


Fig. 5-11. A method of checking for a defective transistor when no exact replacement is available.

SERVICING CHART FOR R-F AMPLIFIERS (contd.)

Trouble	*Possible Cause*	*Checks to be Made*
	E. Defective band-switch (in multi-band receivers)	1. Remove r-f amplifier and mixer transistors from sockets and resistance-check the switch.
II. Noisy operation	A. Defective gang tuning capacitors	1. Check for touching plates or poor wiper contacts.
	B. Poor contacts on bandswitch	1. Clean with a suitable cleaning solvent and lubricate.
III. Oscillations	A. Open bypass capacitors	1. Check bypass capacitors (see sections on servicing i-f amplifiers and converter oscillations).

6. Oscillators, Converters, and Mixers

A transistor oscillator functions in a manner similar to that of a vacuum tube oscillator. Oscillations are sustained in an amplifying device by feeding back a signal in phase with the input signal and with sufficient amplitude to overcome circuit losses. If the power gain of the circuit is greater than 1, oscillations will be sustained.

There are many types and variations of oscillator circuits. However oscillators fall into two general classes — sine-wave and non-sine-wave (e.g., sawtooth, square-wave, etc.). Feedback is accomplished by either L-C or R-C networks.

SINE-WAVE OSCILLATORS

With only a few rare exceptions, all sine-wave oscillators employ inductive or capacitive feedback. There are three basic circuits — Meissner, Hartley, and Colpitts. These circuits and the vacuum tube equivalents are shown in Figs. 6-1, 6-2, and 6-3.

The Meissner Oscillator. Oscillation in this circuit [Fig. 6-1(A)] is by plate signal feedback in phase with the grid signal. The frequency can be varied by variable capacitor C1. This type of oscillator can be adjusted to produce continuous sine waves or be self-quenching, by choice of the proper time constant of C_c and R_g.

The transistorized circuit [Fig. 6-1(B)] is just as versatile. For sine-wave output, base resistor R1 is adjusted for enough bias to

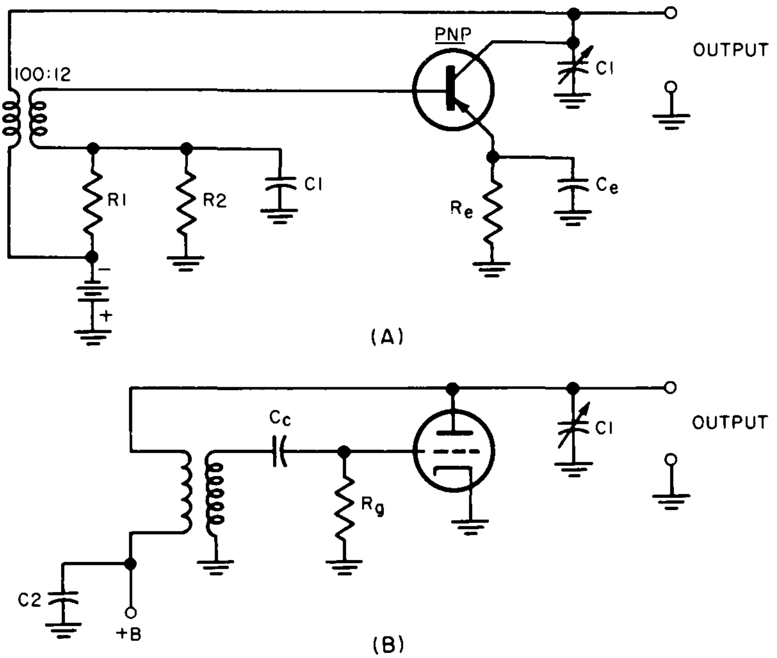


Fig. 6-1. (A) Transistorized Meissner oscillator circuit. (B) Vacuum tube Meissner oscillator circuit.

prevent the transistor from cutting off on positive voltage swings. The circuit can be made self-quenching by readjustment of R1.

Since the transistor is a current-operated device, a voltage step-down (as opposed to the voltage stepup in the vacuum tube circuit) is used between the collector and base. Thus, a small current change in the collector causes a large current change in the base. This action sustains oscillations by overcoming circuit losses.

Stabilizing resistor R_e is normally included in the emitter circuit to compensate for variations between production transistors. Resistors R1 and R2 provide a low-impedance bias source. To prevent self-quenching, the time constant of R1, R2, and C1 is made long compared to that of R_e and C_e. R_e and C_e have a function similar to that of C_g and R_g in the electron tube circuit. Therefore, the emitter time constant is an important consideration.

The Hartley Oscillator. This circuit, in both its transistor and tube forms, is shown in Fig. 6-2. The L-C tuned circuit is common to both the input and output circuits. Voltage from the collector circuit is developed across a portion of L, inducing a current of the proper phase into the base circuit to maintain oscillation. Again, since the transistor is a current-operated device, there is a voltage stepdown from collector to base. However, there is a current stepup to meet the requirement for the oscillator mode of operation.

The Colpitts Oscillator. This is another widely used sine-wave type of circuit. The transistor and vacuum tube forms are shown in Fig. 6-3. As in the Hartley circuit, the tuned circuit is common

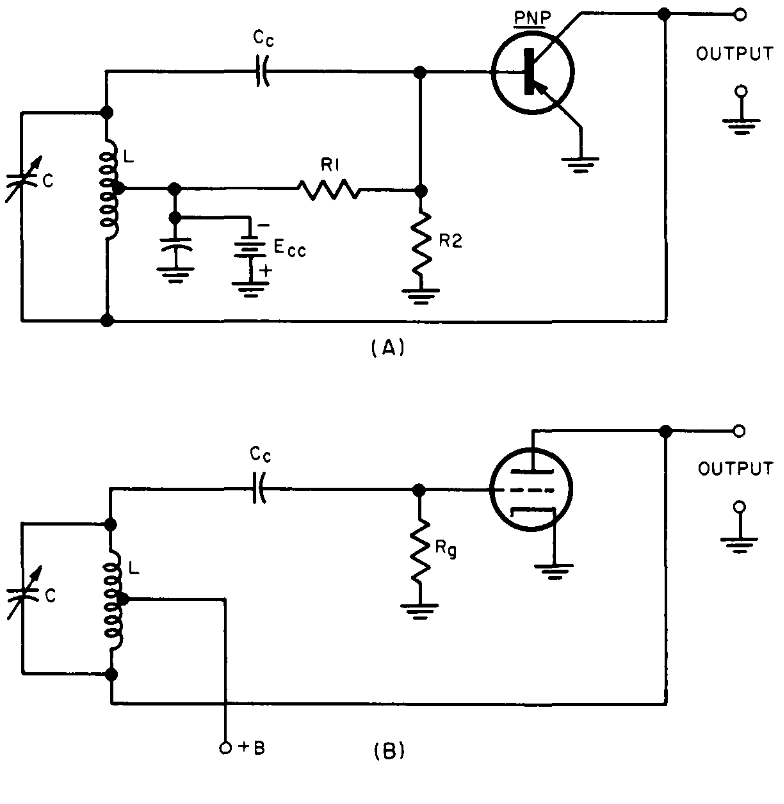


Fig. 6-2. (A) Transistorized Hartley oscillator circuit. (B) Vacuum tube Hartley oscillator circuit.

to both the transistor's input and output. Capacitors C1 and C2 split the signal to provide the proper feedback to sustain oscillation. Resistors R1 and R2 of the transistor circuit provide the proper bias between the base and the emitter.

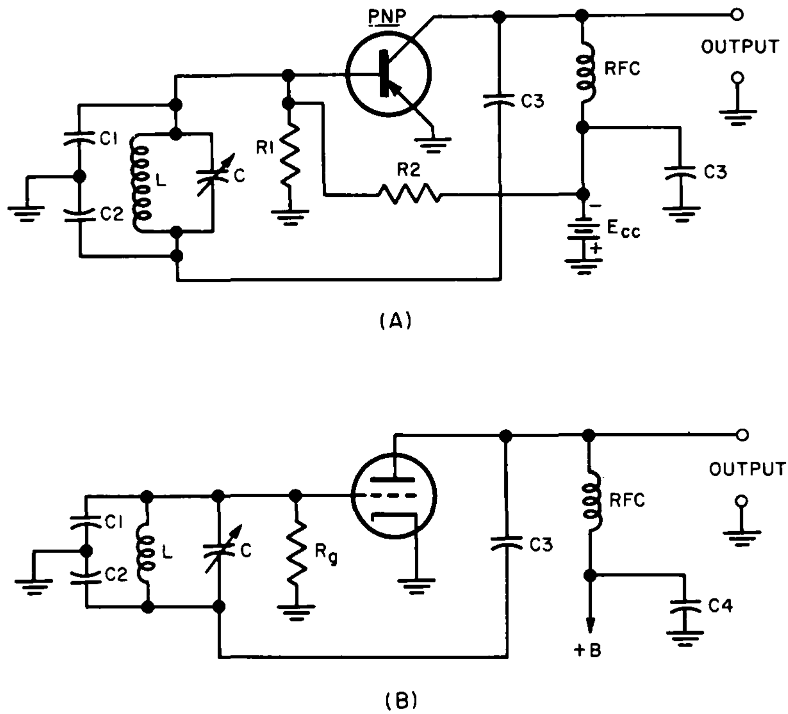


Fig. 6-3. (A) Transistorized Colpitts oscillator circuit. (B) Vacuum tube Colpitts oscillator circuit.

CONVERTER CIRCUITS

The converter is an integrated mixer-oscillator circuit used in radio receivers. The vacuum tube version, using a pentagrid tube, has long been popular in economy radios. In transistorized radios, converter action is accomplished by utilizing the nonlinear characteristics of a transistor.

A typical converter circuit is shown in Fig. 6-4. A ferrite loop antenna is used to capture the signal energy which is transformer-coupled to a low-impedance secondary winding. The current developed in the secondary winding flows in the base-to-emitter circuit of the transistor. T1, combined with C1A, the tuning capacitor, form the oscillator tank circuit. An a-c regenerative voltage is fed back from the collector circuit to the primary of T1. The secondary is a low-impedance winding causing the feedback current to flow in the base-emitter circuit of the transistor. Therefore, both the signal and oscillator currents flow in the base circuit. Because of the

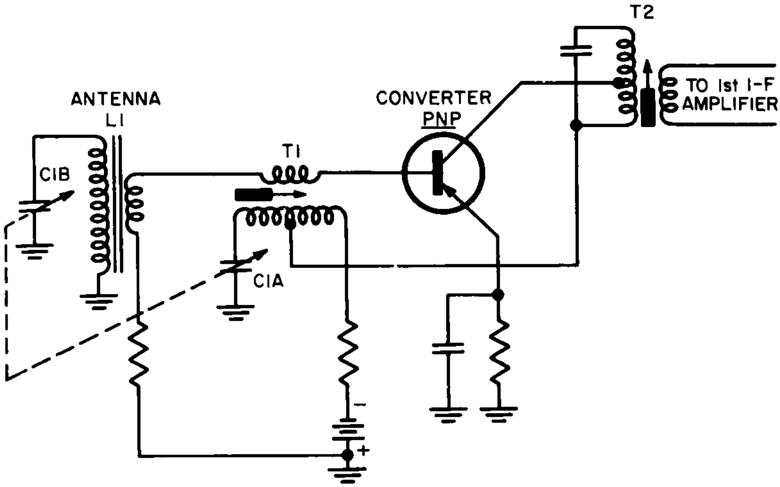


Fig. 6-4. Typical transistorized converter circuit used in many broadcast band portable receivers.

nonlinearities of the transistor, the two signals beat together to create an i-f signal in the collector circuit. The i-f transformer T2 transfers the 455-kc i-f signal to the i-f amplifier transistor.

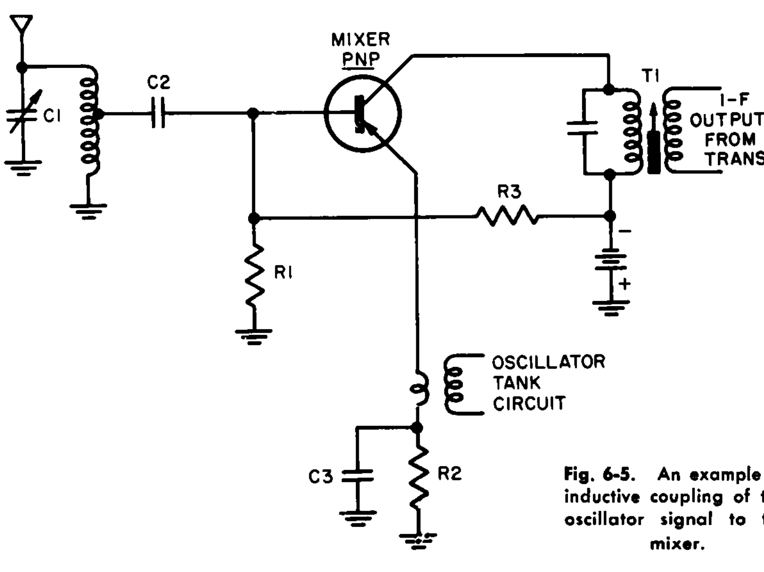


Fig. 6-5. An example of inductive coupling of the oscillator signal to the mixer.

OSCILLATOR-MIXER CIRCUITS

The use of separate oscillator and mixer circuits in a transistor radio offers the prime advantage of increased agc range. It is impossible to agc-control a converter circuit since the oscillator action of the circuit would be affected by the agc-control bias. In many

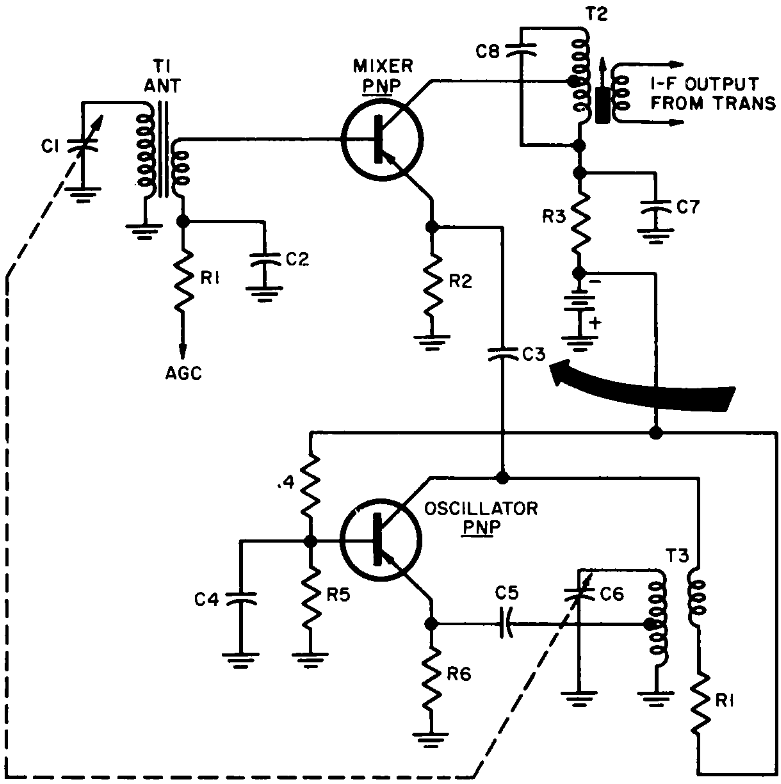


Fig. 6-6. An example of a mixer-oscillator arrangement using capacitive coupling of the oscillator signal to the mixer.

instances, the oscillator would even cease functioning under strong-signal conditions.

However, the use of separate mixer and oscillator circuits permits the mixer circuit to be agc-controlled, while the oscillator's characteristics remain unchanged.

The oscillator signal is most often injected at the emitter of the mixer transistor by inductive (Fig. 6-5) or capacitive (Fig. 6-6) coupling. The injection voltage from the oscillator is set to give maximum gain for the particular transistor and signal at the operating frequency. The optimum voltage depends on the frequency, and a compromise is usually required in a receiver covering a wide band of frequencies on a single tuning range.

AUTOMATIC FREQUENCY CONTROL

Oscillator stability decreases as frequency increases, and therefore an automatic frequency control (AFC) circuit is employed in FM receivers (88 to 108 mc) to keep the local oscillator on frequency. A *varactor* diode is placed across the oscillator tank circuit (Fig. 6-7). A varactor diode is a diode that has a substantial junction capacitance that can be varied as the reverse-bias current through the diode is varied.

In the circuit shown in Fig. 6-7, the varactor diode, D1, is connected across the oscillator tank circuit, C6-C7-L2, through capacitors C3-C4. The reverse bias of the diode is accomplished by rectification of a part of the audio signal when switch S1 is in the

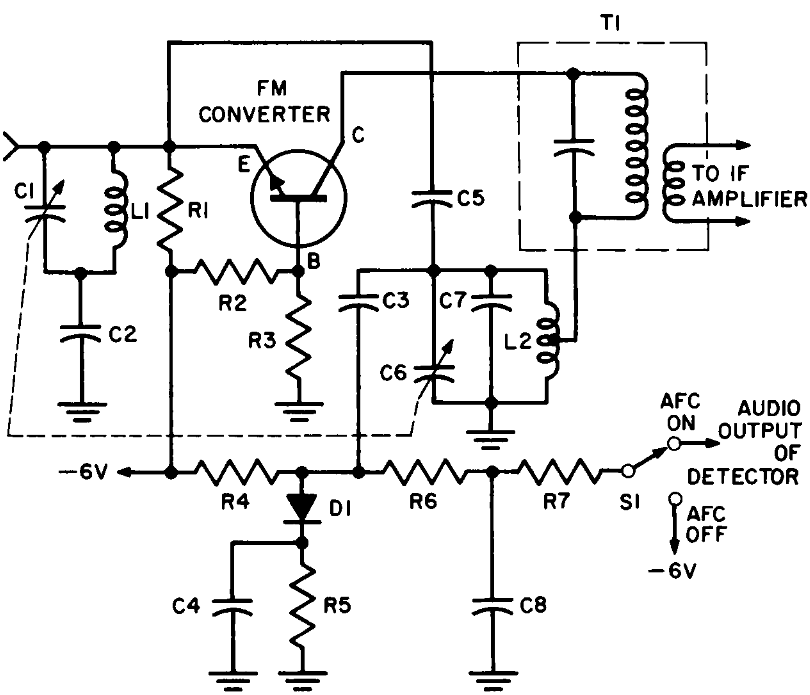


Fig. 6-7. Representative AFC circuit used to control FM oscillator frequency.

"AFC ON" position. In the "AFC OFF" position, the diode is held at a fixed bias point. In the "AFC ON" position, when there is oscillator drift up in frequency, the audio signal level of the detector becomes less positive, providing less bias for diode D1, thus increasing its capacitance while lowering the oscillator frequency. When the oscillator drifts down in frequency, the opposite effect occurs.

SERVICING OSCILLATOR, CONVERTER, AND MIXER CIRCUITS

Quick Check of Oscillator. The local oscillator can easily be checked as follows: With a vtvm, measure the voltage drop across the oscillator emitter resistor (Fig. 6-8). Place one finger on the oscillator tuning capacitor (or use a jumper to short it out). This will stop the oscillator from operating and cause a change in the

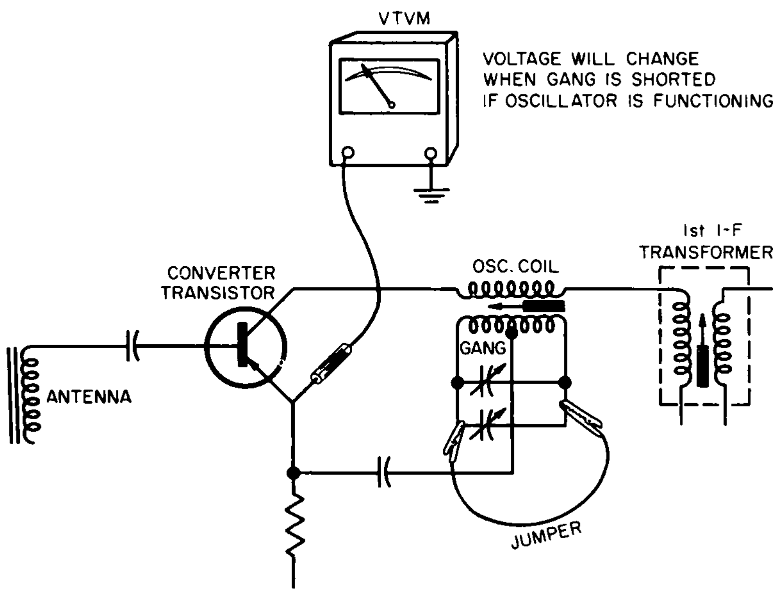


Fig. 6-8. Quick check for oscillator operation.

emitter voltage. If the voltage does not change, the oscillator is not functioning.

If the oscillator is functioning and this is still the suspect stage, check the oscillator frequency. This can be done using a grid-dip meter or by using the following check. Place the defective radio close to an operating radio (preferably so that their antenna loops are close together as shown in Fig. 6-9). Turn the good receiver on and set it to the highest station receivable. Rock the dial of the defective receiver about 455 kc (intermediate frequency) below the station frequency. If the oscillator is operating, a whistle will be

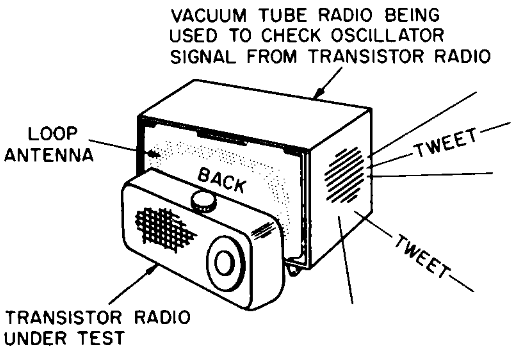


Fig. 6-9. Another working receiver can be used to check oscillator frequency and calibration.

heard from the loudspeaker of the operating receiver every time the signals beat together. The calibration of the entire low end of the radio band may be checked using this procedure.

Quick Check of Mixer Circuit. A quick check of the mixer circuit can be made by using the same quick check procedure described in Chapter 5 for the i-f amplifier. If a click is heard when the collector is touched, but not when the base is touched, the stage is defective. In a properly operating circuit, the click heard when the base element is touched will be slightly louder than when the collector is touched. This check, however, is not a good or truly reliable test of the circuit's operation at intermediate and radio frequencies. A method of checking converter and mixer circuits using a noise generator is described in detail in Chapter 10. This check is more conclusive than the click test since the harmonics of the generator signal are at both intermediate and radio frequencies.

To check the mixer circuit using a standard signal generator, proceed as follows: Inject an i-f signal (30–60% modulation) through a 100- to 500-$\mu\mu$f capacitor, alternately at the base and collector of the mixer transistor. An increase in volume from the receiver's loudspeaker, when the collector is used as the injection point as opposed to the base, indicates normal operation of the mixer circuit at intermediate frequencies. A mixer circuit which operates properly at intermediate frequencies will operate properly at radio frequencies. However, to establish this definitely, it is advisable to perform the following additional check.

Connect a loop (1 to 3 turns of wire) across the r-f generator output cable. Place the loop over the mixer input transformer (Fig. 6-10). (Place loop over the antenna in sets not using an r-f amplifier.) Select a radio frequency (30–60% modulation) at

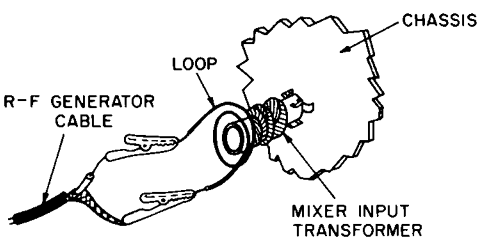


Fig. 6-10. A 2- to 3-loop wire placed across the r-f generator output cable is used to couple the r-f signal to the mixer input transformer.

the high end of the band. Tune the receiver to this frequency. Slowly rock the generator dial to either side of the receiver frequency. If no signal is heard from the receiver speaker, the oscillator circuit is not operating. If a signal of normal intensity is heard, both the mixer and oscillator circuits are operating properly.

When using this check on multiband receivers, perform the test at the high end of each band. Be sure that the generator loop is placed over the mixer input transformer for the particular band being checked. If operation is poor on one band, but good on the other bands, check for a defect in the bandswitch or tuned circuits. If no sound is heard on any of the bands, the oscillator circuit is not operating.

Mixer Gain Check. A properly operating mixer circuit will provide gain at intermediate frequencies of 5 to 10. This gain can be checked using the setup shown in Fig. 6-11. An oscilloscope is used as an indicator and connected across the speaker voice coil. An i-f signal (30–60% modulation) is injected, alternately at the base and collector of the mixer transistor, through a 0.005-μf capacitor.

The signal generator output is kept just high enough to give a measureable indication and not show any signal distortion (clipping of signal due to overmodulation or overloading). The pattern on

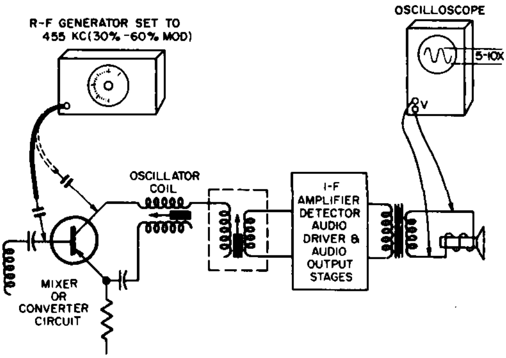


Fig. 6-11. Setup for checking mixer (or converter) stage gain.

the oscilloscope screen should be 5 to 10 times greater when the i-f signal is injected at the mixer collector than when it is injected at the mixer base.

SERVICING CHART FOR OSCILLATOR, CONVERTER, AND MIXER CIRCUITS

Trouble	*Possible Cause*	*Checks to be Made*
1. No signal	A. Inoperative oscillator circuit	1. Low, high, or absent transistor bias voltage will usually indicate the trouble. Check voltage at oscillator transistor elements. In common-base and common-emitter mixer circuits, a forward bias should exist between emitter and base in the order of 0.05 to 0.25 volt. In some rare grounded-base circuits (base connected to ground through a 0.01- to 0.05-μf capacitor) reverse bias may exist between base and emitter. This trouble is usually due to a defective oscillator coil, tuning capacitor, transistor, or open in circuit wiring Less frequent causes are defective resistors, capacitors, or transistors sockets, if used.
		2. Check for defective oscillator coil by making resistance measurements after first removing transistor from circuit. Check for open winding or poor solder connection at a terminal lug. If oscillator coil is defective, use an exact replacement to retain correct dial calibration. When replacing coil, do not disturb circuit wiring, which would cause oscillations or tweets. Do not reverse oscillator coil leads or circuit will not oscillate due to incorrect phase of feedback winding After replacement, realign receiver.
		3. Checks for tuning capacitor defects and replacement are given in section 11-A-1—5 following.
(contd.)		4. Check for defective oscillator transistor by replacing with known good transistor. Testing oscillator transistor in a transistor

SERVICING CHART FOR OSCILLATOR, CONVERTER, AND MIXER CIRCUITS (contd.)

Trouble	Possible Cause	Checks to be Made
		checker may not show the trouble since cutoff frequency is not measured.
	B. Inoperative mixer circuit	This trouble is usually caused by defective input transformer, transistor, or open in circuit wiring, and is usually indicated by improper bias voltages appearing on transistor elements.
		1. Check for defective mixer input transformer by making resistance measurements. Remember to remove transistor from circuit first. Before replacing transformer, check the coil for a break at or near a terminal lug. If break is found, scrape away some of the wire insulation and reconnect wire to terminal lug. If necessary, remove 1 turn from coil to effect repair. An exact replacement should be used for mixer input transformer. Dress transformer leads in same position as original to prevent possible circuit regeneration or oscillation. Dress leads close to chassis, away from other wiring and directly to their connection points. After replacement, check receiver alignment.
		2. Check for defective transistor by replacement with known good transistor.
		3. See service hints in Chapter 5 for i-f amplifiers, which also apply here.
	C. Inoperative converter circuit	1. This trouble applies to receivers using a single transistor as mixer and oscillator, with no r-f amplifier. Follow section I-A-2 above. Also check antenna loop circuit as given in section I-B-1, above.
II. Intermittent operation	A. Defective tuning capacitor	This trouble is usually caused by a short between stator and rotor plates due to bent or warped rotor plates (or, in a rare case, stator plates), or dirt and dust between plates. Intermittent trouble is sometimes caused by defective wiper action.
		1. Check for shorts due to dust or dirt by removing tuning capacitor from chassis, if the receiver is compact miniaturized type (see Fig. 6-12). Apply air pressure (a bicycle pump is adequate) gently to all parts of gang capacitor. Trimmer and stator supports should be wiped with a soft brush (cleaning solvent may be used for better results). Push wiper springs back from rotor shaft and drop cleaning solvent on wiper and shaft; rotate tuning capacitor quickly back and forth. Repeat several times for each wiper until good contact is re-established. When clean, lubricate with grease-type lubricant designed for switch contacts.
		2. Check wiper contacts for loss of tension in wiper spring. If bad, remove spring, bend to increase tension, and replace. Straighten bent rotor plates with needle-nose pliers or a soldering-aid tool.
(contd.)		3. Check trimmer mica insulators for cracks or dirt. If either

SERVICING CHART FOR OSCILLATOR, CONVERTER, AND MIXER CIRCUITS (contd.)

Trouble	Possible Cause	Checks to be Made
		condition is found, remove insulators by unscrewing the trimmer adjustment and lifting up the bronze trimmer plates. Replace cracked insulators; dip dirty insulators in cleaning solvent and gently wipe dry.
		4. Check for bare wire or stator lead so located that it shorts rotor plates during tuning. Dress away or insulate, as required.
		5. An exact replacement should be used for tuning capacitor to maintain original oscillator and mixer tracking (dial calibration) and to avoid regeneration or critical oscillation condition. Other reasons for this are standard considerations—dial stringing, size, capacitance, etc.
	B. Critical oscillator operation	1. Check for defective oscillator transistor by replacing with known good oscillator transistor.
		2. Check for defective oscillator coil by replacement with known good oscillator coil. In the case of converter-type circuit, try also a new antenna loop.
		3. Check for defective capacitors and resistors in circuit (also check i-f transformer in collector circuit).
		4. If, after checks II-B-1, 2, and 3, no defective component is revealed, refer to the manufacturer's service notes on the receiver. Look for changes — different values of emitter resistance, etc., or even a new type of oscillator coil, as indicated by a new part number — made in later production in oscillator circuit. If the trouble is still not disclosed, experiment with emitter bias network (and, sometimes, base bias network) to increase forward bias on transistor, which will increase transistor's current gain and the chance for sustaining oscillations throughout the band.
III. Weak reception (low sensitivity as indicated by gain check)		This trouble is usually due to incorrect alignment or insufficient oscillator injection voltage. However, other frequent causes of weak reception, which should also be checked, are: defective antenna loop, defective input transformer, defective tuning capacitor, low bias on mixer transistor, and high-resistance connections at or within coupling, tuning, or bypass capacitors.
	A. Incorrect alignment	1. Check oscillator alignment (see alignment section later in this chapter).
	B. Insufficient injection voltage	1. Measure oscillator voltage with no signal being received. Measure, using a vtvm having an r-f probe, or with an oscilloscope, at the transistor element receiving the oscillator signal (in converter circuits, this is the element having the oscillator feedback winding). Voltage should not be significantly below the value stated in manufacturer's service notes. Value is usually 0.07 to 0.25 volt rms (0.2 to 0.7 volt peak to peak). If voltage
(contd.)		

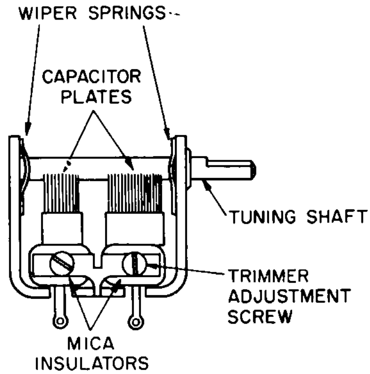


Fig. 6-12. A typical tuning capacitor used in transistorized radios.

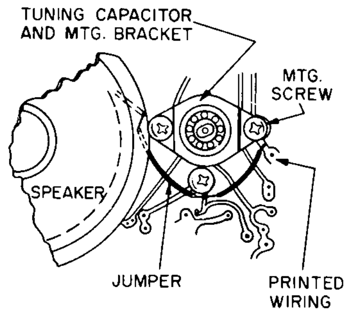


Fig. 6-13. Typical AM receiver using printed wiring where oscillations may occur because of poor ground connections in converter circuit. Jumpers interconnect ground circuits, reducing ground circuit impedance.

SERVICING CHART FOR OSCILLATOR, CONVERTER, AND MIXER CIRCUITS (contd.)

Trouble	*Possible Cause*	*Checks to be Made*
		is low, check oscillator (or converter, as case may be) transistor, or oscillator coil by replacement with known good components.
IV. Oscillations	A. High-impedance ground circuit	This consideration is more critical in transistor radios than in vacuum tube radios because of the lower impedance of the transistor circuit as compared to the tube circuits. A rosin solder connection can, therefore, have a resistance as high as the impedance of the circuit and cause regeneration. The same applies to the internal a-c impedance of the capacitors used in transistorized equipment.
		1. Check all ground solder connections in mixer and oscillator circuits for rosin connections by reheating all ground connections, allowing the solder to become molten and flow. Apply fresh solder to help this process. Interconnect all converter circuit grounds on printed boards with a common jumper wire (see Fig. 6-13). This is particularly important where the tuning gang capacitor is grounded at more than one point.
		2. Check for loose or stripped mounting screws in the tuning capacitor, which would cause a high-impedance circuit to develop. When replacing a stripped screw, be sure that it is not long enough to touch the capacitor plates.
(contd.)		3. Check for "hot" transistor and resulting excessive oscillator signal by measuring the oscillator injection voltage (see III-B-1 above). If high, try another transistor of same type or shunt the oscillator coil primary winding with a 22,000-ohm to 1-megohm resistor (Fig. 6-14).

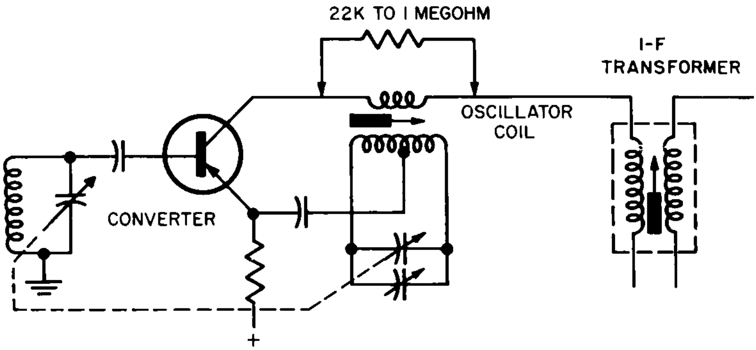


Fig. 6-14. A resistor is placed in shunt with the oscillator coil primary winding to reduce the oscillator voltage where excessive voltage causes whistling.

SERVICING CHART FOR OSCILLATOR, CONVERTER, AND MIXER CIRCUITS (contd.)

Trouble	*Possible Cause*	*Checks to be Made*
V. Distortion	A. Defective mixer circuit	1. Check for open bypass capacitors, poor lead dress, and poor ground connections causing oscillations (see IV above).
	B. Defective oscillator circuit	1. Same as section V-A-1 above.
	C. Defective converter circuit	1. Same as section V-A 1 above.
	D. Poor alignment	1. Follow alignment tips given in the following section.

ALIGNMENT TIPS

The alignment procedure outlined in Chapter 5 also covers oscillator-mixer alignment. However, a few additional tips are presented here.

In the case of multiband receivers, always use the alignment procedure given in the manufacturer's service notes. This is necessary because of the interaction of the various tuned circuits, necessary dummy load, etc.

If the oscillator coil has a slug adjustment, try peaking it. This is done by setting the radio dial to a frequency close to the low end of the band (600 kc on broadcast band), away from any station, and adjusting for minimum noise. This test is very effective near a noise source such as a fluorescent fixture. If adjustment of the oscillator coil gives a noticeable improvement in reception, perform the entire receiver alignment as described in the manufacturer's service information.

Check for mistracking after the chassis is replaced in the receiver case or cabinet. If this occurs, the oscillator trimmer was disturbed during installation. In this case, readjust the trimmer and seal the trimmer screw head with coil cement.

7. AM and FM Detector and AGC Circuits

In all transistor radio receivers, the functions of detection (demodulation) and automatic gain control (agc) are combined into one stage. This stage may employ either a transistor or germanium diode.

The detector receives the modulated i-f signal from the i-f amplifiers. Transformer coupling is used to provide i-f selectivity and match the impedance of the i-f transistor to that of the detector transistor or diode. The detector removes the audio component from the modulated i-f signal and feeds it to the audio driver. The audio signal is recovered by rectifying and filtering the modulated i-f signal.

The detector is also the source of agc voltage. This voltage is proportional to the average strength of the incoming station signal, obtained by taking a portion of the audio signal at the output of the detector and further filtering it to develop a d-c voltage. The agc voltage is then used as a variable bias for the first i-f amplifier. As the incoming signal level increases, the agc voltage increases, biasing the first i-f transistor in a less forward direction and reducing its gain proportionately. The audio signal at the detector is thus maintained at a more constant level to avoid annoying blaring or overload distortion on strong signals. Also, the receiver is allowed to operate at maximum gain on very weak signals.

In receivers having separate oscillator-mixer circuits, the mixer may also be agc-controlled, increasing the agc range. When an r-f amplifier is employed, it too is agc-controlled, increasing the agc range even further and decreasing the likelihood of overloading on extremely strong stations.

OPERATION

Diode AM Detectors. With an understanding of the function of the detector-agc circuit, let us look at actual circuits used in current receivers.

A simple diode detector circuit is shown in Fig. 7-1. The primary of transformer T2 acts as the collector load for the last i-f amplifier transistor. The i-f signal is inductively coupled to the secondary T2. The signal, on negative half-cycles, flows up from ground, through the secondary T2, the diode, and volume control to ground. The signal is rectified, with the i-f portion being filtered by C1. Since only the i-f signal is being filtered at this point, the value of C1 is small (usually 0.02 to 0.05 μf). This capacitor also provides a small amount of bass boost by filtering some of the very high audio frequencies.

The agc voltage is developed at the junction of R1, R2, and C2. This voltage is the result of two opposing currents. The first is the bias current for the first i-f amplifier. This current flows up from ground, through the volume control, R1, and R2, to the 8.4-volt supply. The voltage developed at the junction R1-R2-C2 is the static d-c bias voltage for the first i-f amplifier transistor.

When a signal is received, the diode conducts, rectifying the i-f signal. The detector current flows through the volume control

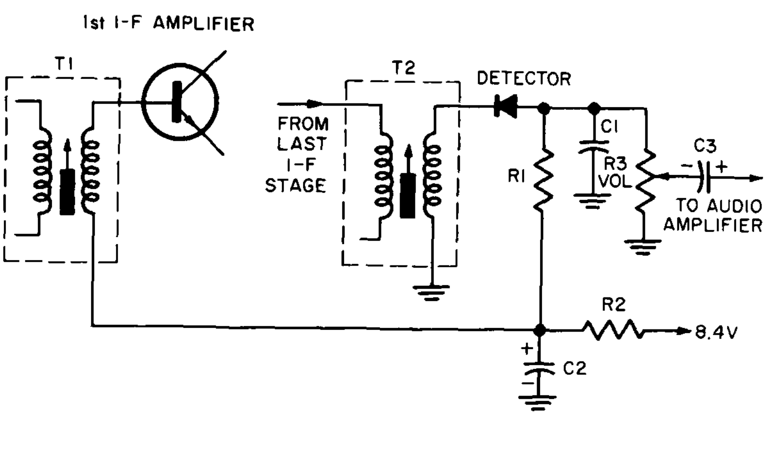


Fig. 7-1. A basic diode detector-agc circuit.

in a direction opposite to that of the first i-f amplifier bias current. The bias current is thus reduced, reducing the voltage on the base of the first i-f amplifier transistor. The transistor is now biased in a less forward direction, lowering its gain. The agc voltage is filtered by C2 to remove the audio component. Hence the value of C2 must be large (usually 10–40 μf).

Transistor AM Detectors. When a transistor is employed as a detector (Fig. 7-2), audio gain is usually achieved. The transistor is biased only slightly above cutoff. Negative half-cycles of the i-f

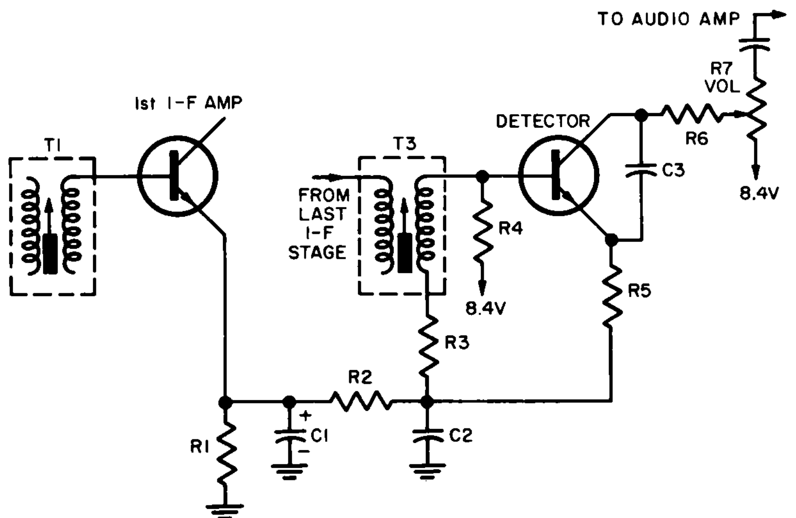


Fig. 7-2. A detector circuit using a transistor to detect. This circuit provides an audio gain of approximately 10—15 db.

signal are clipped, while conduction occurs only on positive half-cycles. The gain is accomplished by the larger current that is caused to flow between emitter and collector. The audio signal is developed across the volume control with C3 acting as the i-f filter.

Here, the first i-f amplifier gain is controlled by varying the emitter voltage. The static zero-signal bias is developed by the resistive divider network composed of R1, R2, R3, and R4 across the 8.4-volt supply. The bias current flows up from ground through R1, R2, R3, and R4 to the 8.4-volt supply.

When a signal is being detected, the detector emitter-to-collector current flows up from ground through R1, R2, and R5, from emitter to collector of the detector transistor, through R6 and R7,

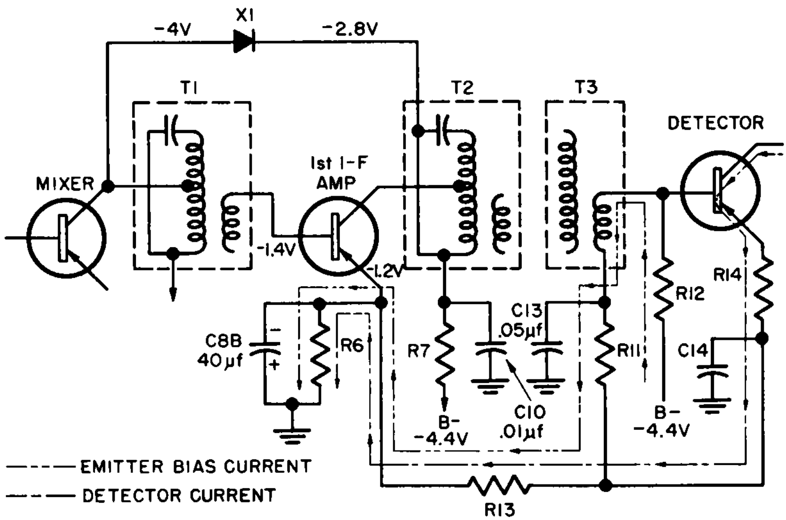


Fig. 7-3. Detector-agc circuit employing an overload diode X1 to prevent distortion on strong signals. The conduction of X1 is controlled by the first i-f amplifier's emitter bias voltage.

to ground. The detector current through R1 is in the same direction as the bias current and thus raises the i-f amplifier emitter voltage, decreasing the transistor's forward bias and reducing stage gain.

A variation in these circuits incorporates the use of a diode connected from the low side of the second i-f transformer primary to the first i-f transformer primary (Fig. 7-3). This system increases the range of agc control to prevent possible overloading on a very strong signal.

When no signal is being received, the diode is reverse-biased (—2.8 volts on cathode and —4 volts on anode provides 1.2 volts reverse bias), and it does not conduct. When a signal is received, the first i-f amplifier emitter voltage becomes more negative, reducing the gain of the transistor. As emitter-to-collector current decreases, the voltage on the collector increases toward the B— line voltage (—4.4 volts). If it were possible to completely cut off the transistor, —4.4 volts would appear on the collector.

As the signal received increases in strength, the diode reverse bias becomes less. As the diode approaches zero bias, the high back resistance of the diode decreases. On very strong signals, the collector voltage exceeds —4 volts, and forward-biases the diode. The diode then becomes a low resistance in series with capacitor C10. The resistance of diode X1 and capacitance of C10 are now in snunt with the primary of T1, lowering its Q and reducing the amount of i-f signal coupled to the first amplifier stage.

Another variation of the transistor detector circuit is shown in Fig. 7-4. Here, the audio load for the detector is located in the emitter circuit, instead of in the collector. This eliminates the need for a blocking capacitor between the detector and audio driver. The

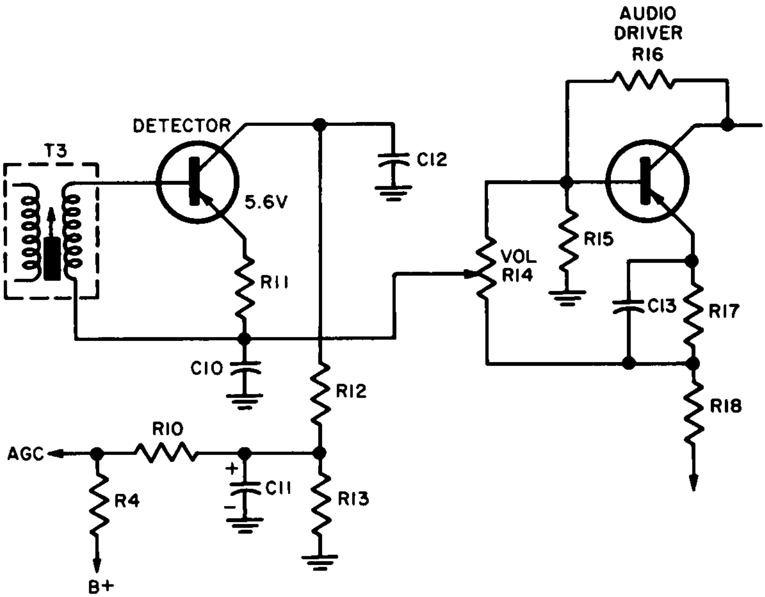


Fig. 7-4. A transistor detector circuit in which the audio signal is d-c coupled between the detector and audio driver transistors. The agc voltage is amplified to increase the agc range.

agc voltage appears across R13, with C11 acting as the agc filter. The agc voltage is coupled to the base of the first i-f amplifier transistor to bias it in a less forward direction, reducing its gain.

FM Demodulation. The frequency changes of an FM signal can be converted into audio signals through the use of either the discriminator or slope detector circuits. These circuits perform essentially the same function as the detector in an AM radio receiver.

Figure 7-5 illustrates a transistorized version of an i-f stage and a discriminator. Circuit operation is virtually identical to the vacuum tube equivalent. Capacitor C2 and the primary of T1 form a parallel resonant circuit for the i-f signal which is coupled through the transformer to the discriminator. Capacitor C3 couples

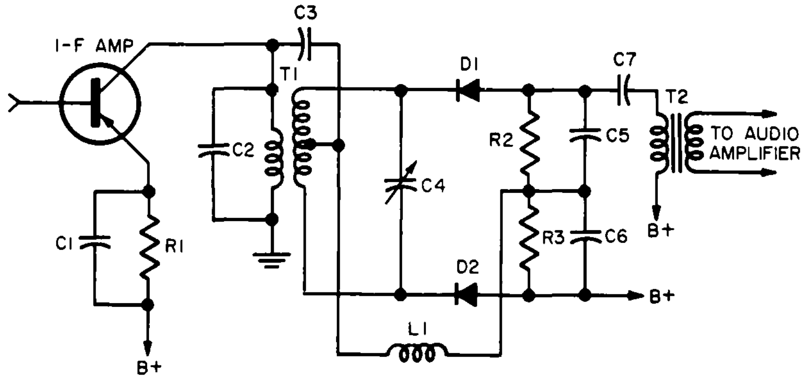


Fig. 7-5. An i-f amplifier and FM discriminator.

the i-f signal to the secondary of T1 for phase shift comparison. The i-f signal, coupled across C3, is developed across coil L1. Capacitor C4 and the secondary of T1 form a resonant circuit for the i-f signal coupled through the transformer. The top half of the T1 secondary, diode D1, coil L1, load resistor R2, and filter capacitor C5 form one-half of the comparison network. The bottom half of the T1 secondary, diode D2, coil L1, load resistor R3, and filter capacitor C6 form the second half of the comparison network.

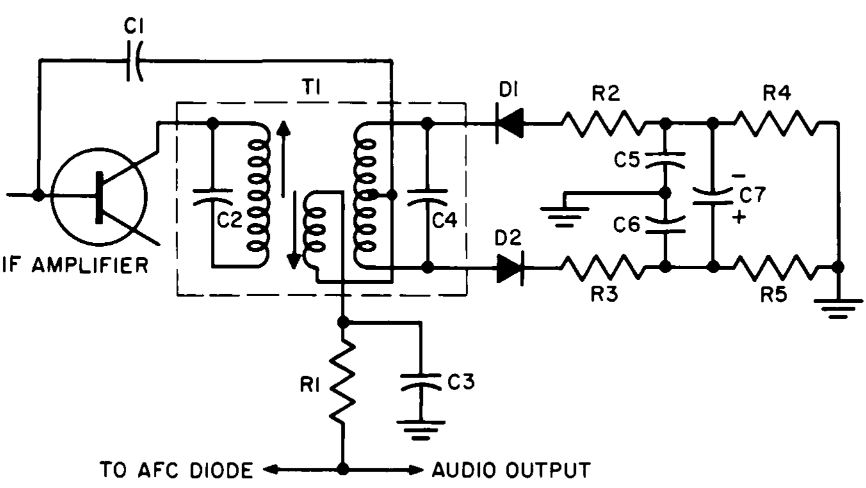


Fig. 7-6. FM ratio detector circuit.

The audio output of the discriminator circuit is taken from the top of C5 and the bottom of C6. The audio output is coupled through C7 to the primary of T2. The audio signal, coupled through T2, is applied to the audio amplifier.

The most popular type of FM detector is the *ratio detector,* shown in Fig. 7-6. Its circuit is very similar to that of the FM discriminator shown in Fig. 7-5. However, there are some key differences; one of the diodes is reversed, there is a large electrolytic capacitor across the load resistors (R4-R5), and the output is taken from a center tap on the transformer secondary. At the resting frequency both diodes conduct equally, and there is no signal output. However, as

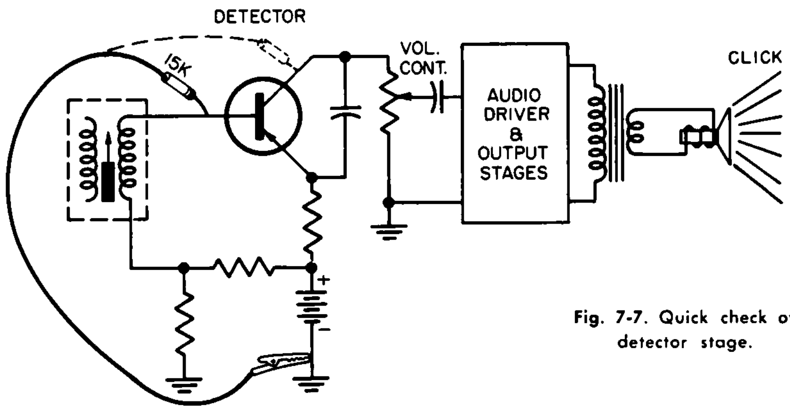


Fig. 7-7. Quick check of detector stage.

the signal shifts in frequency above and below the resting frequency, the diodes conduct to different amounts, thereby unbalancing the circuit and producing an output. The ratio of change depends on the amount of frequency change, and this property gives the name of ratio detector.

Capacitor C7 charges to the peak value of the signal across the transformer secondary, and amplitude differences (from interference) have little effect on the charge on C7, holding the signal output constant. This is the advantage of the ratio detector over the discriminator. It does not require limiter circuits before the detector since it is not affected by amplitude variations.

SERVICING FM AND AM DETECTOR AND AGC CIRCUITS

Quick Check of Detector Circuit. The standard quick-check method (Fig. 7-7) outlined in Chapter 10 may also be used here to check both transistor and crystal diode detector circuits.

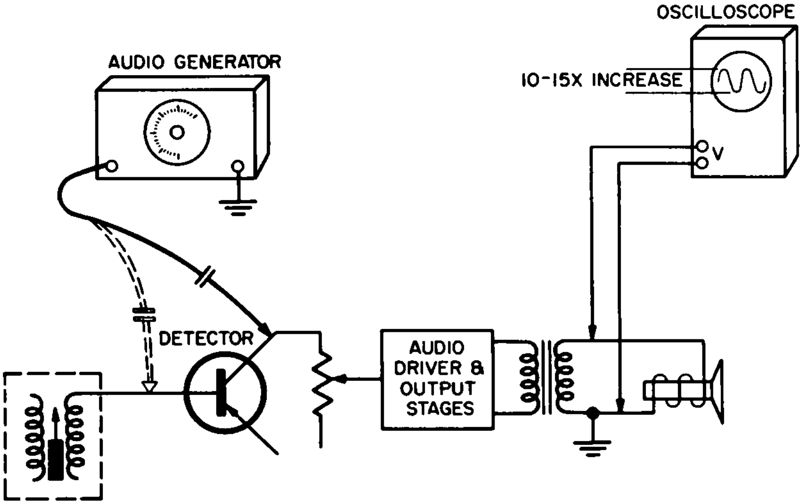


Fig. 7-8. Gain check of a transistor detector circuit. A gain of 10—15X should be measured in a normal circuit.

If a click is heard when the collector of the detector transistor is touched, but not when the base is touched, the stage is not functioning. In the case of a crystal diode, the output terminal can be either the anode or cathode, depending on the type of agc system used. If the click is not heard, this circuit is not functioning.

Gain Check. Detector stages employing a transistor usually provide gain at audio frequencies, as well as acting as a detector. The gain of such circuits ranges from 10 to 15. This can be checked, roughly, using the method shown in Fig. 7-8. An oscilloscope is connected across the speaker voice coil and used as an indicator. An audio signal is injected, alternately, at the base and collector of the detector transistor, through a 0.1–0.05 μf capacitor. The output of the signal generator and receiver volume control is kept just high enough to give a measureable indication. Too large a signal will overload the receiver and not give a true indication of gain. Overloading appears as clipping or distortion of the sine wave signal on the oscilloscope screen. Use an audio signal of approximately 400 cycles.

AGC Circuit Check. A correctly operating agc circuit provides a control voltage to the first i-f amplifier stage (in some rare cases, the second i-f amplifier also) to decrease its gain as the incoming signal strength increases. This can be checked by measuring the

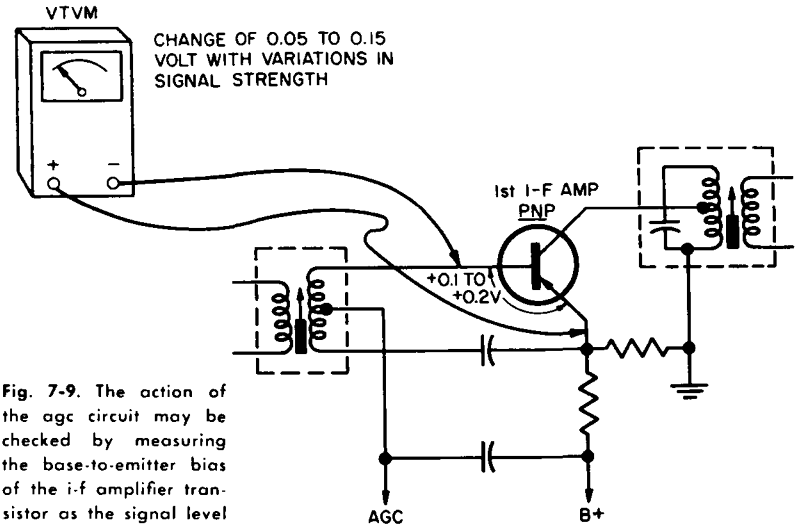


Fig. 7-9. The action of the agc circuit may be checked by measuring the base-to-emitter bias of the i-f amplifier transistor as the signal level is varied.

base-to-emitter bias of the i-f amplifier as the incoming signal level is varied.

Connect a vtvm to the base and emitter of the i-f amplifier transistor (Fig. 7-9). For npn-type i-f amplifier transistors, the vtvm leads should be reversed. With the receiver tuning dial rotated off station, a positive 0.1–0.2 volt forward bias will be measured. As the tuning dial is rotated to tune in a strong station, this voltage will drop 0.05 to 0.15 volt. If no change in voltage or a change in the wrong direction is measured, the agc circuit is not functioning properly.

SERVICING CHART FOR FM AND AM DETECTOR AND AGC CIRCUITS

Trouble	*Possible Cause*	*Checks to be Made*
1. No signal	A. Open i-f transformer winding	1. See checks given in Chapter 5.
	B. Defective transistor	1. Check by replacing with known good transistor. See I-C-3, below.
(contd.)	C. Defective crystal diode	1. Check by replacing with known good crystal diode. However, a resistance check of the diode provides a fairly reliable indication of the condition of the diode (see Fig. 7-10). Check the back resistance of the diode. If less than 20,000 ohms, the crystal is defective. Back resistance should be from 100,000 to 500,000 ohms. A low back resistance causes low gain and pos-

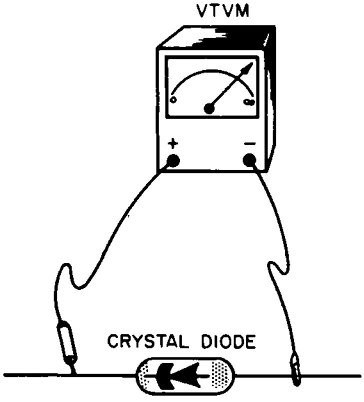


Fig. 7-10. Checking the back resistance of a crystal diode.

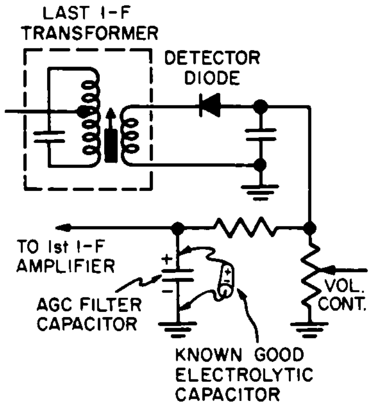


Fig. 7-11. Checking the agc filter capacitor for open condition.

SERVICING CHART FOR FM AND AM DETECTOR AND AGC CIRCUITS (contd.)

Trouble	*Possible Cause*	*Checks to be Made*
		sible distortion. The forward resistance of the diode (100 ohms or less) can be checked by reversing ohmmeter leads.
		2. When replacing the crystal diode, be certain that polarity is correct. Use a heat sink very carefully to prevent heat damage to the diode during soldering. Do not disturb the circuit lead dress; this can cause regeneration.
		3. Check the voltages at the elements of the crystal diode (or transistor, as the case may be) to determine whether the unit is correctly biased. Transistor and diode detectors usually have a slight amount of forward bias between base and emitter, or anode and cathode, respectively. This is usually 0.025 to 0.1 volt.
II. Low volume	A. Incorrectly biased transistor	1. See II-B-1, below.
	B. Incorrectly biased diode detector	1. Check transistor's or diode's forward bias as described in section I-C-3 above. If incorrect by 10 to 20%, volume will drop. This trouble is usually accompanied by distortion. Check for defective transistor or diode by replacement with known good component. Resistance-check base, emitter, and collector circuits with transistor out of circuit.
(contd.)	C. Defective agc filter capacitor	1. Check for opens in agc filter capacitor. If condition is present, decreased receiver sensitivity results, often accompanied by regeneration. Check by paralleling with known good unit and observing polarity (Fig. 7-11).

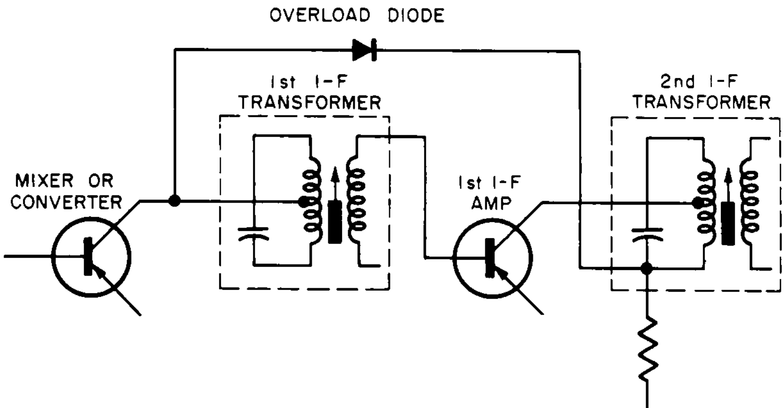


Fig. 7-12. The overload diode should be checked in cases of low gain and distortion (see text).

SERVICING CHART FOR FM AND AM DETECTOR AND AGC CIRCUITS (contd.)

Trouble	*Possible Cause*	*Checks to be Made*
	D. Defective agc overload diode, if used	1. Diode is most often connected from low side of second i-f amplifier transformer primary to high side of first i-f transformer secondary (Fig. 7-12). If shorted or reversed in circuit, low sensitivity results.
III. Distortion (not affected by volume setting) (contd.)	A. Defective detector transistor	1. See III-B-1, below.

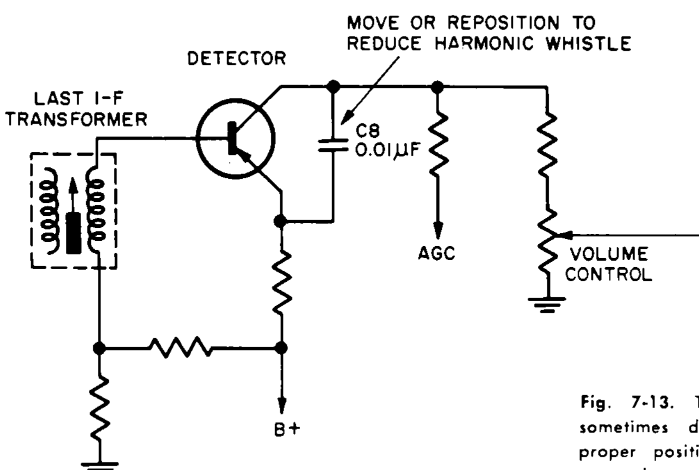


Fig. 7-13. Tweets are sometimes due to improper position of detector bypass capacitor.

SERVICING CHART FOR FM AND AM DETECTOR AND AGC CIRCUITS (contd.)

Trouble	*Possible Cause*	*Checks to be Made*
	B. Defective diode detector	1. Check detector transistor or diode by direct replacement. Also check voltage at transistor or diode elements.
	C. Defective agc filter capacitor	1. See section II-C-1, above.
	D. Defective agc overload diode	1. If open condition is present, distortion will occur on very strong signals. See section II D-1, above.
IV. Oscillations	A. Open agc filter capacitor	1. Check for opens causing regeneration and resultant squeals and whistles on either strong signals only or across entire band (Fig. 7-11). Also check for leaky condition by replacing with known good unit of same capacitance and voltage rating.
	B. Open detector r-f bypass capacitor	1. Check for opens causing regeneration and resultant squeals and whistles either on strong signals only or across entire band by replacing with known good unit of same capacitance and voltage rating.
	C. Poor lead dress and ground connections	1. Check detector circuit grounds for poor connections. Reheat all ground solder connections. Also try interconnecting chassis grounds with a common ground lead.
	D. Improperly positioned r-f bypass capacitor	1. Check for improper location of r-f bypass capacitor (see Fig. 7-13). If incorrectly positioned, try turning capacitor so that it is perpendicular to ferrite-core antenna. In some cases, oscillations are neutralized by coiling a ground jumper lead (grounded at both ends) around detector i-f bypass capacitor and detector transistor.

8. Portable Radio Receivers

The most popular application of transistors is in the portable AM broadcast receiver. In this application, the transistor has virtually relegated the vacuum tube to a museum display. The portable transistor radio is manufactured in an endless variety of electrical and mechanical designs [Fig. 8-1(A)]. These range from pocket-size receivers, smaller than a pack of king-size cigarettes and using miniaturized components [Fig. 8-1(B)] to multiband receivers, housed in beautiful luggage-type cases and capable of receiving signals from distant points on the earth.

INEXPENSIVE PORTABLE RECEIVERS

The most inexpensive AM portable radio receivers employ one, two, or three transistors at most. In an attempt to provide maximum performance with as few components as possible, trf-type circuitry is used in preference to the superheterodyne circuit.

A three-transistor receiver is illustrated in Fig. 8-2. It is housed in a case slightly larger than a pack of cigarettes and has two tuning knobs for antenna and r-f tuning. Station selection is accomplished by rotating the antenna control until the station is heard and then fine tuning with the r-f control for best sound. The r-f setting is always close to the antenna setting because of an interlock arrangement of the two knobs. Two small trimmer capacitors perform these functions.

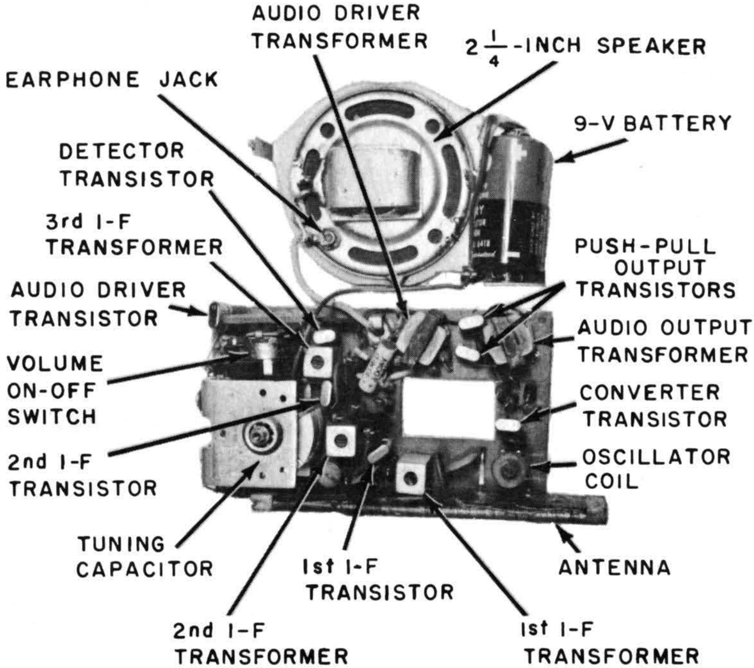


Fig. 8-1 (A)

(A) Seven-transistor miniature radio receiver chassis removed from its case. Westinghouse Model H-587P7.

(B) Miniaturized components used in pocket-size portable transistor radio. a. Two-gang variable capacitor. b. Transistor output transformer. c. Microminiature transistor i-f transformer. d. Strip transistor antenna rod. e. Transistor loop antenna. f. Potentiometer. Parts, a, b, c, courtesy *Argonne;* d, e, *courtesy* J. W. *Miller;* f, *courtesy Clarostat Mfg.* Co.

The antenna loop is tuned by the antenna tuning capacitor. The signal is then coupled to the first r-f transistor amplifier by the secondary winding on the antenna. The output of this stage is applied to the second r-f transistor amplifier by the first r-f transformer T1, which is tuned by the r-f tuning capacitor. The output from this stage is transformer-coupled by a broadband second r-f transformer T2 to the 1N60A crystal diode detector. Agc voltage is developed at the detector output and fed back to the base of the second r-f transistor. The audio signal from the detector is applied to the volume control and then R-C coupled to the audio transistor which drives the earphone unit directly.

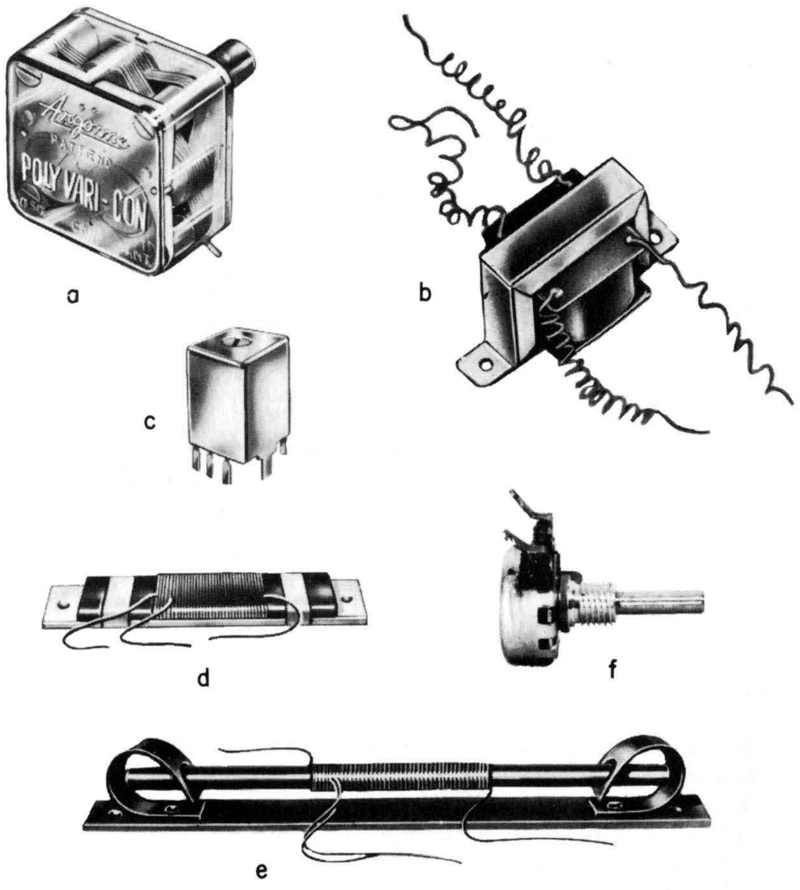


Fig. 8-1 (B)

One- or two-transistor receivers have one or two less r-f amplifier stages, as the case may be. The receivers, because of their inherent design, have less sensitivity and selectivity than the superheterodyne receivers. Also, they are more difficult to tune.

FOUR- AND FIVE-TRANSISTOR RECEIVERS

The four- and five-transistor portable radio receiver represents an inexpensive approach in superheterodyne circuitry. These receivers have sufficient sensitivity and gain to drive a loudspeaker and provide easy tuning and greater selectivity than trf receivers.

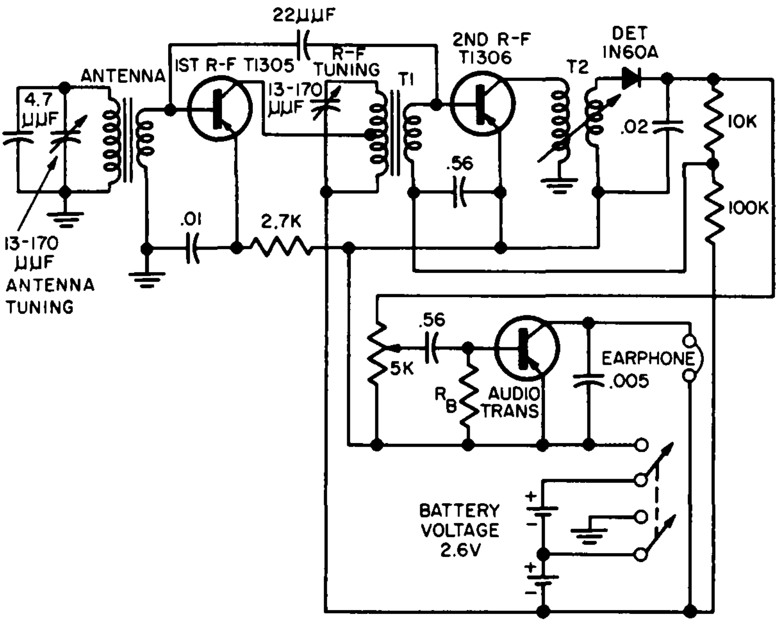


Fig. 8-2. Philco model T-3 three-transistor trf-type portable AM radio receiver.

A representative four-transistor receiver is shown in Fig. 8-3. Transistor Q1 operates as a converter, performing the functions of local oscillator and mixer of r-f antenna and oscillator signals. In addition, it provides some gain for the i-f signal. The antenna is a ferrite-core loop with a secondary winding to couple the r-f signal to the base of transistor Q1. The i-f signal is coupled to the base of the first i-f amplifier through T1.

Two stages of i-f amplification are provided by transistors Q2 and Q3. The stages are neutralized by networks C5-R8 and C10-R12. Transformers T1, T2, and T3 have tapped primaries to match the input and output impedances of the transistors and diode detector. The second i-f amplifier also serves as a reflexed audio amplifier. The audio signal developed across the detector load (R15) is fed back to the base of Q3 through C14. Resistor R13 acts as the audio load, with the signal coupled to the base of audio output amplifier transistor Q4, through C16. The agc voltage is fed to the base of the first i-f amplifier through filter network R5-C6. An overload diode, connected from the collector of Q2 to the collector of Q1, extends the agc control to prevent distortion on very strong signals.

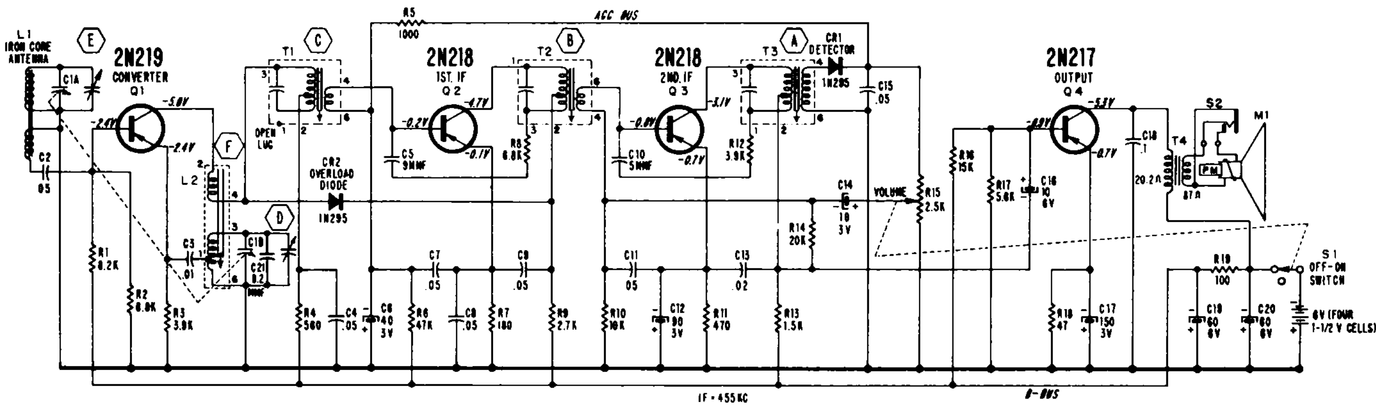


Fig. 8-3. Representative four-transistor superheterodyne AM portable radio receiver—Admiral 4P2 series. The second i-f amplifier is a reflexed circuit also acting as the audio driver stage.

Audio output transistor Q4 is operated class A and drives a 2¾-inch loudspeaker through a matching transformer (T4). An open-circuit receptacle is used for earphone listening. When the earphone jack is inserted into the receptacle, the loudspeaker is removed from the circuit, and the earphone is connected across the secondary of T4.

A five-transistor receiver is shown in Fig. 8-4. This receiver is similar to the four-transistor receiver. However, the diode detector and reflexed audio amplifier have been replaced by a power detector. This circuit detects the audio signal and provides the necessary audio gain to drive the audio output transistor.

PARTS LIST FOR TRAV-LER MODEL TR-250-A

PART NO.	SYMBOL	DESCRIPTION
CC-65	C-1	.02 MFD CERAMIC DISC
CC-64	C-2	.01 MFD " "
CC-64	C-3	.01 MFD " "
CC-66	C-4	.05 MFD " "
CC-63	C-5	.1 MFD " "
CC-64	C-6	.01 MFD " "
CC-82	C-7	33 MMFD±10% " "
CC-66	C-8	.05 MFD " "
CC-63	C-9	.1 MFD " "
CC-82	C-11	33 MMFD±10% CERAMIC DISC
EC-60	C-12	8 MFD 25V MINIATURE ELECTROLYTIC
CC-64	C-13	.01 MFD CERAMIC DISC
CC-66	C-14	.05 MFD " "
EC-60	C-15	8 MFD 25V MINIATURE ELECTROLYTIC
EC-62	C-16	50 MFD 3V MINIATURE ELECTROLYTIC
CC-65	C-17	.02 MFD CERAMIC DISC
EC-61	C-18	15 MFD 12V MINIATURE ELECTROLYTIC
LL-46	L-1	ANTENNA COIL
LO-25	L-2	OSCILLATOR COIL
IR-179	R-1	10KΩ±5% ¼W CARBON RESISTOR
IR-181	R-2	68KΩ±10% " " "
IR-175	R-3	2.2KΩ±10% " " "
IR-176	R-4	6.8KΩ±5% " " "
IR-179	R-5	10KΩ±5% " " "
IR-182	R-6	47KΩ±10% " " "
IR-175	R-7	2.2KΩ±10% " " "
IR-177	R-8	8.2KΩ±10% " " "
IR-179	R-10	10KΩ±5% ¼W CARBON RESISTOR
IR-178	R-11	39KΩ±10% " " "
IR-175	R-12	2.2KΩ±10% " " "
IR-174	R-13	1KΩ±5% " " "
IR-179	R-15	10KΩ±5% ¼W CARBON RESISTOR
IR-172	R-16	330Ω±10% " " "
IR-180	R-17	33KΩ±10% " " "
IR-170	R-18	10Ω±10% " " "
VC-88	R-19	5KΩ±30% VOLUME CONTROL
IR-174	R-20	1KΩ±5% ¼W CARBON RESISTOR
IR-174	R-21	1KΩ±5% " " "
IR-176	R-22	6.8KΩ±5% " " "
IR-171	R-23	180Ω±5% " " "
	SW-1	SWITCH ON VOLUME CONTROL D.P.S.T.
J-1	JK	EARPHONE JACK
SPK-52	S	P.M. SPEAKER
L1-17	T-1	1ST I.F. TRANSFORMER
L1-17	T-2	2ND " "
L1-18	T-3	3RD " "
AT-22	T-4	OUTPUT TRANSFORMER
SC-2	TR-1	2N136 CONVERTER TRANSISTOR
SC-3	TR-2	2N135 1ST I.F. AMP. TRANSISTOR
SC-3	TR-3	2N135 2ND " " "
SC-4	TR-4	4JD1A26 DET. A.V.C. AUDIO TRANSISTOR
SC-5	TR-5	2N187A POWER OUTPUT TRANSISTOR
GC-22	GC-1	ANTENNA SECTION GANG CONDENSER
	GC-2	OSCILLATOR SECTION GANG CONDENSER
BA-2	B	BATTERY-13½V EVEREADY 239
		BURGESS XX9 (OR EQUIVALENT)

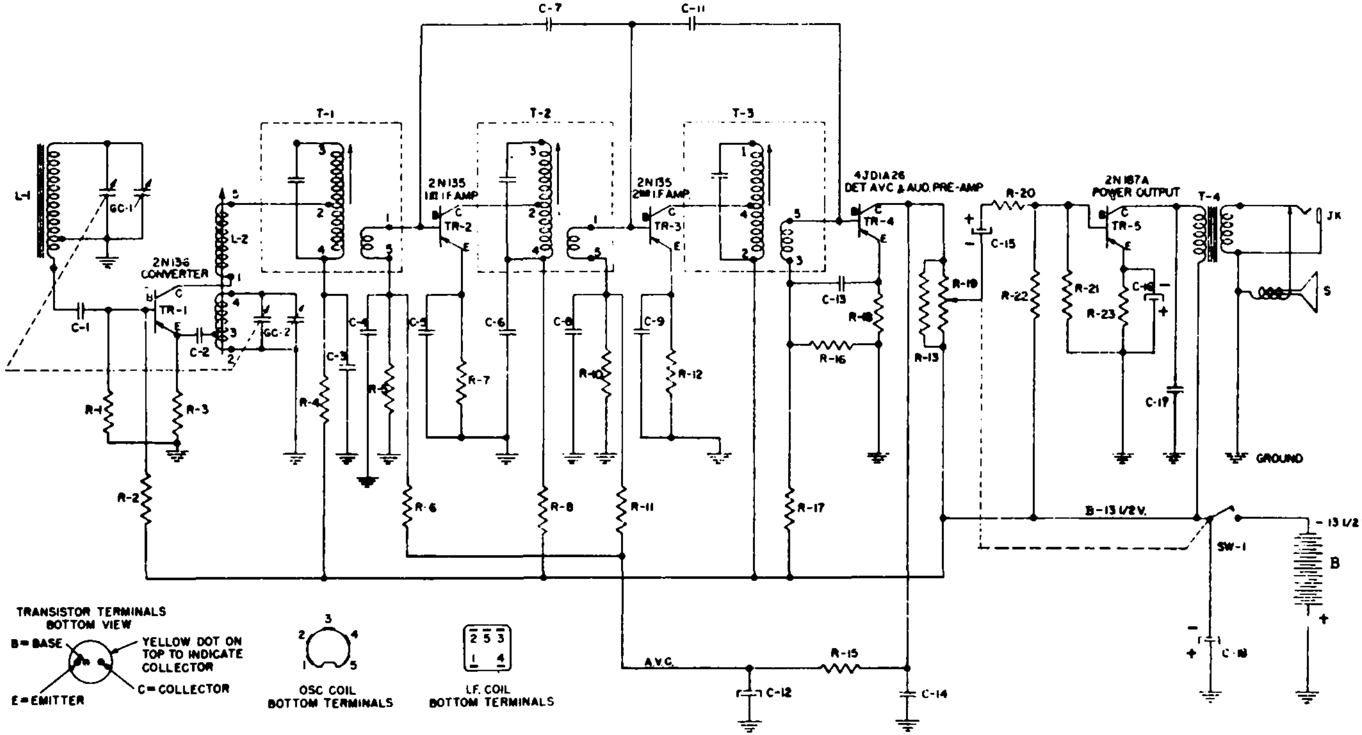


Fig. 8-4. Trav-ler model TR-250A five-transistor AM portable radio receiver. Note the use of a transistor in place of a diode as detector.

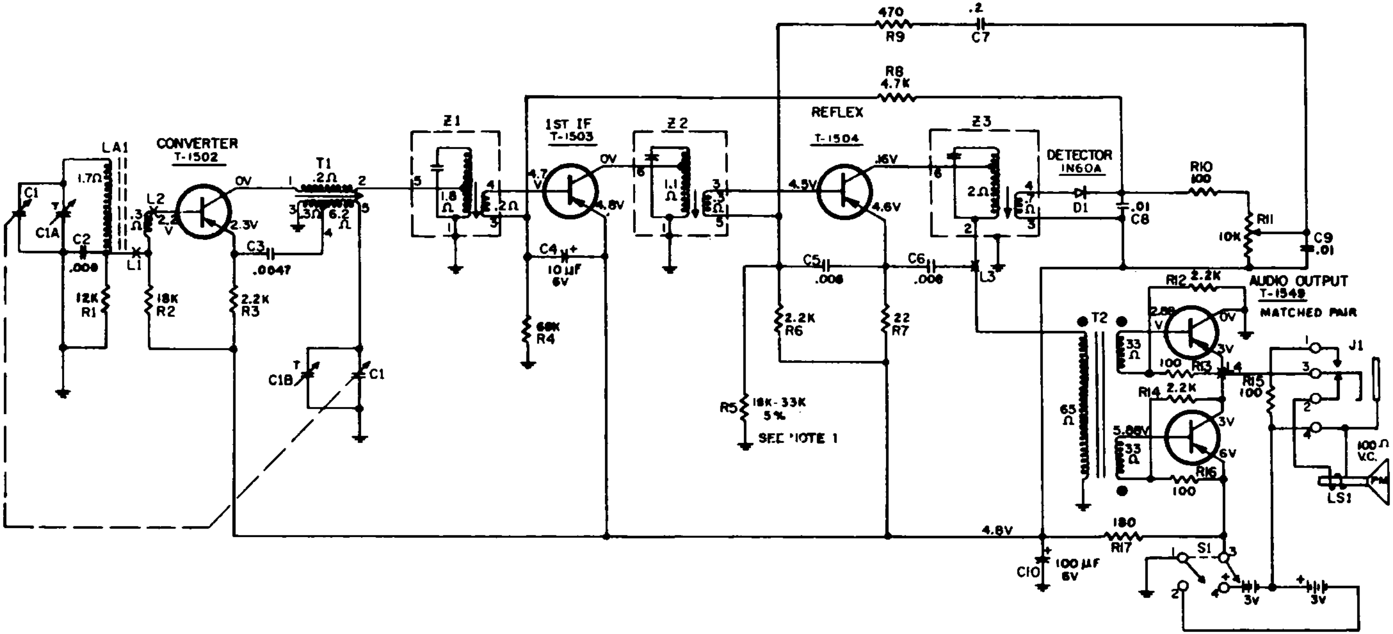


Fig. 8-5. Schematic diagram of the Philco model T-52.

Fig. 8-5 is a five-transistor receiver which makes use of a push-pull power output circuit. The stages of this receiver consist of a converter, one stage of i-f amplification, a reflex circuit, a detector, and the output stage.

The output portion of this superheterodyne receiver contains a matched pair of transistors. Transistor T-1504 is used as a reflex amplifier in that it provides both i-f amplification and audio amplification. After detection, the audio signal is returned to the base input of the reflex amplifier. The amplified audio signal appearing on the collector is then fed to the third i-f primary. The impedance of this winding, which is high with respect to the i-f signals, is negligible at audio frequencies. Therefore, the audio is passed to the primary of the output transformer T2.

When signal tracing this circuit, the signal must be injected at the transistor collector and the input limited to keep the signal across the speaker below 1.7 volts. The value of R5 is selected to allow the reflex transistor (the second i-f) collector to draw 2 ma. This can be checked by measuring the voltage drop across the primary of T2. Dividing this voltage by the primary resistance of T2 gives the collector current. The value of R5 falls within the limits of 18,000 to 33.000 ohms, 5%.

SIX-, SEVEN-, AND EIGHT-TRANSISTOR RECEIVERS

The six-transistor receiver generally introduces the use of class-B push-pull output circuitry to drive the loudspeaker. This offers the well-known advantages of increased power output (increased volume), less distortion, lower power consumption, and longer battery life. The seven-transistor receiver introduces the added refinement of either an r-f amplifier or separate oscillator-mixer circuitry. This results in improved sensitivity and selectivity for the received signal. The eight-transistor receiver usually incorporates both the r-f amplifier and separate oscillator-mixer circuit.

A typical six-transistor receiver is shown in Fig. 8-6. The circuitry of this receiver is similar to the preceding five-transistor radio, up through the detector circuit. However, from this point on, significant differences become apparent. A separate audio driver is employed to first amplify the audio signal. Transformer coupling is used between the driver and output circuits. This provides impedance matching and phase reversal of the signal to the push-pull output transistors. A 300-ohm loudspeaker having a centertapped winding is used, thereby eliminating the need for an output transformer (which would ordinarily be required for impedance matching). The transistors are a matched pair so that conduction on each half-cycle is equal and balanced. An earphone jack is located

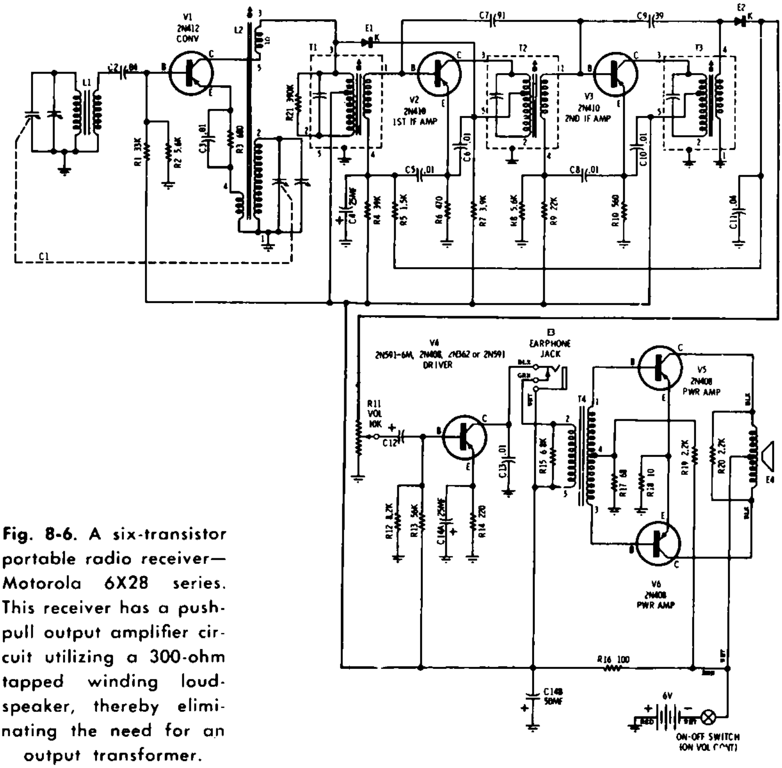


Fig. 8-6. A six-transistor portable radio receiver—Motorola 6X28 series. This receiver has a push-pull output amplifier circuit utilizing a 300-ohm tapped winding loudspeaker, thereby eliminating the need for an output transformer.

in the collector circuit of the audio driver stage. When the earphone jack is used, no signal is fed to the output circuit. Hence, the output transistors do not conduct, reducing the power consumption further.

Power consumption of receivers employing push-pull output circuits is generally lower than receivers employing single-ended class-A circuits. This is because, in the push-pull circuit, the transistors are held at cutoff (or at a point close to cutoff) when no signal is being received. Since no signal is being received over a good part of any program material, the idling current is lower, extending the battery's useful life.

Figure 8-7 illustrates a seven-transistor radio receiver. The basic difference between this and the foregoing unit is the incorporation of separate mixer and oscillator circuits. This makes it possible to also agc-control the mixer stage, in addition to the first i-f amplifier,

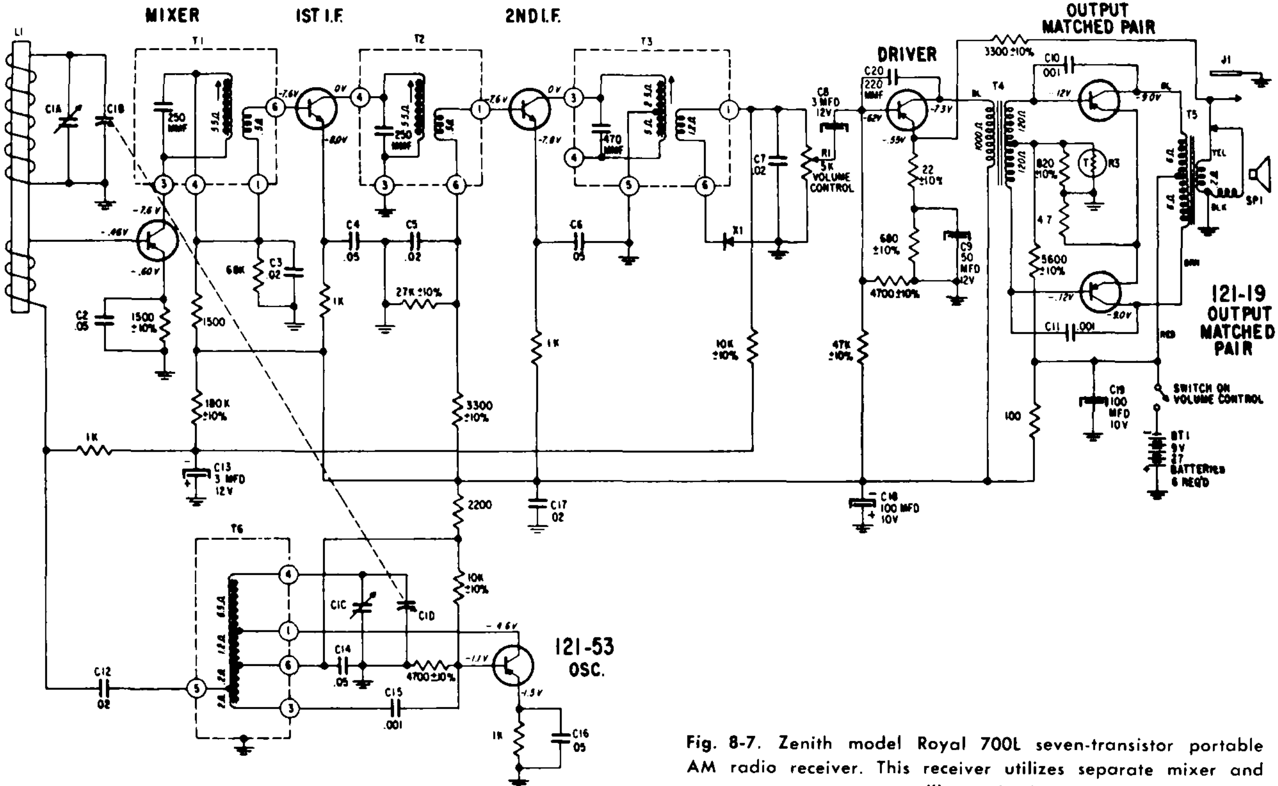


Fig. 8-7. Zenith model Royal 700L seven-transistor portable AM radio receiver. This receiver utilizes separate mixer and oscillator circuits.

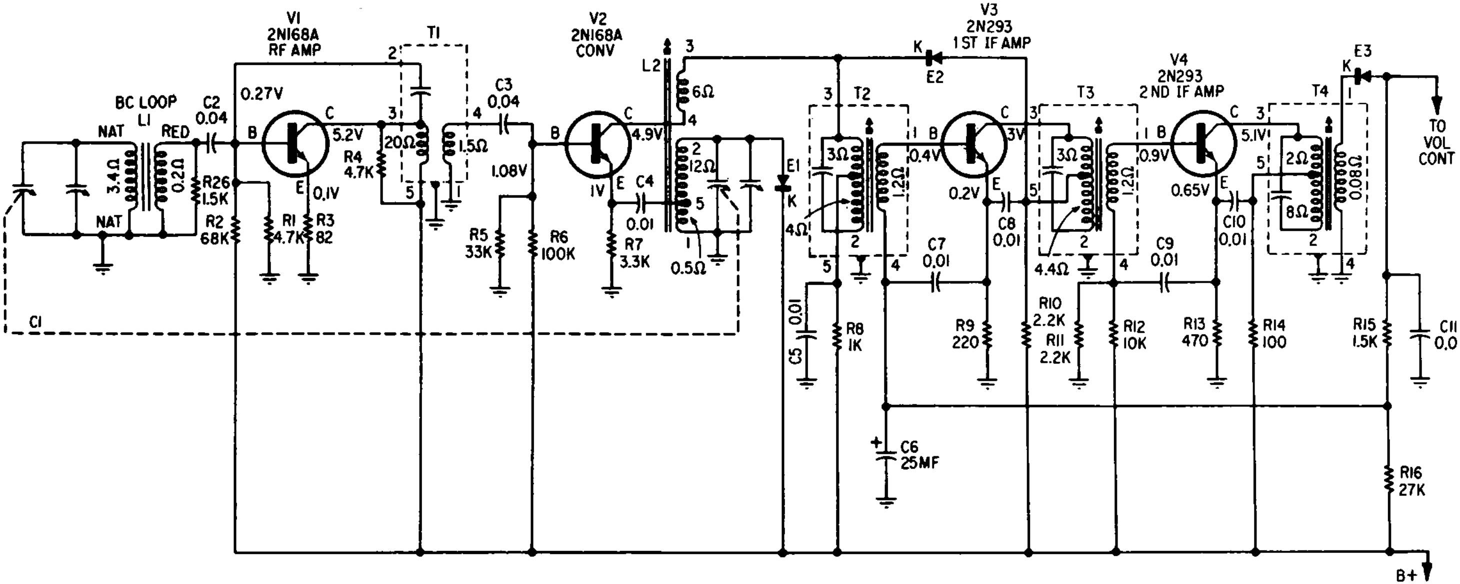


Fig. 8-8. Seven-transistor radio receiver using an r-f amplifier —Motorola 7X28 series.

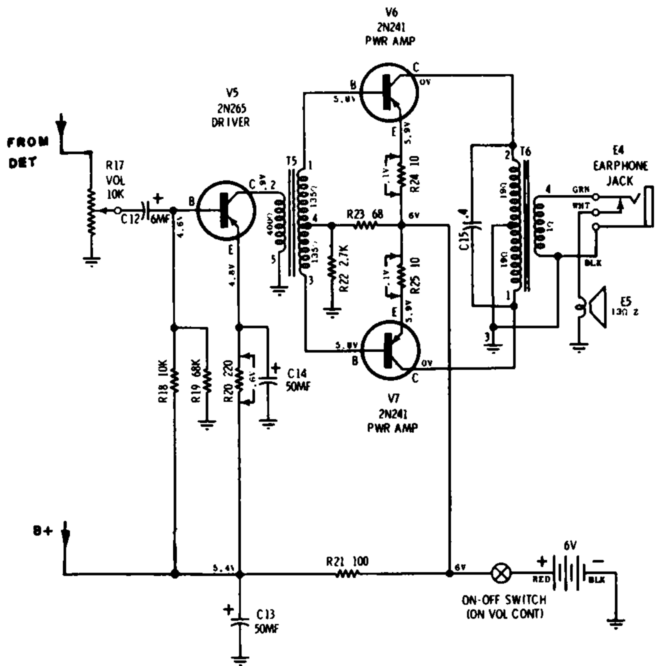


Fig. 8-8. Seven-transistor radio receiver using an r-f amplifier —Motorola 7X28 series.

thereby extending the agc range from very weak to very strong signals. The separate oscillator circuit permits the oscillator to develop a more uniform output across the entire band, and thereby provide uniform sensitivity at both high and low ends of the band. This arrangement also provides better sensitivity at the high end of the band than is normally available using a converter type of circuit.

A seven-transistor radio receiver employing an r-f amplifier is shown in Fig. 8-8. This circuit provides additional gain at radio frequencies, thereby increasing the receiver's sensitivity. Transformer T1 couples the output signal of the r-f amplifier to the base of the converter transistor. This transformer is a broadband type, fixed-tuned to cover the entire AM band. Resistor R4 shunts the transformer's primary, lowering its Q and thereby giving it a broadband characteristic. In some receivers, the primary of this transformer is tuned by an added section of the tuning capacitor to the incoming radio frequency. This arrangement provides an additional increase in sensitivity and selectivity.

INTEGRATED-CIRCUIT RECEIVERS

As a sign of things to come, the General Electric Co. recently introduced its model C2450 AM receiver, in which one integrated circuit contains all the transistors used in the receiver. The receiver schematic diagram is shown in Fig. 8-9, and the printed circuit and components layout is shown in Fig. 8-10.

The receiver is a basic six-transistor receiver. Transistor TR7, labeled "driver," is really connected as a forward-biased diode to provide a stabilized bias for the push-pull output amplifier. As a further cost reduction, a high-impedance center-tapped loudspeaker is employed as the load for the audio-power transistors, thus eliminating the need for an impedance-matching output transformer.

The receiver, which is portable, contains a 3.7-volt chargeable nickel-cadmium battery. The receiver can be plugged into a clock-charger unit (lower left of schematic). The charger is a low-voltage d-c power source that will charge the battery to full capacity in approximately 8 hours.

The integrated circuit (IC-1) contains 15 pins. Since the IC contains only transistors (no resistors or capacitors), conventional troubleshooting procedures can be employed. If one transistor is defective, it can be disconnected by opening the appropriate IC terminals and a discrete transistor substituted in its place. Any standard npn replacement transistor should work satisfactorily and thus prevent the need for replacing the whole circuit if only one of the IC transistors is defective.

IMPORTED TRANSISTOR RADIOS

Transistor radios manufactured in other countries are being sold in very large numbers in the United States. Japan is the largest exporter of these receivers to this country. These radios are comparable, in most respects, to their American counterparts. Their construction, design, and performance matches that of the units manufactured in the United States.

Generally, Japanese transistor radios are smaller in size than American radios. This is accomplished through the use of miniaturized components. One such radio is shown in Fig. 8-11. The radio contains many components which are somewhat smaller than those used in American radios. For example, the radio has a 1¾-inch speaker (compared to 2¼-inch American counterparts). In addition, the receiver employs an extremely compact tuning capacitor housed in its own plastic case. The tuning capacitor's

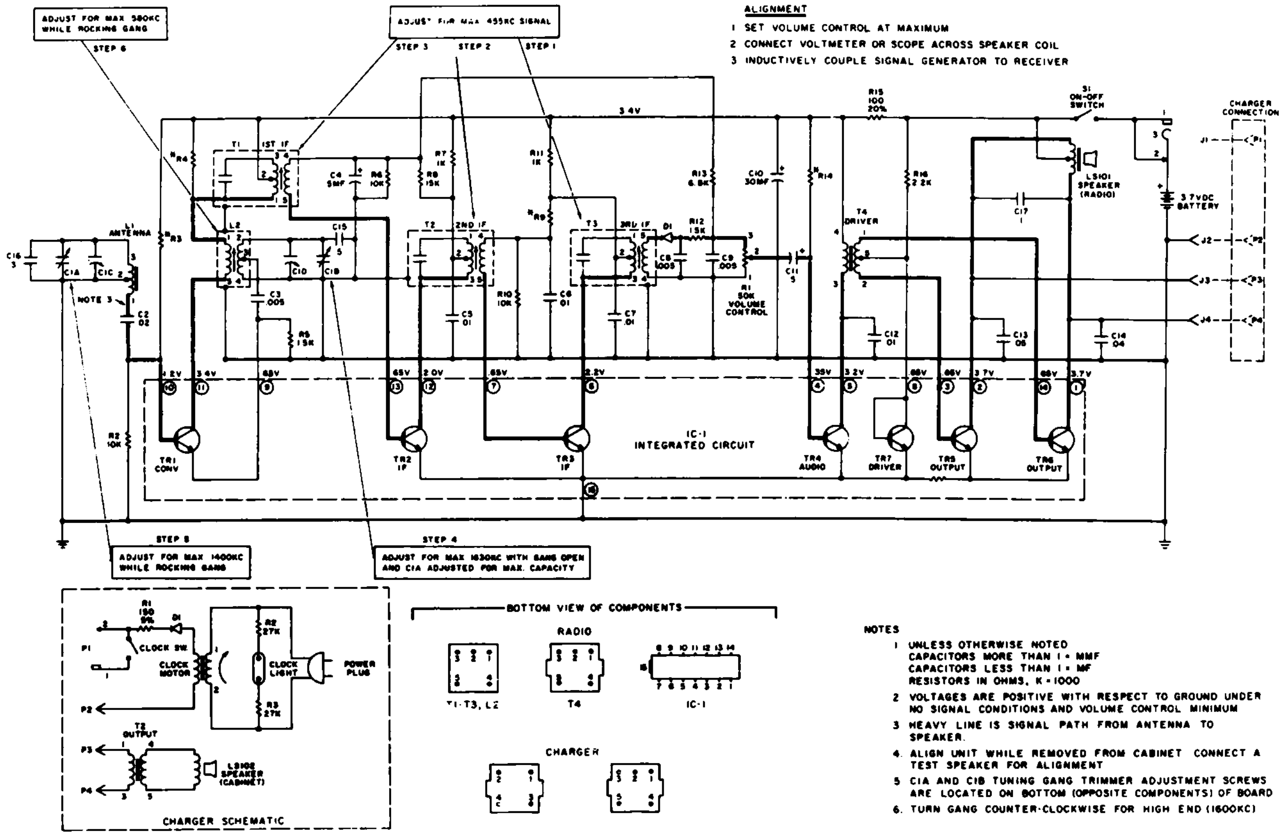


Fig. 8-9. GE model C2450 integrated circuit receiver, with all transistors in one integrated circuit, IC-1.

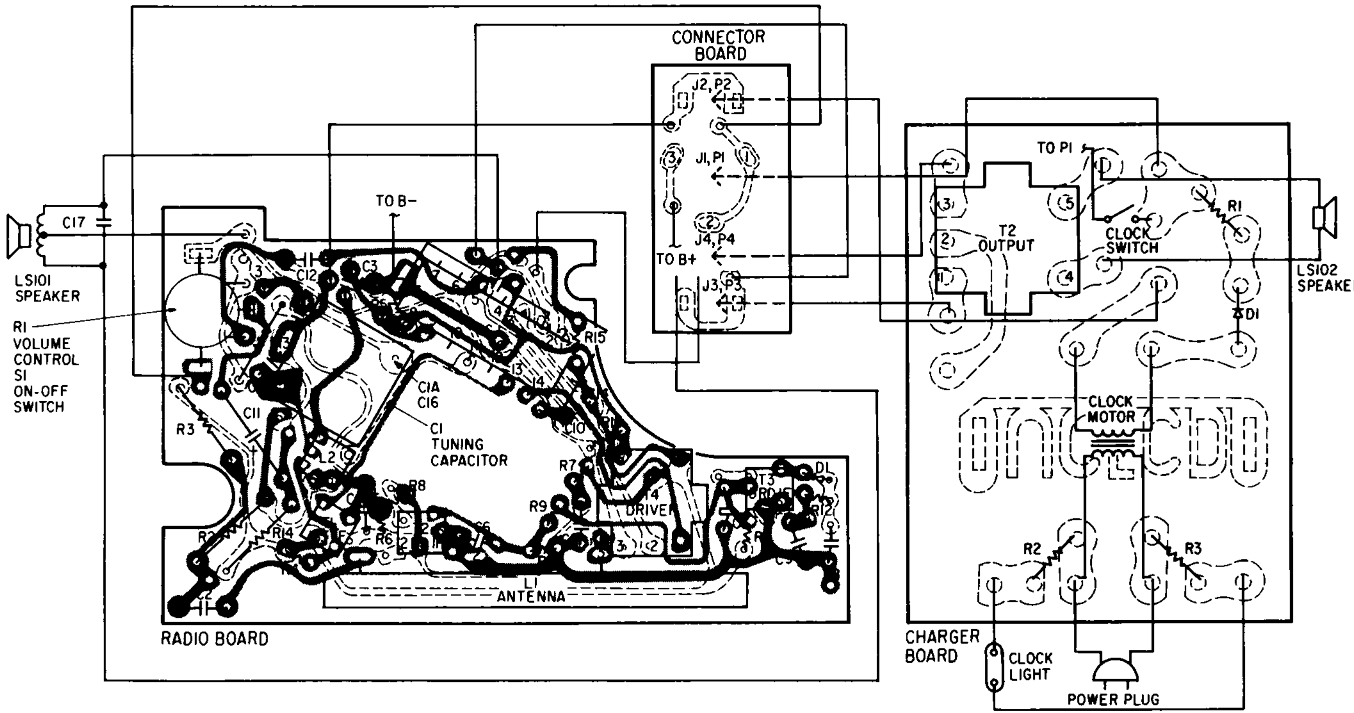


Fig. 8-10. Printed circuit and component layout for GE C2450 integrated circuit receiver.

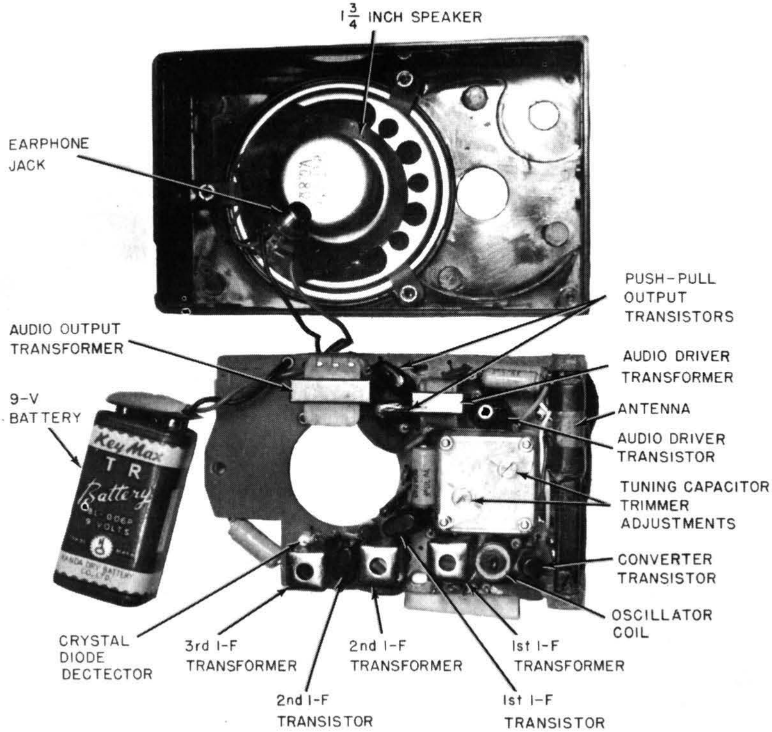


Fig. 8-11. A typical six-transistor Japanese radio chassis removed from its case.

trimmer adjustments are readily available at the top of the capacitor's case, making it possible to align the receiver completely without removing the chassis from the case. The ferrite loop stick type antenna is also of more compact construction, having a smaller ferrite core and more compactly wound winding. The volume control, not visible in the photograph, is miniature in size and held in a plastic housing with the inside exposed. The remaining components are of comparable size and construction to those used in American radios.

The circuitry of a typical Japanese transistor radio is illustrated in Fig. 8-12. This receiver is a six-transistor unit with circuitry similar to an American six-transistor radio. A single transistor converter stage is employed as a front end.

The value of R2 is selected to compensate for variations in transistor characteristics, and therefore may differ from set to set. The value of this resistor determines the base bias and gain of the

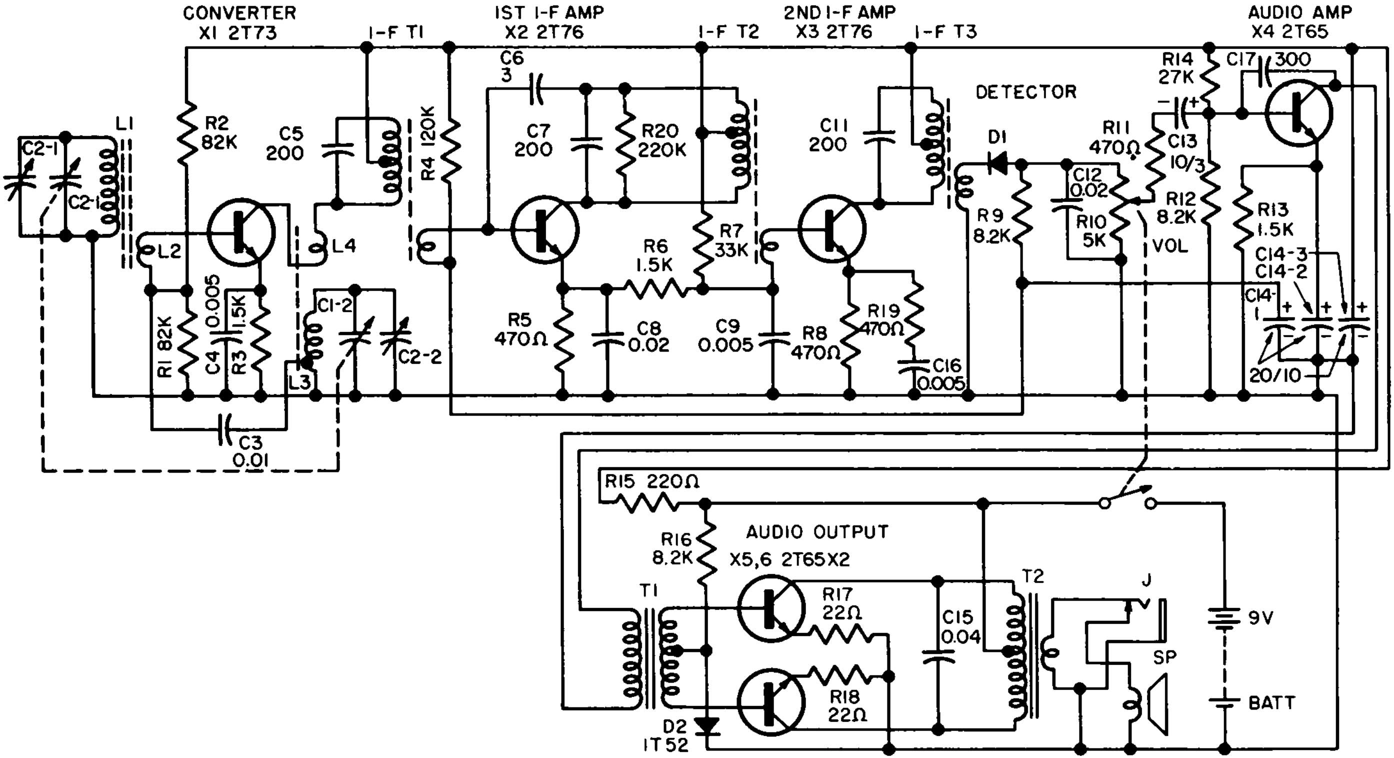


Fig. 8-12. Sony model TR-610 six-transistor portable radio receiver.

transistor. The bias must be set so as to provide sufficient oscillator feedback gain to sustain oscillations throughout the broadcast band. Oscillation is sustained by feedback from a tap on the secondary of the oscillator coil (necessary to match the input impedance of the transistor) through C3 to the base of the converter transistor.

The i-f transformers employ tapped primaries for proper impedance matching and maximum transfer of signal. The first i-f transistor is neutralized by capacitor C6. Resistor R20 is inserted, when necessary, to reduce the gain of the stage to prevent regeneration in the i-f system. A diode detector circuit recovers the audio modulation signal. The audio signal is filtered by R9-C14 and used as an agc-control voltage for the first i-f amplifier.

Transformer coupling is employed between the audio driver and push-pull output circuit for impedance matching and to provide out-of-phase signals for push-pull operation. Diode D2 is a varistor to control the gain of the output circuit. An 8-ohm, 2¼-inch speaker is used as the sound reproducer. An open-circuiting jack is used to provide the earphone facility.

Repairing Japanese Transistor Radios. The Japanese transistor radio presents two problems to the American service man: obtaining replacement parts and obtaining service information. The major components (e.g., tuning capacitor, ferrite antenna, volume control, etc.) are nonstandard as far as American parts distributors are concerned. In some instances, the retailer (in the cases of parts jobbers and mail-order houses) can supply the information and replacement parts. However, in most cases, it will be necessary to contact the radio distributor or importer. When requesting parts from these sources, always give the model number of the radio, a chassis number (if it can be found), a description of the part needed, and any numbers found on the component part being replaced. All this information will ensure that you will receive just what you need as quickly as possible.

The transistors used in the imported Japanese transistor radios are different from American-made transistors. However, many of these transistors are interchangeable with American units. The distributor or importer can usually supply information on transistor interchangeability.

Since Japanese transistor radios are virtually identical to American receivers, the servicing procedures recommended in the earlier chapters of the book would be followed when servicing these units.

MULTIBAND RADIO RECEIVERS

The advent of the completely transistorized multiband receiver just a short while ago completely ended the vacuum tube's use in portable AM receivers. Moreover, it highlights the increasing use of transistors in high-frequency applications and foretells what is to come.

Over a half-dozen radio makers, including foreign sources, are currently manufacturing multiband radio receivers. Most of these radios can receive stations up through the 13-meter (up to 22 mc) shortwave broadcast band. Moreover, they offer excellent sensitivity and selectivity. The use of transistors and their associated miniaturized components has greatly reduced the weight and size of the receivers. In addition, most of the transistorized receivers employ standard flashlight cells that are considerably smaller and less expensive than the vacuum tube receiver batteries, and are available anywhere flashlights are sold.

Many of the multiband receivers are equipped with telescoping whip-type antennas for shortwave reception, earphone jacks, momentary dial-light, bandspread tuning, and provisions for connection of a phonograph (using high-level cartridge).

Most of the multiband receivers have a tuner-like front end, separate from the receiver chassis, and incorporate an r-f amplifier, mixer, and oscillator. Special high-frequency transistors are used. These transistors are specifically designed for use as r-f amplifier, oscillator, and mixer, at frequencies up to 23 mc. They employ shielding between adjacent leads to minimize stray capacitance and coupling between leads. This shield consists of a fourth lead connected to the transistor case and situated between base and collector leads. Therefore, care should be used during servicing so that the case of these transistors does not touch any adjacent circuitry.

A typical multiband receiver is shown schematically in Fig. 8-13. This is an eight-transistor receiver providing reception in four bands, from 200 kc to 20 mc. The respective bands cover the following approximate frequency ranges: 200–400 kc, 550 kc–1.6 mc, 2–6 mc, and 6.5–19.5 mc. The i-f amplifiers, detector, and audio amplifier stages are basically the same as the circuits used in the single-band receivers discussed earlier. The receiver's front end, however, illustrates the different design approach required for high-frequency reception.

A simplified schematic diagram of the receiver's front end (switches and all circuits not functioning have been omitted) in the long-wave position (200-400 kc) is shown in Fig. 8-14. The ferrite-core-type antenna serves as a signal pickup loop with the r-f signal being tuned (selected) by the tuned circuit composed of L102-C105-C102. The r-f signal is fed from a low-impedance tap on L102, through C106, to the base of the r-f amplifier transistor. Coil L102 functions as an autotransformer, providing an impedance

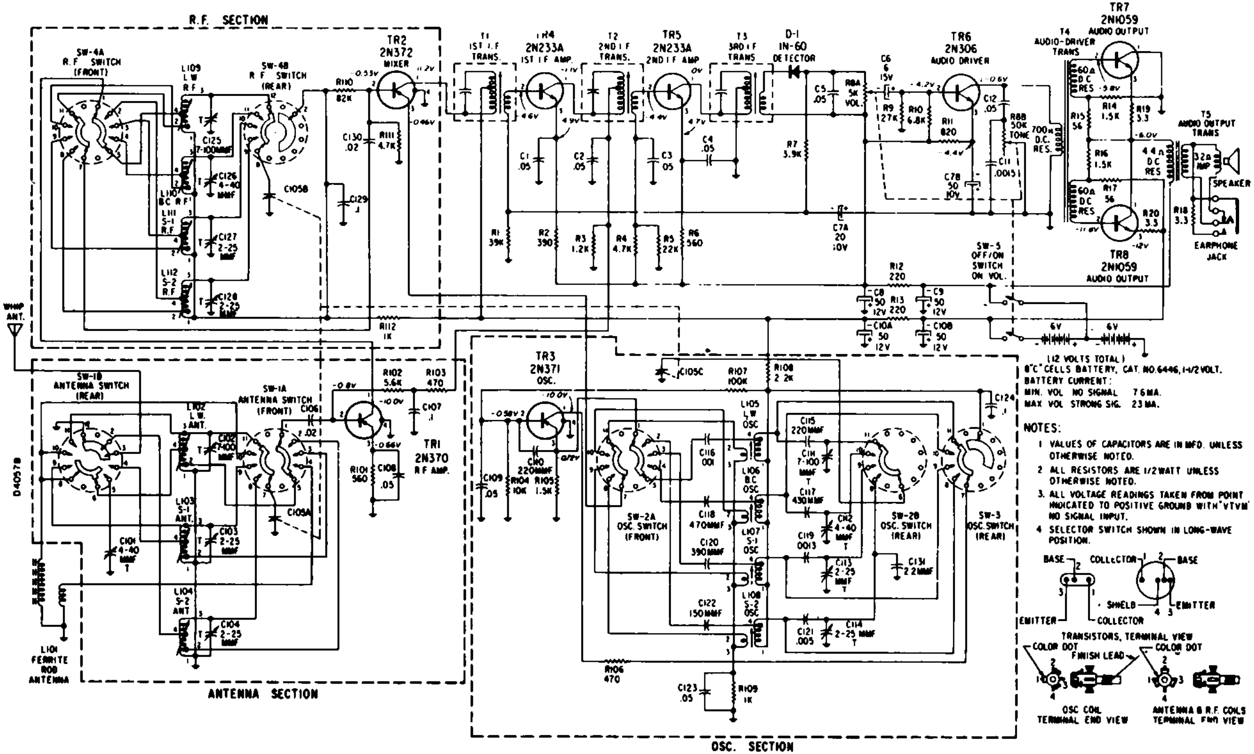


Fig. 8-13. Sears Roebuck model 222 multiband AM radio receiver.

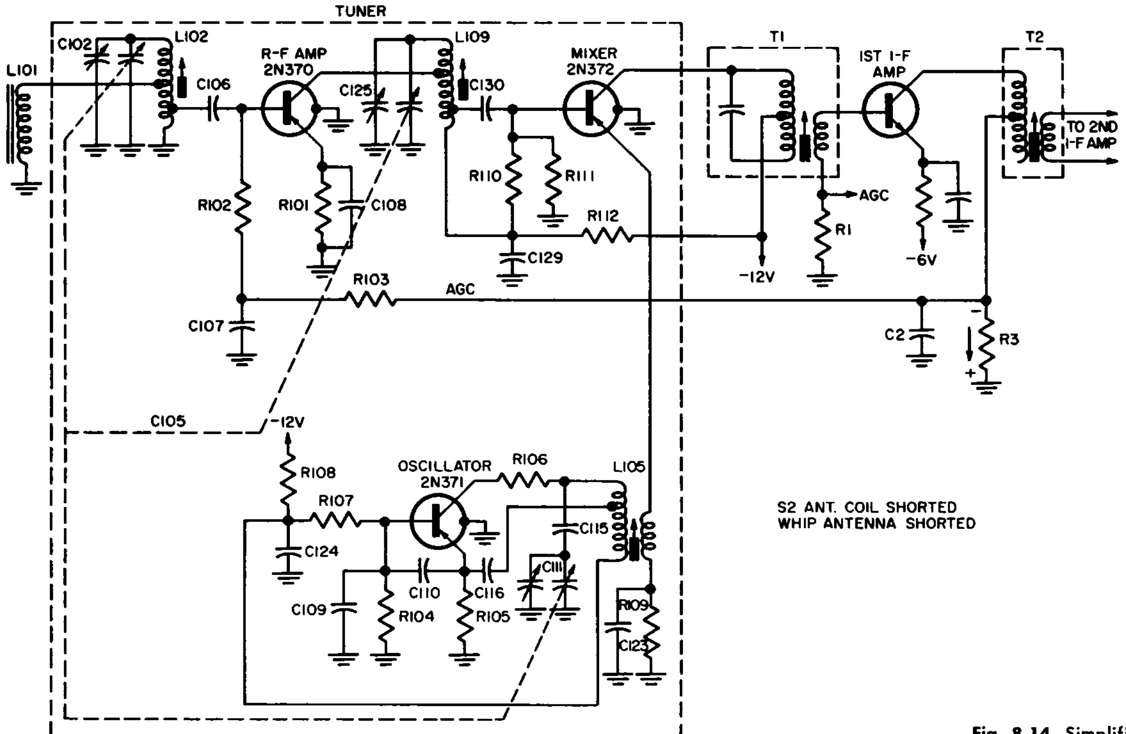


Fig. 8-14. Simplified schematic of Sears Roebuck model 222 front end in long-wave mode of operation.

match between the r-f tuned circuit and the input impedance of the transistor.

The gain of the r-f amplifier is controlled by the agc-control voltage. This can be seen by examining the operation of the first i-f amplifier. The agc-control voltage is present on the base of this transistor. As the agc voltage increases (becomes more negative as a result of higher detector output) the transistor is biased in a less forward direction. The emitter-to-collector current of the first i-f amplifier transistor decreases as the agc voltage increases. This current flows from emitter to collector, through the primary of T2, through R3, to ground (positive side of battery). The voltage drop across R3 thus becomes more negative as the agc control voltage increases. This negative voltage is impressed on the base of the r-f amplifier transistor through the network composed of R102-C107-R103-C2 (filter networks). Thus, the r-f amplifier's gain is reduced to compensate for increases in incoming signal level.

The amplified r-f signal is coupled to the base of the mixer through the autotransformer action of L109. The mixer is operated close to zero bias to ensure proper conversion through rectification and amplification. The oscillator signal is injected into the emitter through a small winding on the oscillator coil.

The oscillator is a form of the Hartley circuit with feedback from collector to emitter to sustain oscillations. The circuit is stabilized by the fixed base-bias network composed of R108-R107-R104, and emitter resistor R105.

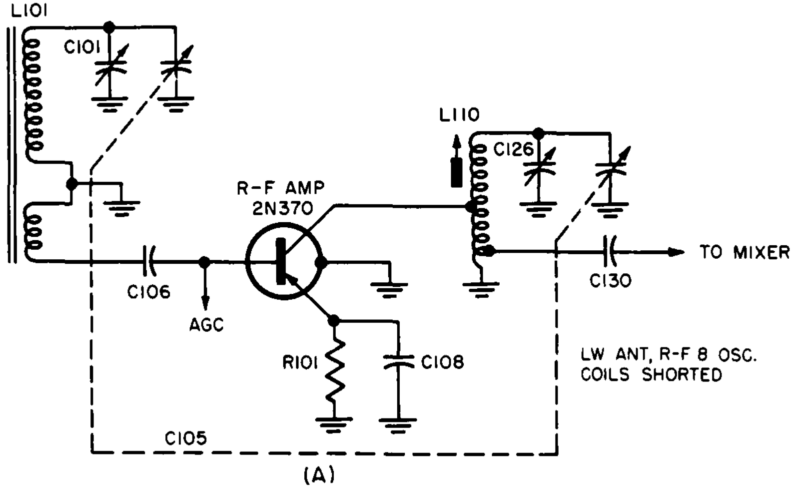
When the broadcast band (BC) is selected, the mixer and oscillator circuits operate in the same manner as in the long-wave (LW) band. However, the r-f amplifier circuit is now as shown in Fig. 8-15(A). The ferrite-core-type antenna is now tuned to the desired frequency by C105 and C101. The selected r-f signal is then fed to the base of the transistor through an added winding on the antenna rod.

When the shortwave bands are selected (S1 and S2 positions) the r-f amplifier is as shown in Fig. 8-15(B). The ferrite-core antenna is not used. Instead, the telescoping whip antenna is coupled to the base of the r-f amplifier transformer through the autotransformer action of L103.

The action of the band-selector switches is such that sections SW1B, SW4B, and SW3 short and ground the unused coils as the selector switch is switched to progressively higher bands.

FM TRANSISTOR RADIOS

Nearly all FM receivers are combined with an AM receiver to form an AM-FM receiver. A table model AM-FM receiver is shown



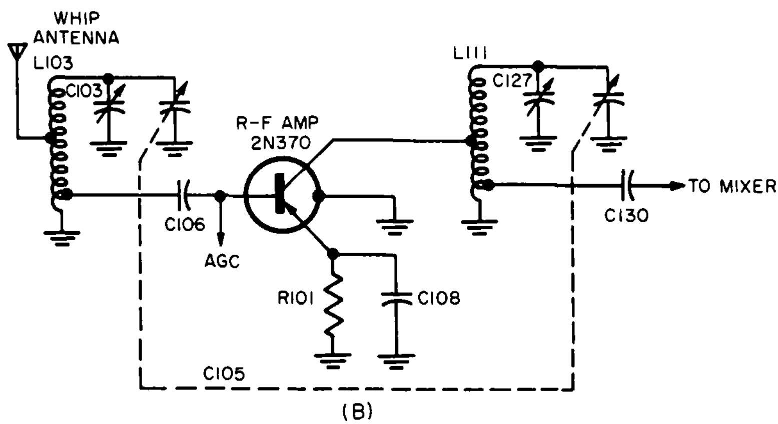


Fig. 8-15. Simplified schematic of Sears Roebuck model 222. (A) R-F amplifier circuit in BC position. (B) R-F amplifier circuit in S1 position (S2 is the same with the exception of tuned circuit changes).

in Fig. 8-16. This unit operates from the 120-volt a-c power line through a-c power plug P501. The a-c voltage is rectified by CR501 and filtered by C502 and R502. Resistor R501 serves as both a current-limiting resistor and fuse. Should a short circuit develop in the receiver, this resistor should burn out to protect the other components in the receiver. When repairing a receiver of this type that is completely "dead," check the fusible resistor first.

Transistor Q1 is the FM-RF amplifier. It has an untuned input that can be connected to an external antenna (terminals F and G)

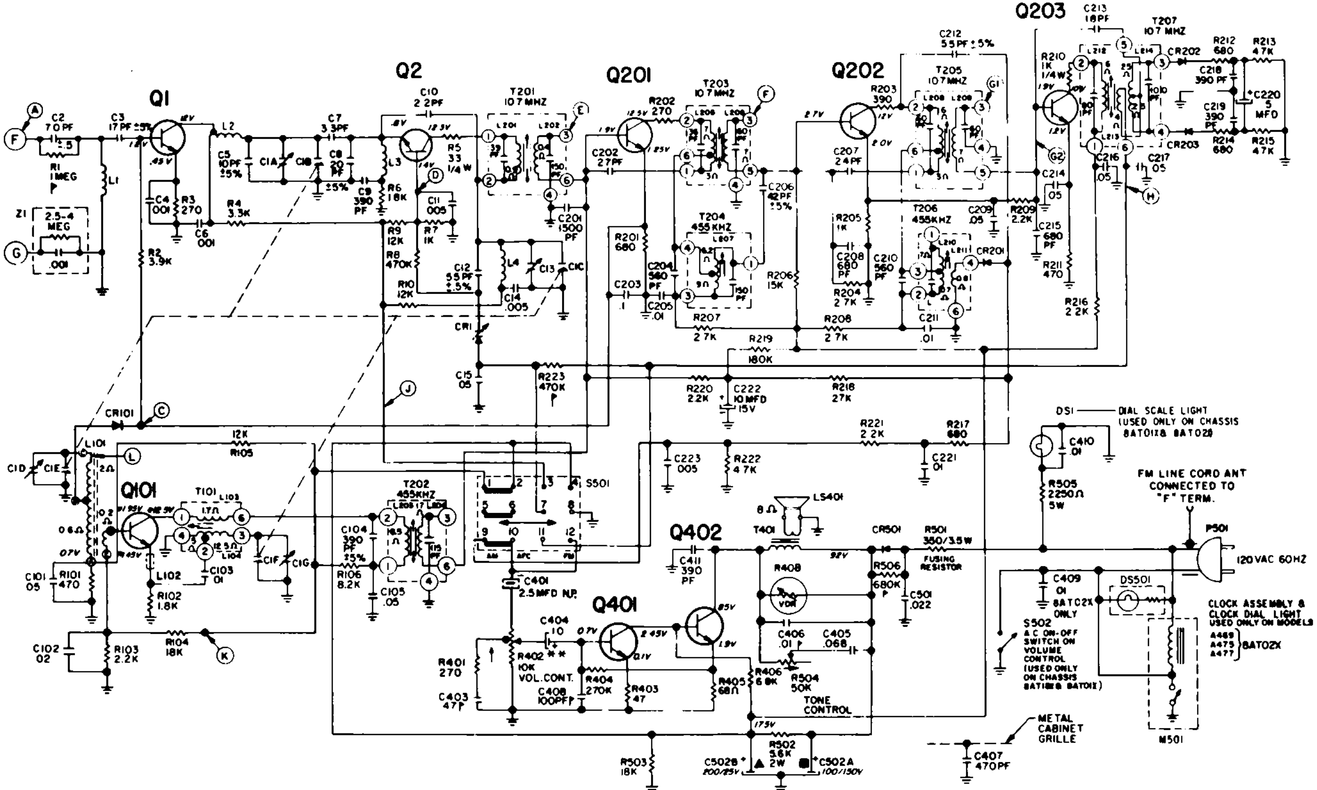


Fig. 8-16. Zenith model A418 AM-FM radio.

or to the a-c power line via capacitive coupling in the a-c power cord (notice the "FM Line Cord Ant." that is part of the a-c plug P501). The output of the RF amplifier is fed to the FM converter (Q2) through a tuned circuit (La, C5, C1, C8). The oscillator tank for the converter (L4, C13, C14, C1C, C12) is shunted by a varactor diode (CR1) to provide AFC. The output of the converter is fed to the IF amplifier (Q201) through a tuned transformer (T201). Three stages of FM-IF amplification are used (Q201, Q202, Q203). FM demodulation is accomplished by a ratio-detector circuit (CR202, CR203).

The AM receiver section consists of a converter (Q101) whose output is transformer-coupled to two stages of IF amplification (Q201, Q202). CR201 is the AM detector with AGC voltage being fed back to Q201 and Q202 through resistors R218, R219, R220, and R206. Capacitor C222 filters the AGC line.

Either the AM or FM signal is selected by switch S501 and fed to the audio amplifier. Switch S501 also provides power to either the FM-RF amplifier and converter or the AM-converter, depending on the position the switch is in. The center section of the switch controls the FM-AFC. When the switch is in the right-hand position, the input to the varactor diode (CR1) is grounded, turning off the AFC. When the switch is in the center position, the ground is removed, thereby feeding the control voltage to the diode and providing AFC.

The audio-amplifier section consists of a driver amplifier (Q401) whose collector current is also the base-to-emitter current for the power amplifier (Q402). The power amplifier is a single-ended class A amplifier.

9. *Automobile Transistor Radios*

The advent of the 12-volt, negative-ground electrical system in automobiles and the introduction of power transistors led to the development of, first, the hybrid radio (vacuum tube and transistor) and then the all-transistor auto radio. Today, all auto radios sold are of the all-transistor type, although the hybrid type may be encountered in older automobiles.

ALL-TRANSISTOR RADIOS

All-transistor auto radios are basically the same as their portable radio brothers, but there are several differences. The auto radio requires a substantially higher audio-power output to overcome the high ambient noise level in the automobile. Further, auto receivers employ less efficient rod antennas, mounted on the outside of the auto, and therefore include an r-f amplifier to improve signal sensitivity and provide greater signal-to-noise characteristics. Furthermore, auto radios often have additional features such as push-button tuning, tone control, and front and rear speakers.

AUDIO-POWER OUTPUT STAGE

The audio-power output stage usually develops from 2 to 6 watts of audio power. The stage may be either single or double-ended. A typical circuit is shown in Fig. 9-1. This is a single-ended class A power amplifier developing approximately 3 watts of audio power. Transformer T2 is an autotransformer tapped to provide the necessary impedance match for the speaker. Resistors R1, R2, R3, and R4 form a voltage divider to provide the necessary forward bias for the power transistor. Resistor R1 is a positive-temperature-coefficient resistor whose resistance increases as temperature increases, thereby reducing excessive forward bias of the transistor and preventing overload and thermal runaway. Additional protection is provided by fusible-resistor R4, which will open if the collector current is excessive.

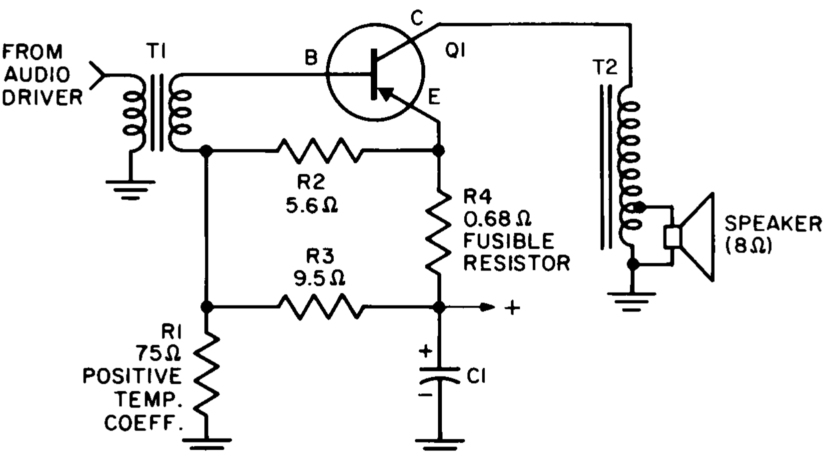


Fig. 9-1. Typical single-ended audio-power output stage for auto radios.

The circuit shown in Fig. 9-2 is that of a push-pull (double-ended) power amplifier. L5 is a center-tapped audio choke that gives high impedance at audio frequencies at the collector terminals of the output stage. The speaker, provided with a 40-ohm voice coil, is connected directly across the choke, which matches the relatively low impedance of the transistor to the speaker without the need of an output matching transformer. D-C current in the speaker does not exceed 0.2 ma because of the relationship between the static resistance of the choke (3 ohms) and the speaker (40 ohms). Under static d-c bias conditions, both collectors are at essentially the same positive voltage, resulting in a near-zero voltage drop across the speaker.

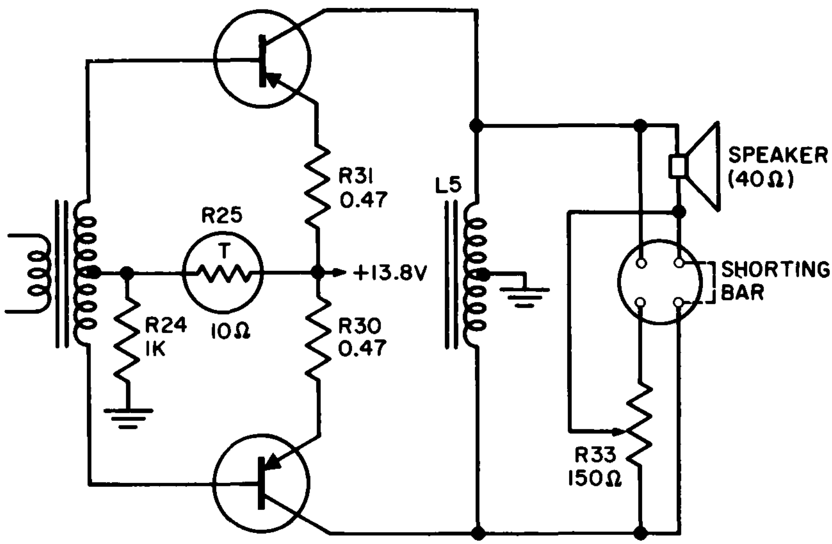


Fig. 9-2. Typical push-pull audio-output stage for auto radios (Motorola type CTA63).

The transistors in Fig. 9-2 are operated class AB with bias established by R24 and R25. Stabilization and temperature compensation are achieved by the use of unbypassed emitter resistors, R30, R31, and PTC (positive-temperature-compensated) resistor R25.

Control R33 is a rear-seat-speaker fader control. When only one speaker is used, a shorting bar bypasses this control. When a second speaker is connected to the radio, the control divides the output signal between the two speakers.

R-F AMPLIFIER STAGE

All auto receivers employ an r-f amplifier to improve sensitivity and selectivity. A typical circuit is shown in Fig. 9-3. The receiver uses a unipole-type antenna mounted on the outside of the automobile. The capacity of the antenna, together with L1, forms a resonant tuned circuit. Capacitor C2 is adjusted to compensate for too much antenna capacitance. C2 is adjusted only once, when the receiver is installed; called the "antenna trimmer," it is usually located adjacent to the antenna receptacle. The receiver is then tuned to a weak station at the high end of the band, and C2 is adjusted for maximum signal output.

The r-f signal is coupled by C3 to a second tuned circuit (C1, L2), which transformer-couples incoming r-f signals to the base of

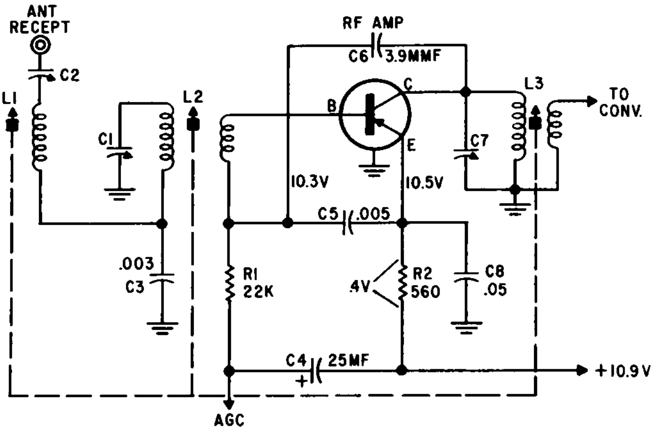


Fig. 9-3. Typical circuit for r-f amplifier.

the r-f amplifier transistor. The transistor operates with a tuned load composed of C7-L3.

With no signal, the transistor has a high forward bias for full-gain operation. When a strong station is received, the AGC voltage reduces the forward bias of the transistor, reducing the gain accordingly. C4 filters the audio signal from the AGC line. If C4 were to open, it would cause audio distortion on strong signals. In some cases, it may cause the receiver to block on strong signals.

TYPICAL AUTOMOBILE RECEIVER

A typical automobile AM-FM receiver—the Motorola Model FM-108M—is shown in Fig. 9-4. This receiver operates directly from the auto's battery. The power lead is protected by a 5-amp fuse. A low-pass filter (L15-C76) prevents engine noise and other auto-generated noise from entering the receiver through the power line. E6, a transistor used as a diode, is reverse biased and acts like a zener diode to regulate the voltage fed to either the AM-r-f converter and i-f amplifier stages or the FM-r-f oscillator and mixer stages.

The FM section includes an r-f amplifier, separate oscillator and mixer, four i-f amplifier stages, and a detector. Automatic frequency control of the oscillator circuit is provided by diode E1. This is a varactor-type diode whose junction capacitance can be changed by varying the reverse current through the diode. The capacitance of the diode is effectively across the oscillator tank circuit through C25 and C26. If the oscillator frequency shifts above the carrier resting frequency, the FM detector output becomes more positive, thus

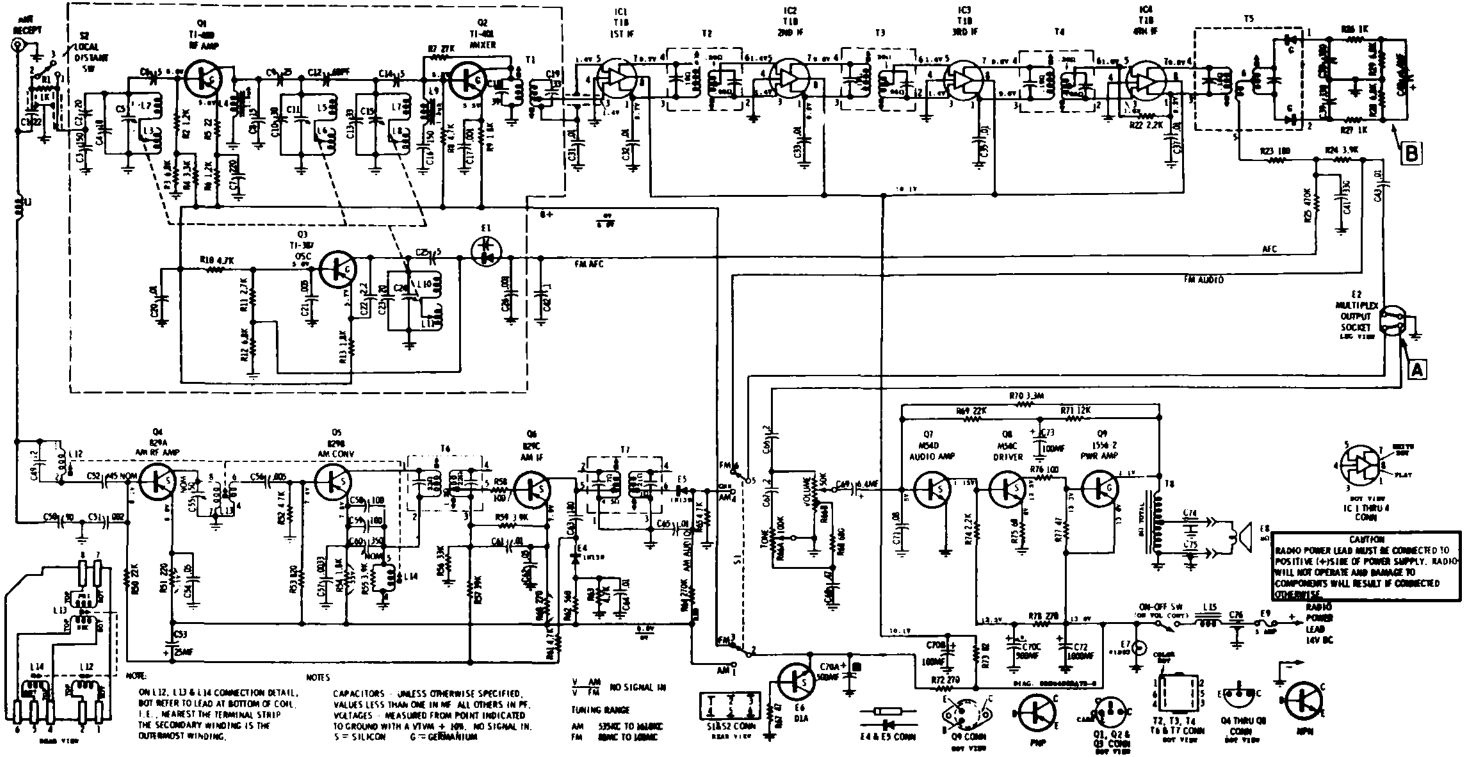


Fig. 9-4. Typical AM-FM auto receiver (Motorola model FM-108).

decreasing the reverse bias of the diode, increasing its capacitance, and lowering the oscillator frequency to correct tuning. If the oscillator shifts below the carrier center frequency, the FM detector output goes negative, increasing the reverse bias of the diode, decreasing its capacitance, and increasing the oscillator frequency.

The i-f amplifiers employ integrated-circuit amplifiers. The first three i-f amplifiers are identical. The last IF amplifier has a reduced supply voltage so that it provides limiting action. The servicing procedures for integrated circuits will be found in the chapter on "Troubleshooting Techniques."

The AM section of the radio is fairly conventional. It contains an r-f amplifier, converter, i-f amplifier, and diode detector. Diode E4 develops the AVC bias voltage that controls the gain of both the r-f and i-f amplifiers.

The audio section consists of two small signal amplifiers and a power amplifier. Direct-coupling is used between stages to improve the low-frequency response. Choke T8 is the load for the audio-power amplifier with an impedance matching tap for the speaker. Negative feedback is provided by R69, R70, R71, and C73 to improve the high frequency response, reduce distortion, and increase stability.

HYBRID RECEIVERS

The early transistor auto receivers utilized a hybrid system employing both tubes and transistors. Although no longer being manufactured, many of these receivers are still in use, and a service technician is bound to run into them. Therefore, this brief discussion on hybrid receivers is presented.

A low-cost hybrid receiver is shown in Fig. 9-5. The radio employs conventional circuitry, with the incoming signal feeding into a 12BL6 r-f amplifier and then to a 12AD6 converter. The r-f signal is beat with the local oscillator signal to develop a 262.5-kc i-f signal. The r-f, oscillator, and mixer stages employ permeability tuning. The i-f signal is amplified by the 12BL6 i-f amplifier and transformer-coupled to the 12DL8 detector. The dual-diode portions of this tube provide detection and develop the avc voltage which is fed back to the i-f, converter, and r-f amplifier tubes. The remaining section of the tube provides the audio drive for the transistor output stage. This section has four elements, but functions as a triode. The first grid (pin 3) is really an auxiliary grid, next to the cathode and operates at a fixed positive potential. This enhances the control characteristics of the control grid (pin 7) and provides high transconductance in proportion to plate voltage.

The output of the driver section of the 12DL8 is transformer-coupled to the base of the power audio output transistor. This transistor is operated in a class-A single-ended circuit to drive a low-impedance loudspeaker through an autotransformer load. The base bias of the transistor is adjusted by control R14, to set the

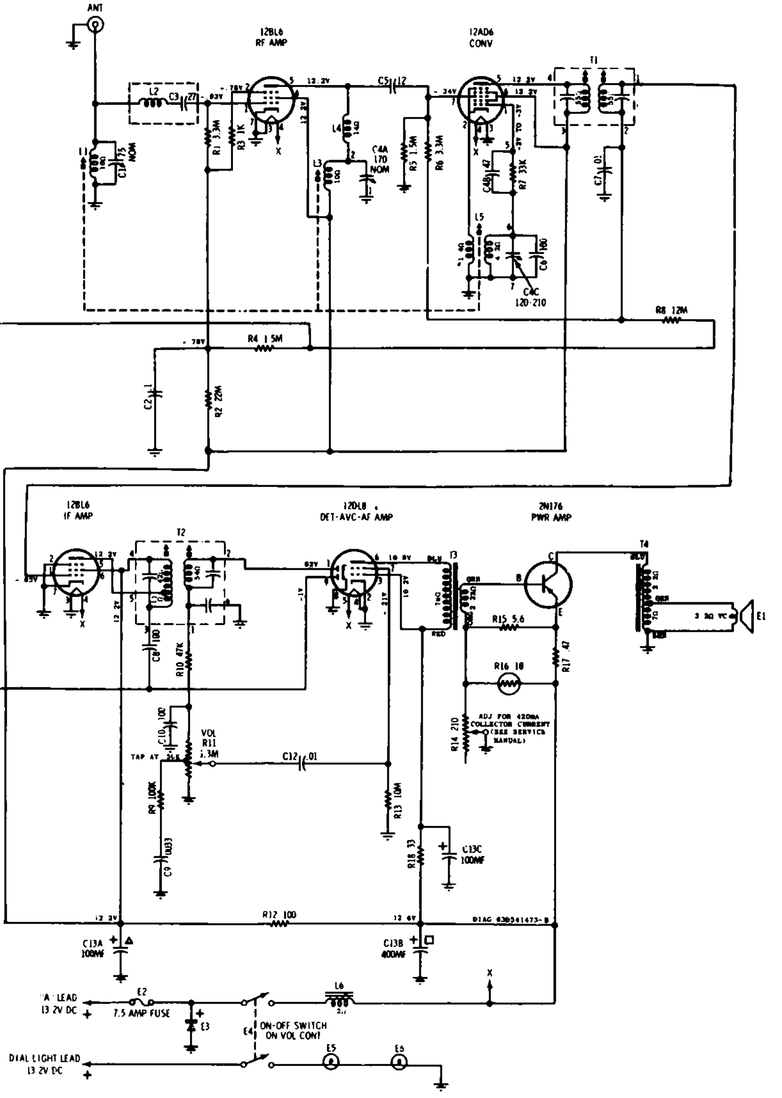


Fig. 9-5. Motorola model 825, a typical hybrid automobile radio receiver for cars with a 12-volt electrical system.

best power sensitivity consistent with good operation. Resistor R16 is a varistor to stabilize the circuit and prevent "runaway" due to temperature rise.

All the stages derive their power directly from the automobile battery through the filter networks. Diode E3 is a selenium unit to protect the receiver from reverse power supply polarity and shunt any large negative voltage pulses to ground.

Note that full avc voltages are not applied in the conventional manner. If this were done, severely strong signal distortion and grid blocking could result with low-plate-voltage tubes. The full avc voltage is utilized on the r-f amplifier by applying the avc to the control and suppressor grids through R1 and R3. Hence strong signals which cut off the r-f amplifier tube are series-fed to the converter tube through the suppressor grid-to-plate capacitance. On some hybrid receivers the avc on the grid of the r-f amplifier is reduced, resulting in more continuous operation of the tube and affording maximum selectivity.

SERVICING ALL-TRANSISTOR AND HYBRID AUTO RADIOS

The servicing of transistor auto radios requires the same procedures described in the previous chapters, *with the exceptions noted here.* These exceptions pertain to the radio power supply circuits, power amplifier servicing, and noise-type interference.

Automobile receivers, on the bench, may be operated from a d-c power supply having a minimum rating of 500 ma. A regulated power supply is desirable. If a regulated low-voltage power supply is not available, a battery eliminator may be used if the following precautions are taken.

Battery eliminators, which are a-c operated, usually have a high surge voltage which can damage the transistors. To prevent this surge, connect a permanent load across the output terminals of the battery eliminator. For example, in a 12-volt receiver, a 20-ohm 20-watt resistor or four 12-volt pilot lamps in parallel will provide the necessary load. Turn on the battery eliminator, adjust the voltage to 14 volts, and then turn on the radio. Do not turn on the receiver before adjusting the voltage output of the battery eliminator.

On the bench, the radio may be powered by a battery eliminator or a spare auto battery. Most battery eliminators have an extremely high a-c ripple content which may damage the transistors and other low-voltage components. The a-c ripple content of a battery eliminator should therefore be checked with a calibrated oscilloscope (Fig. 9-6). A good eliminator should have less than

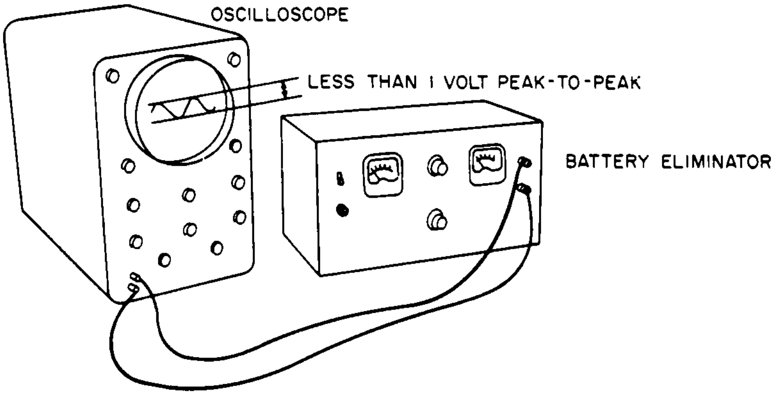


Fig. 9-6. Checking the ripple content of a battery eliminator with an oscilloscope.

a 1-volt (peak-to-peak) a-c ripple. Since transistor power supplies require low voltage output, high-capacitance electrolytic capacitors added to the filter system reduce the a-c ripple appreciably. Many so-called battery eliminators are unsuited to transistor power supply usage.

Transistor equipment often has a wide range of power requirements from very low current at low output to very high current at maximum output. The supply must therefore have good regulation, or the voltage will rise and fall as the load is varied. Such poor regulation will make analysis very difficult, if not impossible. Whenever possible, a battery power supply should be used. A battery shunted by a rectified a-c source makes an ideal supply (see Fig. 9-7). The battery will filter and stabilize the output from the

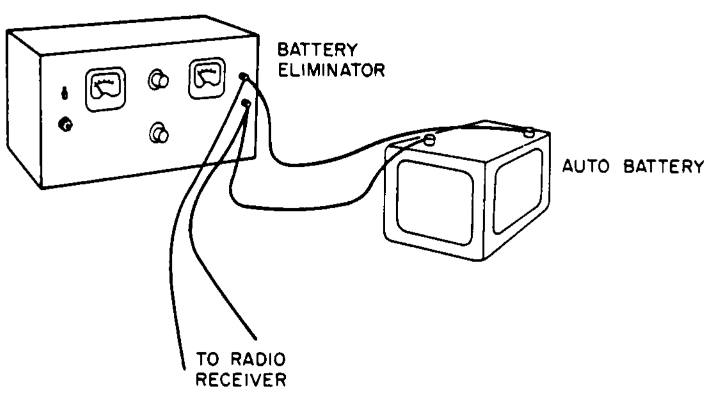


Fig. 9-7. A battery shunted by a rectified a-c source makes an ideal supply.

battery eliminator and the eliminator will ensure that the battery is always at full charge.

With the set out of the car and on the bench, the chances of connecting the supply voltage backwards are very great, especially for those accustomed to working on vibrator-type sets. These receivers generally have no polarity or, in the case of the synchronous vibrator, will not work if connected backwards. Transistor radios not only fail to work if the battery terminals are connected backwards but may be ruined while you are trying to locate the trouble.

Transistor auto radios operated from a 6-volt battery source, which is insufficient for vacuum tube operation, usually employ a transistor power oscillator-rectifier circuit (Fig. 9-8) to replace the vibrator. The a-c voltage developed in the transformer primary is rectified by the diode in the transformer secondary. The transformer steps the voltage up to the necessary value for the tube circuits. Power for the transistor circuits is taken off before the oscillator circuit.

The power oscillator circuit can be checked using the procedures and methods given in Chapter 6. The rectifier circuit is simple and straightforward and can be checked using the standard voltage and resistance measurements. One exception, however, is the *varistor* used to provide voltage regulation. To check the varistor, remove all the tubes from the receiver, unsolder one end of the varistor from the circuit, and connect a milliammeter in series with the varistor. In such circuits, properly operating varistors will pass 8–15 ma in this check.

When installing a new transistor auto radio in a car, be sure that the battery lead polarity is correct. Most manufacturers provide a means for reversing polarity in the radio itself. One such example is shown in Fig. 9-9. In this receiver, the jumper from the on-off switch and ground lead is reversed between terminals 1 and 2. The manufacturer's instructions in this matter should be followed precisely, in order not to damage the transistors in the radio.

Audio Power Transistor Circuits. There is a warning which must precede any discussion of servicing audio power transistor circuits: *Never operate a power transistor unless it is firmly bolted to its heat sink.* The heat sink is usually made of aluminum and is generally mounted on the outside of the main chassis (see Fig. 9-10). The heat sink is really a radiator, serving the same purpose as the radiator in a gasoline engine. Operating an engine without its radiator is no more unthinkable than operating a power transistor without its heat sink. Overheating and permanent damage to the transistor will result if this rule is not observed.

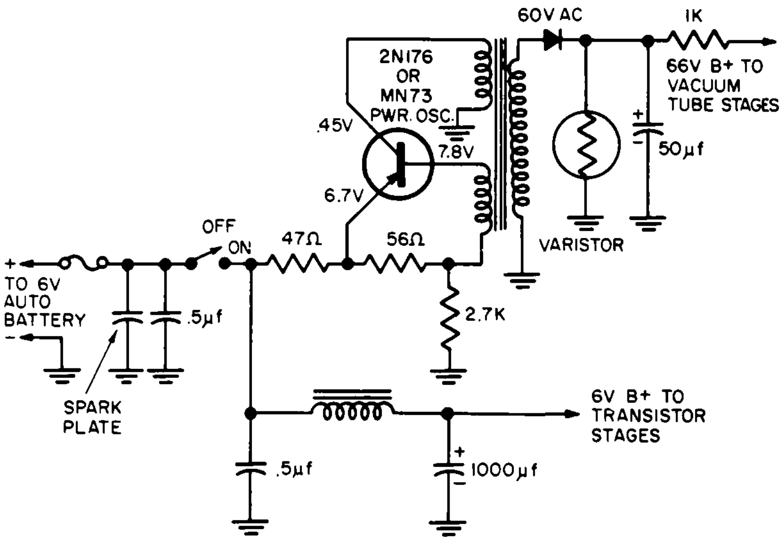


Fig. 9-8. The Motorola model 406 AM auto radio is a typical circuit, used in hybrid auto radios (operated from a 6-volt battery) to increase the voltage necessary for the vacuum tube circuits. Note the use of the varistor for voltage regulation.

When replacing a power transistor, it is important to replace the mica washer which will almost always be found between the transistor and heat sink. This washer has a critical thickness and, if lost or damaged, replacing it with another having a much greater

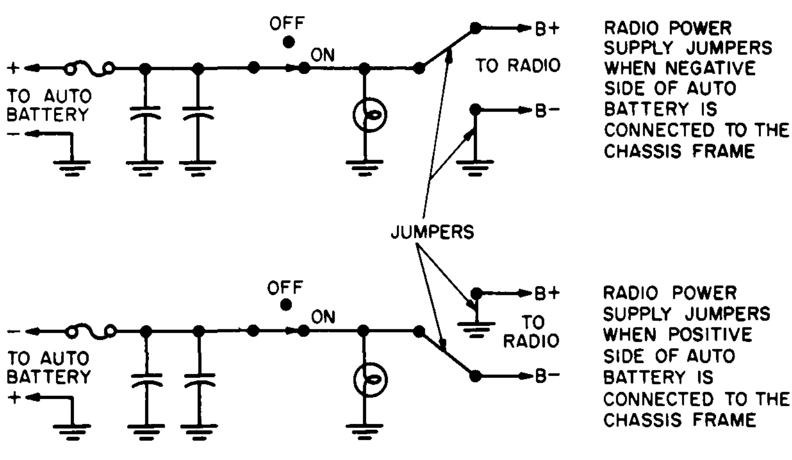


Fig. 9-9. Motorola model 406 AM auto radio shows a typical method used to reverse the input polarity of a transistor radio supply.

thickness or some other heat conducting characteristics may result in shortened transistor life.

Be sure to bolt the transistor down onto the insulator securely. This is to insure proper heat transfer to the heat sink. A small amount of silicon compound or grease is sometimes applied to the two surfaces of the insulator to improve the heat transfer further. When replacing a transistor, be sure to reapply this compound.

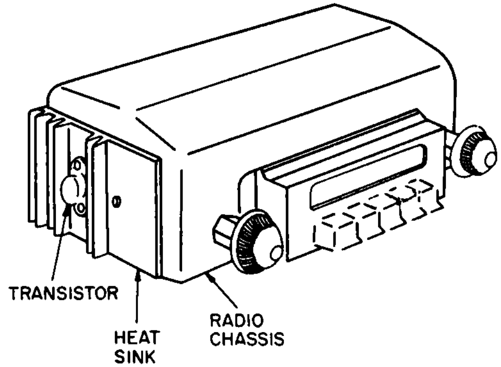


Fig. 9-10. The power audio output transistor(s) is most often mounted on the outside of the receiver case in a special heat-dissipating device.

When replacing the transistor radio in the auto, be sure that the power transistor's case is not shorted to ground by the speedometer shaft or other bare metal objects under the dashboard. Be sure that they are cleared away from the radio receiver case.

NOISE IN AUTO RECEIVERS

Auto transistor radios are more susceptible to noise interference than are other types of portable radios. This is because of their inefficient antennas, which pick up less signal, and the presence of strong noise signals in the automobile, most particularly the motor ignition system. In addition, the greater vibration, temperature range, and humidity encountered by automobiles often aggravate noise conditions.

Noise interference is generally either of two types: static or oscillation. Static is a "frying" noise that may occur regularly or irregularly. Oscillation is a "whistling" noise that is usually very high in pitch.

Static noise may originate outside the auto, as well as from inside the auto. Since the external sources usually are beyond our control, we will confine our discussion to internal static noise sources. Static noise is most often caused by arcing within the radio or the auto.

Arcing can occur in components such as IF transformers, tuning capacitors, pilot lamps, volume and tone controls, and loose or broken connections (particularly on printed-circuit boards). The stage where trouble exists can be isolated by signal tracing. Merely disable one stage at a time (momentarily short emitter to base) until the static disappears. A signal tracer with demodulator probe may be very useful for this purpose.

Oscillation noise, which usually originates in the radio, is caused by regeneration in a stage or between stages. The most likely culprits are the decoupling capacitors. Check the main filter capacitors in the power supply and all other electrolytic decoupling capacitors by bridging with a known good capacitor. Also check the decoupling capacitors in the RF, converter, and IF and AGC circuits by bridging with known good capacitors.

Other sources of noise that usually fall into the static or oscillation categories are: spark-plate capacitor, defective speaker, defective antenna (poor ground or open inner-conductor) and automobile components. Auto noise can be caused by any auto components that produce a high voltage transient. Such noise can be suppressed through the use of graphite radio-noise suppression wire in the ignition system; bypass capacitors at the ignition coil, generator, and regulator; and grounding straps between components and body.

Effects of Air Temperature. There are two forms of transistor trouble which have created some perplexing problems and a few unnecessary return service calls. Transistors, being resistors of a very special sort, are greatly affected by temperature. When they are very cold, they lose some of their gain and most of their power output. When they are very hot, they react similarly. Some customers in the northern parts of the country have awakened on a sub-zero morning to find the radios in their cars sounding very strange, and have immediately concluded that they needed repair. After the set gets into the warm shop or after driving a few miles with the heater on in the car, it appears to be quite normal again.

A similar situation can result from the heat of a summer day at the beach or in the desert. The radio seems to be quite distorted and to have lost much of its sensitivity, particularly if it is an all-transistor receiver.

Both of these situations are normal to transistor sets and are corrected as soon as the equipment is restored to a more normal temperature. There is no solution to the problem with presently known techniques. In these cases, the situation should be explained to the customer so that he realizes that this is not due to trouble in the receiver.

VACUUM TUBES IN HYBRID RADIOS

One additional precaution is appropriate at this point, even though it does not apply directly to transistors. *Never measure the 12-volt tubes found in hybrid auto radios in a standard tube checker unless the manufacturer definitely states that test voltages do not exceed the 30-volt maximum ratings on these tubes.* Failure to comply with this rule will result in permanent tube damage.

10. Troubleshooting Techniques

Transistors are very stable devices and have an exceptionally long life. However, they can be damaged by the application of too much heat, excessive or improper voltages, or mechanical abuse. The same conditions apply to the newly developed miniaturized components and printed circuit boards used in compact transistorized equipment. The servicing technician should, therefore, read this chapter through before beginning actual repair.

SIGNAL TRACING

The click test, as used in signal tracing vacuum tube radios, does not work with transistor radios. This is due to the low input impedances of transistorized circuits. In addition, grounding the base of a transistor may cause excessive conduction and damage the transistor.

Modified Click Test Method. The i-f and audio stages of a transistorized radio may be checked quickly with a modified form of the click test. This consists of placing a small momentary d-c voltage on the collector of the transistor used in the preceding stage. A special test lead (Fig. 10-1) should be constructed for this purpose.

To signal trace using the modified click test, connect the clip end of the lead to the positive side of the battery. Then touch the resistor end of the test lead to the collector of each transistor. For example (Fig. 10-2), touching the lead to the collector of the converter transistor checks the receiver from the first i-f amplifier stage to the loudspeaker. If a click is heard when the test is performed, it indicates that the signal path is good from this point to the loudspeaker. When using this test on a dead receiver, start at the loudspeaker and work toward the antenna.

Noise Generator Method. Another quick (and more reliable) method of signal tracing a transistor radio is provided by the *noise generator.* This device provides an a-f and an r-f signal rich in harmonics. A Motorola unit which is commercially available is shown in Fig. 10-3.

This generator is a transistorized multivibrator, operating on a fundamental in the audio range at approximately 400 cycles and creating harmonics all through the broadcast band. This continuous

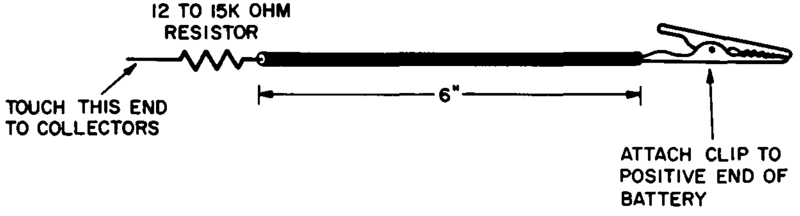


Fig. 10-1. Test lead for signal tracing transistorized radios using the click test method.

range of frequencies will save a great deal of time in switching frequencies from audio to i-f, to r-f, etc., during radio servicing.

Two types of output are available—direct and radiated. The *direct output* can be used to signal trace a dead radio and is especially useful on transistorized radios where the practice of shorting components to produce clicks, or a response, is to be avoided to prevent possible damage to transistors.

Any enterprising do-it-yourselfer, however, can easily construct a noise generator. Two such units are shown in Figs. 10-4 and 10-5. The circuit shown in Fig. 10-4 is a blocking oscillator using a single transistor and transformer. The circuit values are not critical, and almost any low power transistor will work. In fact, an audio-power output transistor and its associated output transformer will do nicely. R1 should be adjusted for optimum frequency. If the circuit does not oscillate when you first connect it up, try reversing the transformer secondary; the phasing may be incorrect. When using an npn type transistor, merely reverse the polarity of the battery.

The circuit shown in Fig. 10-5 is a two-transistor collector-coupled

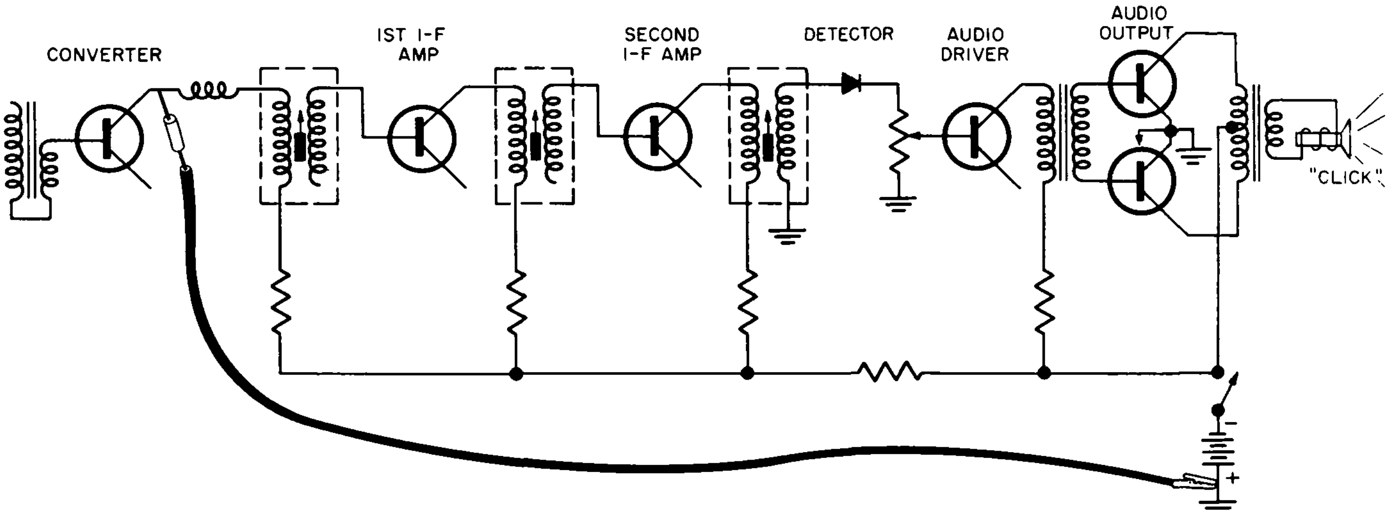


Fig. 10-2. Click test for transistorized radios. When the end of the resistor is momentarily touched to the collector of the converter transistor, a click is heard from the loudspeaker.

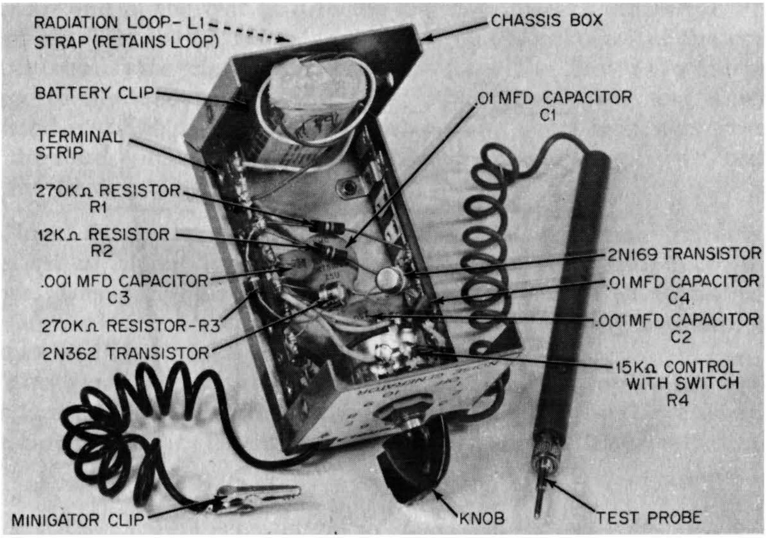


Fig. 10-3. Interior view of a noise generator. *Courtesy Motorola.*

multivibration circuit. Again, almost any switching or audio transistor will work. Reverse the battery when using npn-type transistors.

Signal tracing with a noise generator is begun at the loudspeaker. Connect the generator across the loudspeaker winding. A tone will be heard from the speaker if it is operating properly. The intensity of the tone depends upon the impedance of the loudspeaker. High-impedance loudspeakers yield a louder tone than low-impedance units.

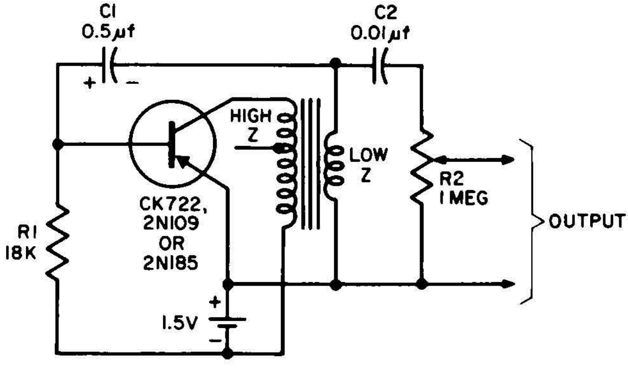


Fig. 10-4. Circuit for a noise-type signal generator using a blocking oscillator circuit.

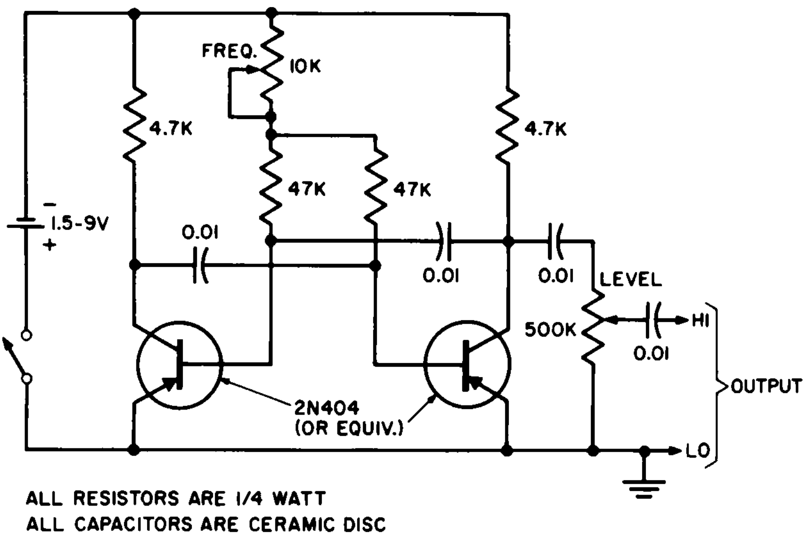


Fig. 10-5. A collector-coupled multivibrator circuit used as a noise-type generator.

If the loudspeaker is operating, then proceed to touch the noise generator output lead to the base element of the radio output, audio driver, detector, and i-f amplifier transistors, in turn. In the case of commercial noise generators, a ground connection from the generator case to the radio chassis may be required for some circuits.

The volume of the tone will be just audible when injected at the base of the audio output and second i-f amplifier transistors, since a minimum amount of gain for audio and i-f frequencies is present at these points. As the generator is moved to the audio driver, detector, and first i-f amplifier transistors, the tone's loudness will increase greatly.

A check of the antenna can be made by forming a 6- to 8-turn coil of ordinary hookup wire and connecting it across the generator output. The diameter of the coil should be just large enough to fit over one end of the antenna's ferrite core. As the coil is brought near the antenna (holding it parallel to or over one end of the ferrite core), the generator tone will be heard.

Failure to hear a signal at any point in the signal tracing procedure indicates that a circuit malfunction exists between the point where the tone was last heard and the point at which it is not heard.

The local oscillator section of the transistor radio can be checked with the following procedure: Using the loop coupling system described, couple the noise signal into the receiver's antenna. Rotate the tuning capacitor to minimum capacitance (fully open).

Touch the oscillator adjustment screw on the tuning capacitor with your finger. This will cause the oscillator to stop functioning. The tone will also stop. Now, with your finger still on the trimmer, rotate the tuning capacitor to maximum capacitance (fully closed). A tone will now be heard. This indicates that the converter stage is passing the intermediate but not the radio frequencies (oscillator inoperative). In other words, conversion is no longer taking place and the transistor is functioning only as an i-f amplifier.

If the noise generator's signal is passed at both high and low ends of the tuning capacitor's range, the oscillator is operating. However, if the signal is heard only at the low end of the band, the converter circuit is operative at intermediate, but not at radio, frequencies (oscillator not working). If the tone is not heard at either end of the band, the converter circuit is completely inoperative.

The technician should first use the noise generator on a transistor radio which is operating properly, in order to become familiar with the instrument. For example, the user should know from experience the approximate loudness of the tone at all the test points in the standard transistor receiver. This will then indicate if the relative gains of the various stages are up to par.

Signal Generator Method. The most reliable and accurate signal tracing device is, of course, a signal generator providing known audio, i-f, and r-f signals. The 400-cycle fixed frequency audio output (provided by most generators) is used to trace the audio circuitry. A 455-kc signal is used to signal trace the i-f stages (in a few rare exceptions, lower i-f's are used; the manufacturer's service information should be consulted in this case). Signals of 600 kc and 1.4 mc should be used to check the operation (sensitivity and calibration of dial) of the converter circuit. These tests are performed using the procedures described in the preceding section on the noise generator method.

When signal tracing with a signal generator, always connect a capacitor (0.01 to 0.1 μf) in series with the generator's hot lead. This will avoid shorting out the bias voltage of the transistor. The ground lead of the generator may be connected to either side of the battery if the receiver uses a printed wiring board. If a metal chassis is used, connect the ground lead to the chassis.

Keep the generator signal level as low as possible (just audible). Do not inject strong signals into a transistor circuit. This is particularly important in low-level stages.

In converter circuits, do not inject the signal at the elements of the transistor as this will stop oscillator action. Rather, use a radiated signal as shown in Fig. 5-9. In an r-f amplifier stage, use a radiated signal or clip the "hot" lead of the generator to the insulated body of a circuit resistor or capacitor (capacitive coupling).

TESTING JUNCTION TRANSISTORS

Transistors are usually either all-good or all-bad. It is rare that they will develop low gain or intermittent conditions, as does a vacuum tube. This characteristic makes transistor testing relatively simple. In fact, a good test of a transistor can be performed with just an ohmmeter. An ohmmeter test will detect an open or a shorted junction, the relative leakage current, and the relative gain of a transistor.

To use an ohmmeter for transistor testing, it is first necessary to determine the polarity of the ohmmeter leads. To do so, connect the ohmmeter to a voltmeter or a known good semiconductor diode. Set the ohmmeter to either the R $\times$ 100-ohm or R $\times$ 1K-ohm range (the internal battery is usually 1.5 V for these ranges) and connect the "common" lead of the ohmmeter to the positive lead of the voltmeter. Connect the "ohms" lead to the negative lead of the voltmeter. If the voltmeter reads up-scale, then the ohmmeter's "common" lead is positive and its "ohms" lead is negative. If it reads down-scale, its polarity is just the opposite.

When using a diode to determine ohmmeter polarity, set the ohmmeter to the R $\times$ 100-ohm or R $\times$ 1K-ohm range, and connect the "common" and "ohms" leads of the ohmmeter to the anode and cathode terminals, respectively, of the diode. A reading of less than 100 ohms indicates that the ohmmeter's "common" terminal is positive. A reading of 100K ohms or more indicates that the ohmmeter's "common" terminal is negative.

After establishing the polarity of the ohmmeter, set the ohmmeter to the R $\times$ 100-ohm or R $\times$ 1K-ohm range and check the forward-to-back resistance (resistance in both directions) of the base-to-emitter junctions and base-to-collector junctions as shown in Figs. 10-6 and 10-7. A forward-to-back resistance ratio of a good low-power transistor junction is 100:1 or better. The emitter-base resistance should be higher than the collector-base resistance.

When checking power transistors, use the R $\times$ 10-ohm or R $\times$ 100-ohm ranges. Power transistors have lower forward-to-back resistance ratios than low-power transistors.

If a transistor gives a low-resistance reading in both directions across a junction, that transistor junction is shorted. If a transistor gives a high-resistance reading in both directions across a junction, that transistor junction is open. After this reading has been taken, connect the transistor as shown in Fig. 10-8. This set-up tests both

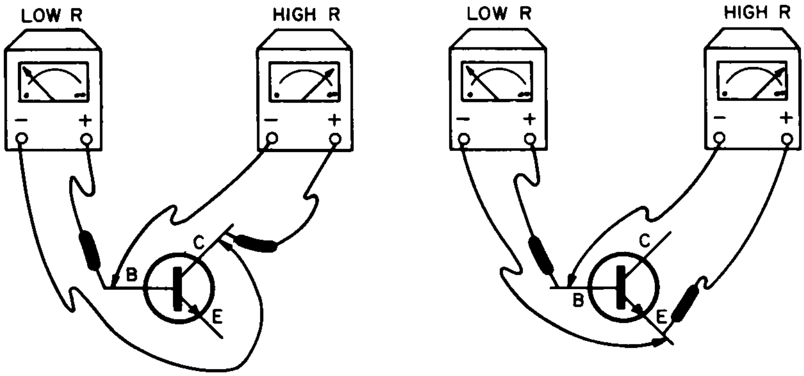


Fig. 10-6. Testing npn transistors with an ohmmeter. The low resistance should be 50 to 500 ohms. The high resistance should be 50K to 5 megohms. The forward-to-back ratio should be 100:1 or better.

junctions simultaneously. With no connection made to the base, the ohmmeter should read a resistance between the forward (approximately 100 ohms) and back resistance (greater than 50K ohms). If the resistance is less than 5K ohms, the transistor has a high leakage current. The lower the resistance, the poorer the transistor's leakage-current rating.

Now, connect a jumper from base-to-emitter, which should cut off the transistor, producing a resistance greater than 50K ohms. Next, connect a jumper from base-to-collector, which should saturate the transistor (approximately 100-ohms resistance). The ratio

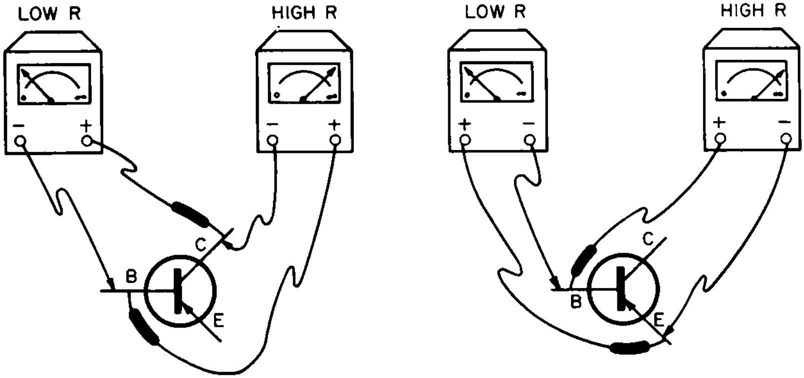


Fig. 10-7. Testing pnp transistors with an ohmmeter. The low resistance should be 50 to 500 ohms. The high resistance should be 50K to 5 megohms. The forward-to-back ratio should be 100:1 or better.

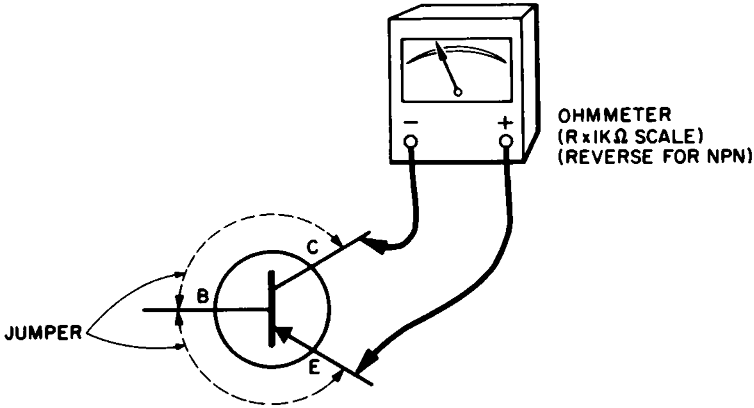


Fig. 10-8. Checking transistor with ohmmeter to determine approximate gain.

between these two readings is a good indication of the d-c gain (beta) of the transistor. This test may be used to select high-gain transistors from among similar types of units. For example, a typical resistance ratio would be 100K-ohms/5K-ohms, which equals a d-c gain of 20.

IN-CIRCUIT JUNCTION TRANSISTOR TESTING

Junction transistors can be tested without removing them from their respective circuits. These tests are d-c tests to increase or decrease the conduction of the transistor by changing the bias on the transistor. If the transistor responds to these changes, it is performing its basic transistor function.

Figure 10-9 illustrates how to test a junction transistor in a circuit by increasing its conduction. Connect a voltmeter across the emitter resistor, or from collector to emitter if there is no emitter resistor. In receivers that are operated from an a-c power line, use only a high-impedance vom, differential voltmeter, or vtvm isolated from the line. Then connect a 10K-ohm resistor between collector and base to increase the forward bias of the transistor. The voltmeter connected across the emitter resistor should indicate greater voltage because of increased conduction. The voltmeter connected from collector to emitter would indicate less voltage.

A more conclusive test is to decrease the conduction of the transistor by shorting the base-to-emitter. Now, the emitter-resistor voltage should decrease, and the collector-to-emitter voltage should increase.

When testing power transistors, the decreased-conduction test is preferable to the increased-conduction test since the latter may cause the transistor to pass excessive current.

If the transistor uses a self-biasing base resistor, as shown in Fig. 10-10, the increased-conduction test is performed by bridging R_{11} with another resistor of equal value. Hence, if R_{11} is 10K ohms, use a bridging resistor of 10K ohms.

CHECKING FIELD-EFFECT TRANSISTORS

FET's are physically similar in their construction to standard-junction transistors and hence the usual precautions observed in working with bipolar transistors should be followed in FET circuits. Additional precautions are necessary when replacing MOS-FET's because of their extremely high input resistance.

In testing a J-FET, it is best to use a vtvm, particularly for resistance measurements. The meter internal-voltage source should be low (3 volts maximum), and the current from the meter to the transistor must be limited. Either high voltage or high current can damage an FET.

Caution: Do not measure the front-to-back gate ratio of MOS-FET's (IG-FET's) with an ohmmeter. The gate-source or gate-drain junction of a MOS-FET should never be forward biased, either in operation or during an ohmmeter test.

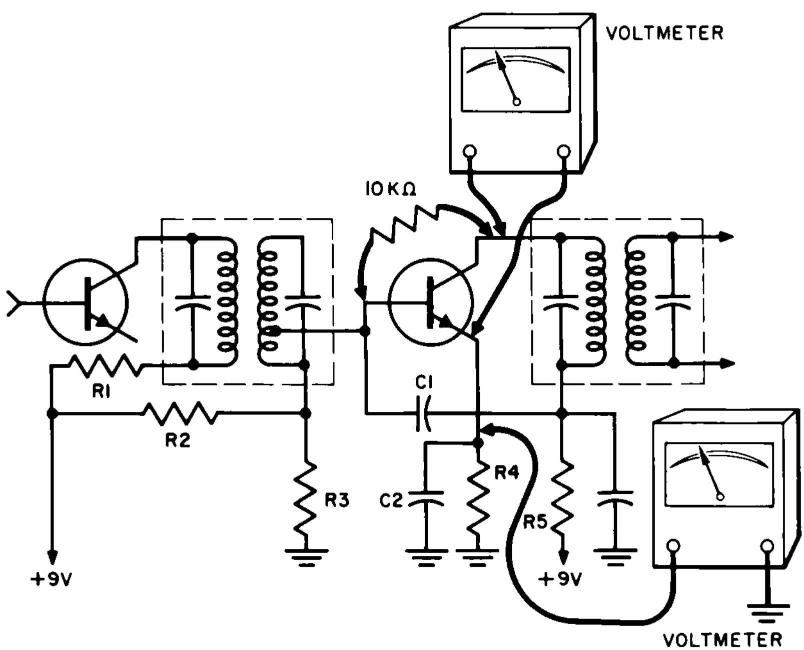


Fig. 10-9. In-circuit transistor testing.

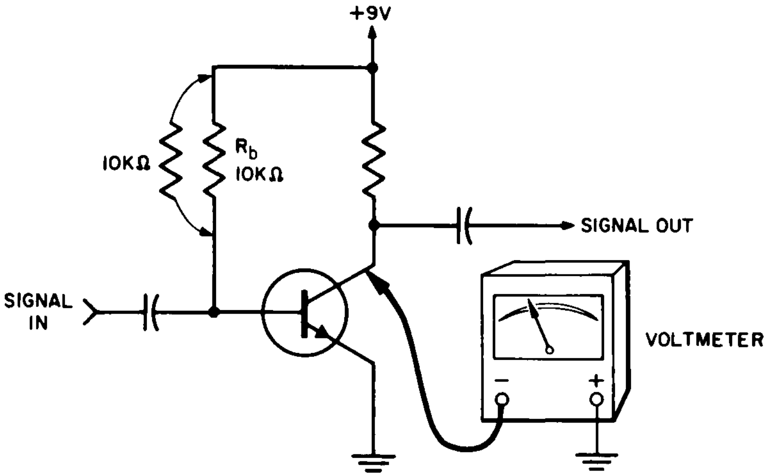


Fig. 10-10. In-circuit transistor testing of self-bias amplifier.

The FET can readily be tested for operation in a circuit as described in the previous section or by measuring the bias voltage between source and ground (refer to Fig. 10-11). If the gate has control of the channel current and limits the source voltage (channel current through R_s) to the indicated 2 volts, the FET is probably good.

To check the gate control, measure the drain voltage while *momentarily* shorting R_s. The drain voltage should drop as a result

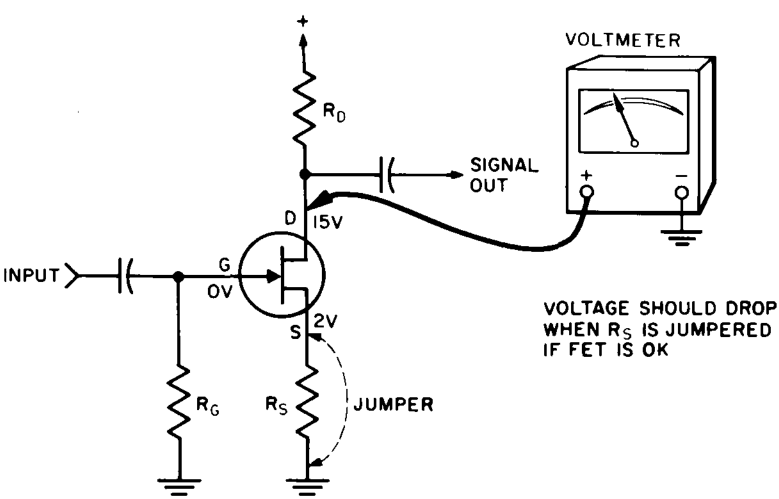


Fig. 10-11. In-circuit testing of FET by momentarily shorting bias resistor.

of the increased current when the bias is removed. If the current increases and lowers the drain voltage, the gate controls the channel current, and the FET is probably good.

To check the gate leakage, measure the gate-to-ground voltage. It should be zero. Any leakage will show up as gate voltage, assuming the coupling capacitor is good.

Caution: Do not attempt to "turn-on" an FET, as can be done with a junction transistor, by connecting a resistor between the supply (or drain) and gate. This forward-biases the gate junction, and the resulting current can quickly destroy the transistor. The gate-channel junction cannot withstand any appreciable current. Even if the gate is not destroyed, it can damage the gate region, resulting in leakage.

An out-of-circuit test of a J-FET or MOS-FET can be made using the circuit shown in Fig. 10-12. The voltmeter is connected to measure the source-to-drain voltage. When the switch is closed, the bias on the gate is decreased, the source-to-drain current decreases, and the source-to-drain voltage increases. The ratio of "ON" to "OFF" voltage readings is an indication of gain and can be used to compare transistors to find high gain units. Gate leakage can be determined by measuring the voltage across R_g with the switch closed. This voltage should be near zero. A transistor with a higher voltage across R_g has a higher gate leakage and a lower gain. When testing a MOS-FET with more than one gate, perform this test with each gate separately.

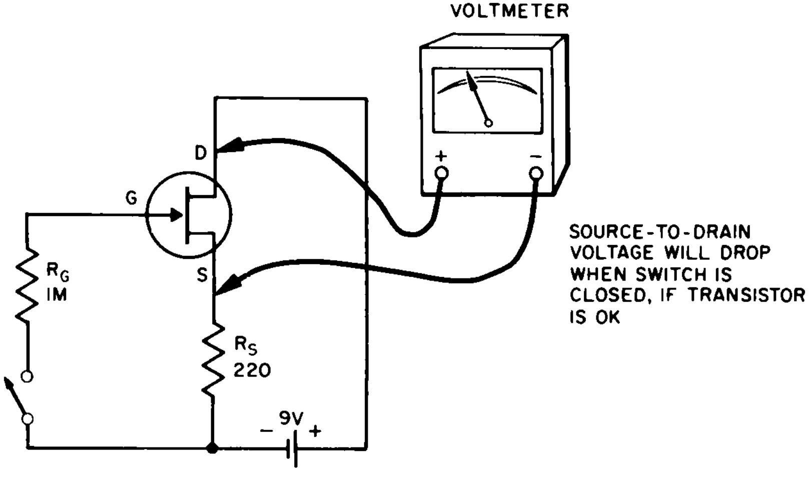


Fig. 10-12. Static test of an N-channel FET (when checking P-channel FET, reverse battery and voltmeter).

IDENTIFYING UNKNOWN TRANSISTORS

When servicing a receiver without a schematic or one that does not employ standard "2n" type transistors, we still have to be able to identify whether we are dealing with pnp or npn type transistors. Furthermore, when buying unmarked bargain "surplus" transistors, we have the same problem. The problem is further compounded by manufacturers who do not use standard lead arrangements (standard lead arrangements are shown in Fig. 10-13). A method for identifying leads and transistor types is as follows:

1. Using an ohmmeter, on the R $\times$ 1,000-ohm range, check the resistance between each pair of leads with both polarities of the meter leads until a pair is found that have high resistance in both directions. These are the collector and emitter leads. The remaining lead is the base lead.
2. Check the resistance from the base lead to each of the other leads with both polarities of the ohmmeter. The type of device, pnp or npn, can be identified by referring to Fig. 10-14.

When checking J-FET's, a low resistance (usually 1,000 ohms or less) will be measured between source and drain with both polari-

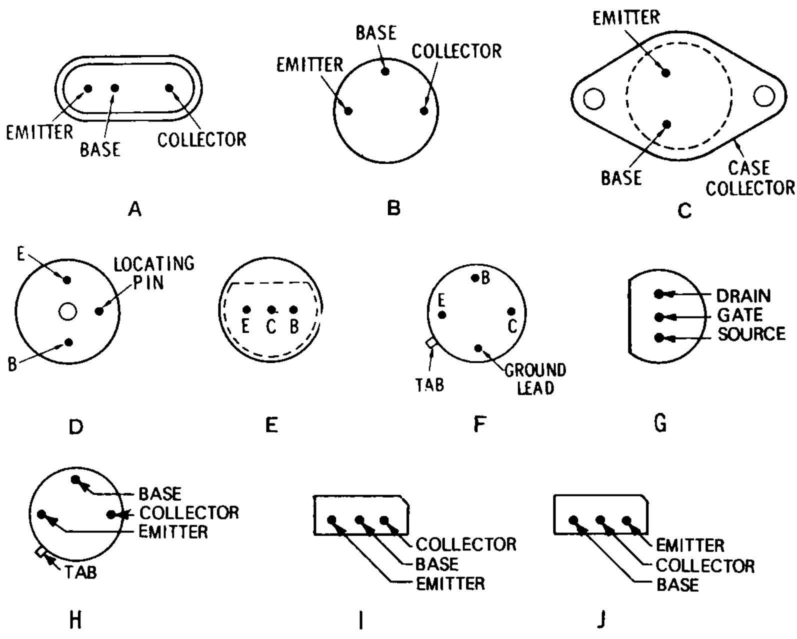


Fig. 10-13. Lead configurations commonly used on transistors.

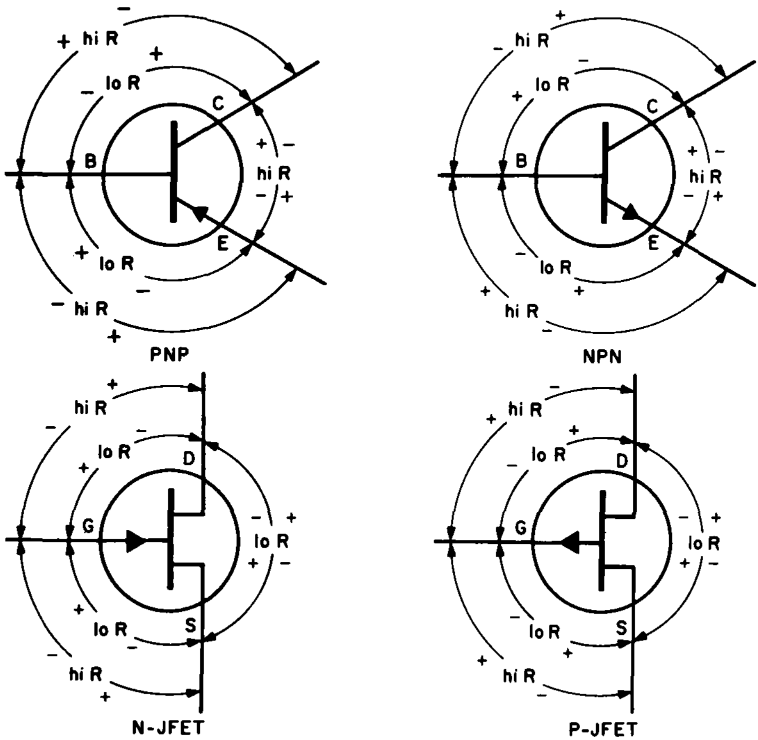


Fig. 10-14. Resistance readings for low-power type transistors.

ties of the ohmmeter. Then the source-to-gate and drain-to-gate resistances will be as indicated in Fig. 10-14.

A MOS-FET transistor will have a low resistance between source and drain (usually less than 1,000 ohms). Then because of the extremely high resistance between the gate and the channel, the transistor can be checked using a battery and resistor to bias the device between high and low channel resistances, as shown in Fig. 10-12. If the MOS-FET has more than one gate, perform the check on each gate.

IDENTIFYING POWER TRANSISTORS

The foregoing checks may also be performed on power transistors, with the following exception. The resistance between collector and emitter will show a high resistance ratio, as shown in Fig. 10-15. The resistances should be checked against a known good power transistor since variation in ohmmeter designs will affect this test.

FINDING A SUBSTITUTE TRANSISTOR

The foregoing transistor tests will tell you if a transistor is good or bad. However, the actual replacement of a defective transistor can present a problem, particularly on foreign-made radios or transistors not using a standard identifying number. The problem can usually be solved by stocking a line of standard replacement type transistors, such as the Motorola HEP series, the RCA "Top-Of-The-Line" series, or the Sylvania replacement series. Substitution then proceeds as follows:

1. It is often difficult to remove and replace a transistor on a printed circuit so that it is often better to cut the printed circuit tracks, as shown in Fig. 10-16, to remove the defective transistor from the circuit and temporarily solder the replacement transistor in place. Be sure the replacement is of the same type as the original (pnp or npn). With the replacement in place, check the performance of the radio. Try several different transistors to find the optimum device. If there are any squeals, howling, or poor sensitivity that cannot be corrected by retuning, try another transistor.
2. When you have found the best replacement transistor, remove the old transistor and solder the new one in place. Apply a drop of solder across the cuts in the circuit tracks, or use wire jumpers to bridge the cuts. If the circuit board has a coating over the circuit, scape away the coating before soldering.

The above procedure will usually work because bias requirements for transistor radios are not too critical. If you are concerned that the transistor rating may be exceeded, open the emitter circuit and check the emitter current to make sure that it is below the rating. With no signal, this current should be less than 2 ma for low-power transistors, less than 100 ma (peak) for power transistors in portable radios, and less than 1 amp (peak) in auto radios. In auto

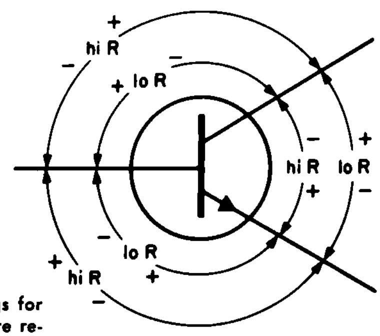


Fig. 10-15. Resistance readings for a power transistor (polarities are reversed for a pnp type).

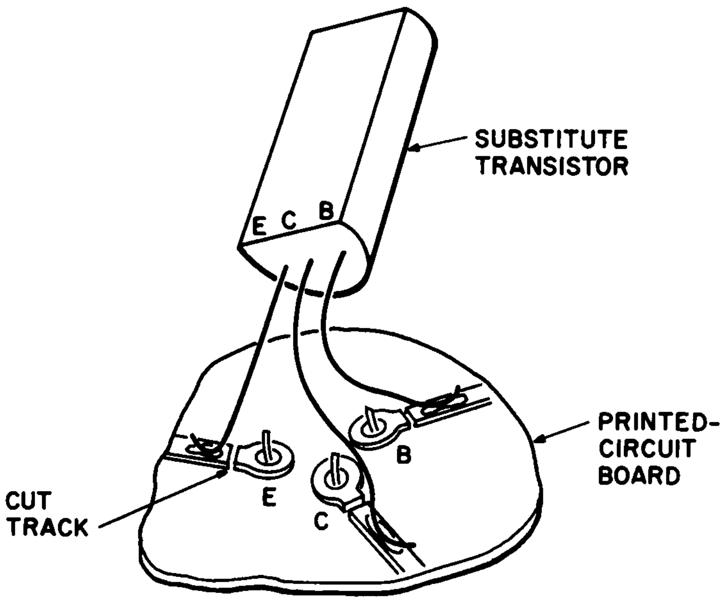


Fig. 10-16. Easy substitution of new transistor in circuit by leaving old transistor in place, cutting tracks, and soldering replacement to tracks.

radios, be careful that the transistor used can work at the higher voltages required.

In selecting a replacement transistor, a replacement type r-f transistor will work well in any other transistor radio r-f, i-f, or audio-driver circuit. However, replacement i-f and a-f transistors do not usually work well in r-f circuits.

In selecting power transistors, the mounting requirements, current handling ability, and breakdown voltage rating are the paramount concerns. In replacing power transistors, it is a good idea to replace any insulating washers used. These washers are usually supplied with the replacement transistor. Also apply silicon grease between the transistor and its heat-sink to increase heat transfer.

TESTING DIODES

Diodes can be tested using an ohmmeter as shown in Fig. 10-17. When the positive terminal of the ohmmeter battery is connected to the anode of the diode, it should show a low resistance. When the ohmmeter leads are reversed, it should show a high resistance.

A defective diode will show essentially the same reading in both directions.

This test is the same for all types of diodes, including power diodes, detector diodes, varactor diodes, and zener diodes. When

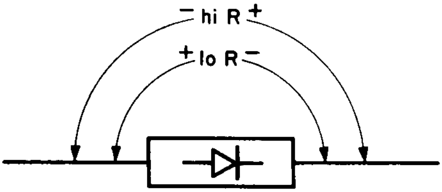


Fig. 10-17. Resistance test of a diode with an ohmmeter.

testing zener diodes, it is often advantageous to verify the correctness of the zener voltage. This test, using the arrangement shown in Fig. 10-18, requires a variable d-c regulated power supply, a milliammeter, and a voltmeter. The power supply must be able to provide a voltage greater than the zener voltage rating of the diode. The test is as follows:

1. Connect equipment as indicated, with power off.
2. Set power supply voltage to zero and turn on power supply.
3. Monitoring the current and voltage on the meters, slowly increase the supply voltage. When the zener voltage is passed, the milliammeter should indicate a sudden increase. Continue to increase

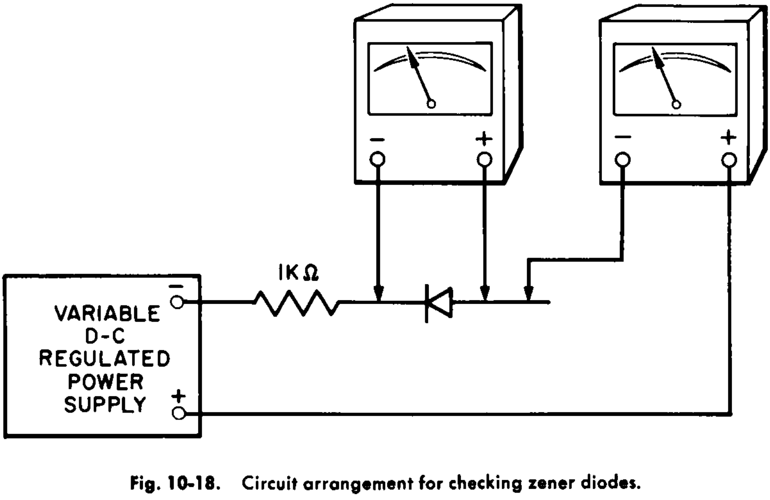


Fig. 10-18. Circuit arrangement for checking zener diodes.

the supply voltage until the diode current rating is reached (as shown on the milliammeter), being careful not to exceed the diode's current rating. The voltage across the diode should increase until the zener voltage is reached; then it should remain constant as the supply voltage is increased further.

SERVICING CIRCUITS USING IC's

A few general points should be kept in mind when servicing circuits utilizing IC's. First, all of the techniques and precautions of transistor service also apply to IC's. Second, because of the many internal circuits and because replacements are probably not readily available, it is important to be sure that a "suspected" IC is defective before actually replacing it. Third, some IC's are soldered onto printed-circuit boards. Hence, it is often inconvenient, if not impossible, to remove an IC, try another, and then reinstall the original. You will not be able to "try" IC's as you can tubes.

Voltages. Each section of an IC is probably d-c coupled from input to output. Internal defects usually cause a considerable change in terminal voltages. Thus, measure those voltages and compare them with the recommended values.

In taking voltage readings at IC terminals, be extremely careful about "slipping" and also about grounding or applying too much voltage to some IC circuits. The comparatively low-current, low-voltage, low-power components in IC's are easily damaged or destroyed.

Any drastic change in voltage at an IC terminal is usually a reliable indicator of IC failure, assuming the external circuitry is operating correctly. For example, in Fig. 10-19, we see the FM-i-f amplifier section of an AM-FM auto radio. Four IC's are used in the four stages of i-f amplification. Each stage uses the same IC. The supply voltage fed in on terminal 8 is normally 10.1 volts. IC terminals 1, 3, 5, and 7 are all supplied and controlled internally. Terminals 3 and 5 should be 1.4 to 1.6 volts, and terminals 1 and 7 should be 9.2 to 9.7 volts. These voltages should be independent of normal variations in the supply voltage at terminal 8. As long as the voltage on pin 8 is normal, any drastic change in the voltages at terminals 1, 3, 5, and 7 would indicate a defective IC.

A low supply voltage on pin 8 could be due to a short within the IC. This can be located by cutting the track to terminal 8 of each IC and observing whether the voltage returns to normal. If the supply voltage returns to normal when the supply voltage to one particular IC is cut, it indicates that a short actually does exist in this particular IC.

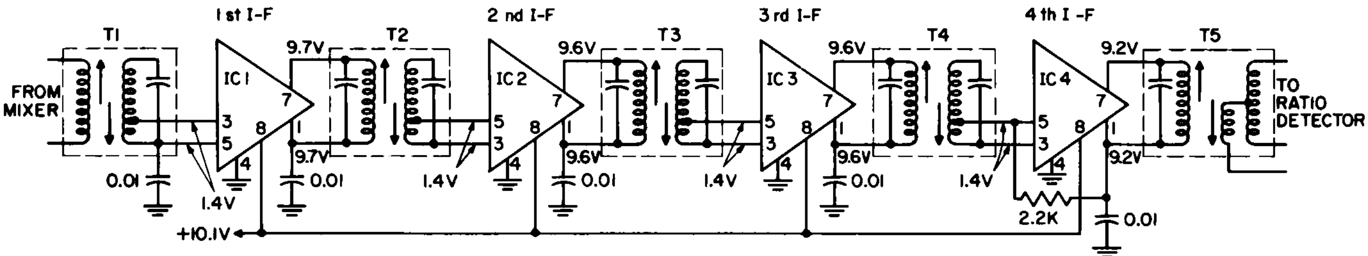


Fig. 10-19. FM i-f amplifier section of AM-FM auto radio (Motorola model FM 108M).

Signal Tracing. Signal tracing is accomplished in the same manner as it is for discrete component circuits, except that there are fewer accessible points. In Fig. 10-19, a 10.7-mc signal injected at terminal 3 of each i-f should produce an amplified 10.7-mc output at terminal 7. If there is a loss of signal or no gain, proceed to check the IC's voltages as described in the previous section.

Replacement. Remember to check all external circuit components to be absolutely sure the trouble is not external to the IC. If the IC's voltages are "off," and all external components check-out, then the IC can be replaced with reasonable assurance that it is defective. It should be replaced with one of an identical type; few alternative replacements for linear IC's exist at this time.

When installing the new IC, be sure that all connections are good low-resistance connections. IC's are usually much higher gain devices than single transistors and hence are more subject to self-oscillation as a result of impedance in the ground circuit.

IN-CIRCUIT VOLTAGE MEASUREMENTS

The most important voltage to be measured on a transistor is the bias voltage between base and emitter. This voltage will generally range between 0.05 and 0.2 volt for germanium and 0.3 to 0.7 volt for silicon transistors. If the voltage is incorrect by more than 10–20%, distortion, low gain or excessive current drain will result. Generally, in transistor radios, the collector-to-emitter voltage ranges between 2 and 12 volts (this will, of course, vary with battery voltage and stage being measured).

If the transistor is good and incorrect voltages are measured at transistor terminals, they are usually caused by "cold-solder joints" on the printed-circuit boards, shorted capacitors, open transformers or resistors.

IN-CIRCUIT RESISTANCE MEASUREMENTS

When resistance-checking a circuit, remove the transistor from the circuit. If the transistor is soldered to the printed wiring board, disconnect one terminal of the component to be checked from the board. This is necessary since the voltage that appears across the terminal leads of an ohmmeter can cause conduction of the transistor, and therefore erroneous ohmmeter readings. In addition, this voltage may also cause the transistor to conduct beyond its capabilities and permanently damage it.

CURRENT MEASUREMENTS

A check of the current drain of a defective receiver will indicate whether some defective component in the receiver is causing excessive conduction. Typical defects which cause high current drain are a fused transistor, shorted or leaky electrolytic capacitor, incorrect bias on transistor or incorrect battery polarity. In these cases, the current may be double or triple the normal receiver current drain.

To check the current drain, place a milliammeter (approximately 100 ma) in series with the battery. An alternative is to turn the receiver off and connect the meter across the terminals of the on-off switch.

Generally receivers with push-pull audio output stages have an idling current ranging from 5 to 10 ma (no signal being received). This will increase to as high as 50 ma when a signal is being received. In receivers having class-A audio output stages, the current drain remains fairly constant from signal to no-signal conditions. The current drain will range from 10 to 20 ma, depending on the number of transistors used and the battery voltage.

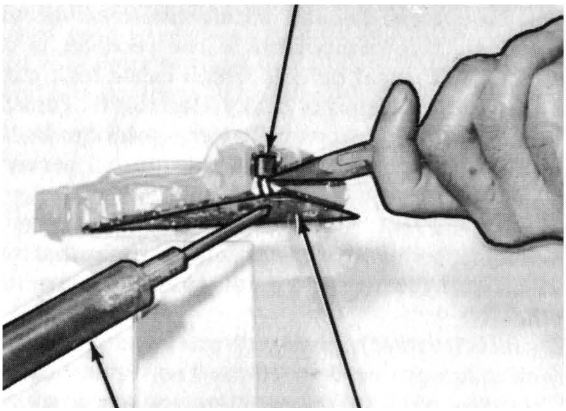
WORKING WITH TRANSISTORS AND INTEGRATED CIRCUITS

Although transistors and integrated circuits have a life expectancy which can be considered infinite, they are easily damaged by excessive heat and improper voltages. Permanent damage can be done to the crystal-lattice structure and the distribution of certain impurity atoms in the transistor. In addition, transistors and integrated circuits have limited heat-dissipating ability because of the extremely small dimensions. Therefore, they are sensitive to heat and current, and certain precautions must be observed when servicing transistor radio receivers.

Heat. Use a low-wattage soldering iron for all soldering (such as the iron described in Chapter 11). If the transistor is in a socket, remove it from the socket prior to soldering components into the circuit. If the transistor cannot be removed from the circuit, use a needle-nose plier or a device similar to a heat sink at the element being soldered to absorb the conduction of heat. An example of this procedure is shown in Fig. 10-20.

Always solder as quickly as possible. Use a low melting point, rosin-core solder (e.g., eutectic solder consisting of 63% tin and 37% lead). Tin the leads before soldering. Be sure the soldering iron is hot enough to melt the solder quickly before beginning.

TRANSISTOR



SMALL TIP TYPE SOLDERING IRON

PRINTED CIRCUIT CHASSIS

Fig. 10-20. To prevent heat damage to the transistor, use a needle-nose plier as a heat sink at the transistor lead to conduct heat away from the transistor.

Keep the transistor leads as long as possible to prevent conduction of heat to the transistor. Do not have battery voltage applied to the receiver at this time.

When replacing integrated circuits, use a soldering iron with a special tip that heats all the connections simultaneously. Such an iron is shown in Chapter 11.

Voltage and Current. Be careful when probing around in transistor radio receivers. Indiscriminate tugging, pushing, and touching of leads and components can create momentary current surges. These currents can do great damage in low-impedance transistor circuits. Likewise, touching the transistor terminals together will disrupt the existing bias and momentary current surges may cause the transistor to fuse. Do not have voltage applied to the receiver when installing or removing transistors from a circuit.

WORKING WITH PRINTED CIRCUITS

To replace a component on a printed circuit board, proceed as follows: Heat the solder joint on the printed side and draw the component lead through (use a soldering aid tool, described in Chapter 11, to help loosen crimped leads). Heat and clean out the lead hole with the soldering aid and a wire brush. Form the leads of the replacement component and insert leads into proper holes of the printed circuit board. Resolder the leads using a recommended solder, and remove the excess flux with alcohol. Clip off any excess lead wire.

Two methods of repairing breaks in the printed copper wiring are shown in Fig. 10-21. Cut a piece of hookup wire about ½ inch longer than the break. Tin both ends. Center the wire over the break, along the conductor. Heat both ends of the wire and the printed wiring to solder the wire ends to the ribbons. Clean off excess flux with alcohol.

If the printed circuit wiring should become raised from the board, clip off the raised section, and replace it with a section of standard hookup wire. Secure each end at mechanically sturdy tie points.

Broken printed circuit boards may be repaired with Pliobond cement. Apply the cement to both parts of the board, then press together and clamp in position. Allow the board to set for 24 hours. After the board has been repaired, the printed wiring should be bridged with pretinned wire soldered to the printed wiring. If

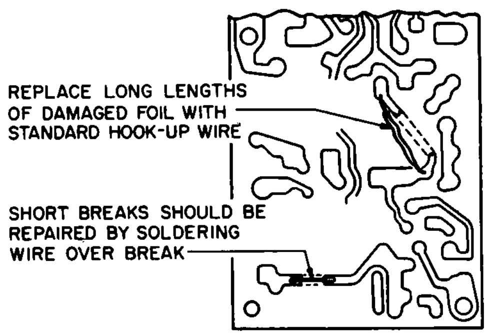


Fig. 10-21. A method of repairing wiring on a printed circuit board. *Courtesy RCA.*

heavy components are mounted on the broken section of board, it may be necessary to strengthen the repair joint with an added piece of phenolic board material (using cement).

To check for cold-solder connections to the board, turn the receiver on and run an insulated tool over the wiring side of the board (an alignment tool will do very well). Also, gently move the components on the other side of the board back and forth to find the bad connection. If these techniques do not prove successful, try reheating the printed circuit connections of the inoperative circuit with a soldering iron.

In the case of intermittent operation of the receiver, the trouble may be due to a "microcrack" in the wiring on the printed board. This can often be located by flexing the printed board with the receiver turned on. A close examination of the copper ribbon with a magnifying glass may also disclose the break. These cracks can be repaired easily by carefully flowing solder over the break.

COMPONENT REPLACEMENT

Batteries. When a battery nears the end of its useful life, its internal resistance rises rapidly. Therefore, the battery voltage should be measured under load (in the receiver, with the unit turned on) as the first step in troubleshooting a transistor radio.

If the battery voltage is found to be less than two-thirds its rated value, the battery should be replaced. A weak battery causes loss of sensitivity, distortion, and, in some cases, harmonic beats or audio oscillations (squeals).

Be careful not to install batteries in a receiver backwards. This may permanently damage the receiver's transistors and low-voltage electrolytic capacitors.

Batteries deteriorate rapidly in excessive heat. Therefore, do not leave the receiver turned on near a source of heat.

Run-down batteries should be replaced as soon as possible. The chemical action, in very many cases, causes it to leak battery acid. This acid may permanently damage the receiver with its corrosive action.

Electrolytic Capacitors. Electrolytic capacitors used in transistor radio receivers are of the low-voltage type and, therefore, can easily be damaged by mishandling. This point should be borne in mind when making ohmmeter checks in the receiver. Always maintain the correct voltage polarity across electrolytic capacitors.

Transformers. Transformers used in transistor radio receivers (e.g., i-f and audio) are matching the medium impedance of the preceding transistor's collector circuit to the low impedance of the following transistor's base circuit. Therefore, all transformers are of the stepdown type. Hence, a definite loss of signal voltage (increase in signal current) will be measured during signal tracing between the primary and secondary of i-f and audio transformers.

Replacements. Since impedance matching between stages in transistor radio receivers is very critical, use exact replacements for defective components which affect impedance matching (e.g., oscillator coils, antennas, i-f transformers, volume controls, audio driver, output transformers, and loudspeakers).

11. Tools and Test Equipment

Good servicing is based on good tools, good techniques, and good test equipment. All three are musts before embarking on the servicing of transistorized equipment. Troubleshooting techniques for transistor radios were discussed in Chapter 10. Here we will discuss how the technician must adapt himself to this new field with some new tools and test equipment.

HAND TOOLS

When servicing compact transistor radio receivers, it is advantageous to use smaller than normal servicing tools (Fig. 11-1). Note that most of these tools are of the type used in the servicing of printed circuitry. There is relatively little difference in the tools required in servicing transistorized and printed circuitry, with much of this circuitry found together in equipment.

A small low-wattage soldering iron with a relatively narrow tip will be found very helpful. In addition, specialized soldering tips can further simplify removal of integrated circuits, transformers, coils, and other multi-lead components on printed-circuits boards. For direct chassis work, however, it may be necessary to use a larger 100-watt iron or a soldering gun. Small diagonal cutters and long-nose pliers will be found useful for getting into tight spots. Curved needle-nose pliers can also act to an advantage.

A small relatively stiff-bristled brush is a useful tool for cleaning excess solder from component terminals that need to be unsoldered cleanly. A small wire pick or soldering aid is useful for handling short leads on components. A thin-blade knife permits separation of flat component contacts from sealed wiring surfaces such as those which are to be found on some transformer cans. Solvent such as denatured alcohol or lacquer thinner should be used to

Fig. 11-1. Small servicing tools for servicing compact transistor radios. Courtesy RCA.

remove the protective coating of wax or silicon resin and to clean areas of circuitry before and after repairs have been made on the sealed wiring. When a protective coating has been removed in order to make a repair, be certain to recoat the area with silicon resin or lacquer to seal out moisture or dust.

In addition to the above tools, a magnifying glass will often come in handy. A typical small soldering iron is shown in Fig. 11-2. This unit is a heavy duty 40-watt unit having a tip diameter of only 1/4 inch and an overall length of only 8 inches; it is ideal for transistorized circuitry work. For instant heat in close chassis work, a soldering gun such as that shown in Fig. 11-3 works well. While rated at 150 watts, it has a tip size of only 1/4 inch. If possible, the soldering iron should have a temperature control to keep the iron from getting too hot while it is not being used. The

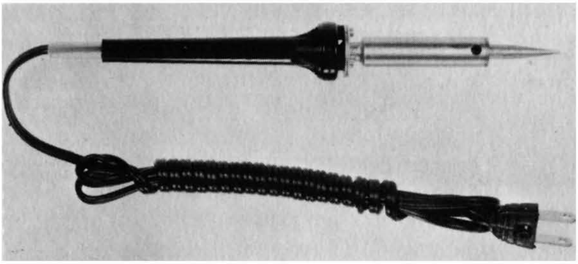


Fig. 11-2. Small, heavy duty, 40-watt soldering iron with tip diameter of 1/4 inch and overall length of 8 inches. Courtesy *Wall Mfg. Co.*

soldering iron should be checked to be sure it has no a-c leakage, as leakage currents from a soldering iron can harm transistors. Where possible, a hand iron should be used in preference to soldering guns to avoid the possible danger to transistors due to induced currents.

Figure 11-4 shows a set of soldering aids of considerable value to the technician doing transistor and printed circuit work. The forked ends are used to straddle the wire and permit easy unwinding and removal, or to guide it into another lug for soldering. The curved end may be used for scribing and for circuit tracing when tracing down loose connections. The pointed end makes a good solder reamer. The brush and knife are used as was described.

Fig. 11-3. Soldering gun rated at 150 watts with tip size of 1/4 inch and overall length of 8 inches for instant heat in close chassis work. Courtesy *Wall Mfg. Co.*

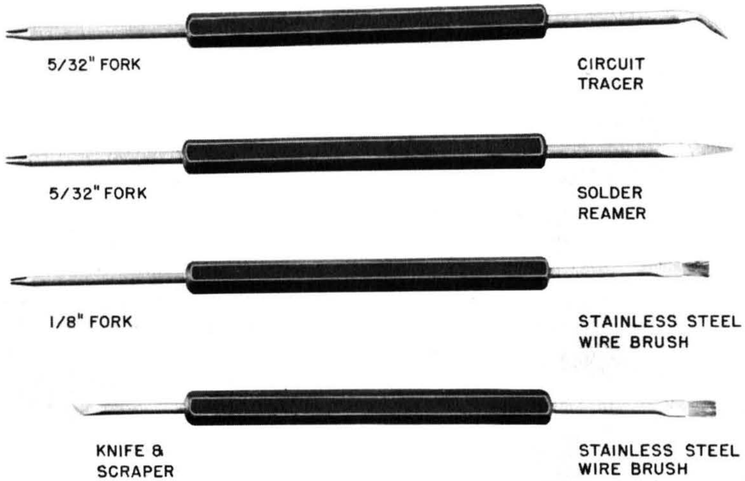


Fig. 11-4. Soldering aids. Courtesy *Erikson Tool Co.*

TEST EQUIPMENT

All test equipment should contain transformer type power supplies. Transformerless test equipment should be used only when an isolation transformer is placed between the equipment and the a-c power line.

Voltmeter. A vacuum tube voltmeter (vtvm) is recommended for all voltage measurements. The vtvm should have a sensitivity of 10 megohms or better. If a multimeter is used, it must have a sensitivity of 20,000 ohms per volt or better on all ranges; otherwise, excessive current will be drawn from the circuits being checked.

The low voltage range of the voltmeter should be 1.5 volts or less full scale, with an accuracy of at least ±1%. This is necessary since the d-c voltage at the base of a transistor is of such small magnitude that comparatively small variations in voltage become large variations percentage-wise. For example, if the normal base bias of a transistor should be 0.05 volt, and the actual voltage measured is 0.09 volt, there is an 80% increase (0.04 volt). Therefore, a very accurate and sensitive voltmeter should be used to measure voltages in transistorized equipment. One such instrument is shown in Fig. 11-5. Generally, circuit checks made with an accurate voltmeter are more useful than resistance checks.

A high input-impedance vom is very desirable. Today, the FET has made this possible. Many battery-operated transistorized vom's, usually referred to as "FET-vom's" are available. Being battery-operated, they are isolated from the a-c power line and can be used to take "floating" measurements (for example, across the collector load) without endangering the radio. Several are also a-c-line operated.

The FET-vom usually has a d-c input resistance greater than 10 megohms and a very sensitive input (for example, 1 volt full scale), both of which are useful in measuring the base-to-emitter bias voltage. The FET input circuit of the FET-vom should contain protection for the FET against over-voltage.

Fig. 11-5. Typical vtvm recommended for use in servicing transistor radios —RCA model WV-98A. Note the very large meter face with a 1.5-volt full deflection scale.

Ohmmeter. Ohmmeters must be of the low current type, not passing more than 1 ma on any range. This current should be checked by connecting a milliammeter (which must have a low resistance) in series with the ohmmeter's leads. The current drawn on all ranges should then be checked. Generally it is safe to use an ohmmeter with a battery rating of 3 volts or less, if used on the R $\times$ 1000 scale or higher.

Transistor Testers. There are already over 15,000 registered transistors and probably another 15,000 that are unregistered "in-house" transistors for which only the manufacturer and his supplier know the specifications. Therefore, transistor testers cannot be made to test specific types as tube testers do. Instead, the commercial transistor tester provides essentially the same d-c tests that were described in the previous chapter. Most testers also provide a low-frequency a-c gain test. It is questionable whether this provides any more reliable data than the d-c tests. No tester provides a high-frequency gain test for r-f, i-f, and oscillator transistors.

The transistor testers do provide a better indication of leakage since they generally test the transistor at a higher voltage than do the ohmmeter tests described previously. The great advantage of transistor testers is that they save considerable time for someone doing a great deal of transistor equipment repair. A typical transistor tester is shown in Fig. 11-6.

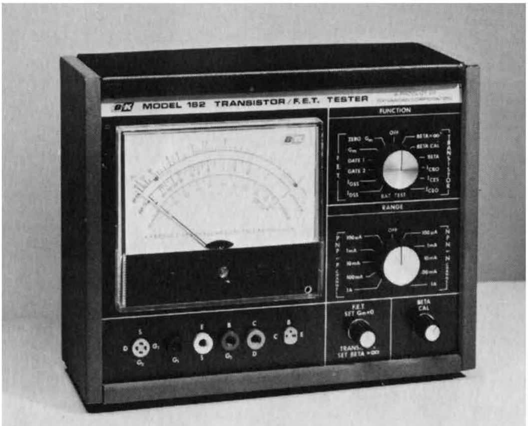


Fig. 11-6. B & K model 162 transistor tester.

Oscilloscope. Oscilloscopes used in servicing transistorized equipment must have a high sensitivity (0.1 volt per inch or better). This sensitivity is required since the signals present at the base of a transistor are generally of very low amplitude. The oscilloscope input impedance should be at least 1 megohm. A low-impedance probe is not required for signal tracing, since transistor circuitry is all low or medium impedance.

Capacitor Checker. Capacitor checkers should *not* be used to test the low-voltage electrolytic capacitors used in miniaturized transistor radio receivers. Most capacitor checkers apply voltages far in excess of the ratings of these low-voltage capacitors, and can very easily damage them.

Power Supplies. Battery eliminators are not recommended for use with transistorized equipment unless they have been specifically designed for the purpose (i.e., have low ripple content and good regulation). Power supplies for use with transistor radios should be

Fig. 11-7. Low-voltage power supply (Eico model 1025).

capable of providing up to 30 VDC and 300 ma. They should be protected against overload by a fuse or current-limiter circuit. They should utilize a transformer to isolate the output from the power line (for safety). They should have less than 10-mv ripple, and although not absolutely necessary, a voltage-regulator circuit is desirable. An additional convenience is a built-in voltmeter and ammeter. An economical power supply that meets these basic specifications is shown in Fig. 11-7.

A simple power supply for servicing portable transistor radios can easily be constructed by the technician. One such unit is shown in Fig. 11-8. The power transformer was designed for use in tube tester service and provides a great number of low-voltage taps on the secondary. Only the voltages used in transistor receivers are used; however, if the power supply is also to be used for other purposes, these taps can be employed. The transformer primary provides three taps used to compensate for line voltage changes. A silicon rectifier is used because it provides better regulation. Large-value electrolytic capacitors provide the necessary filtering and low power-supply impedance. As an added convenience, the technician can incorporate a voltmeter across the output and a milliammeter (0–100 ma) in series with the output to provide indications of the receiver's operation.

Signal Tracers. For those doing a large amount of transistor radio servicing, a signal tracer, such as the one shown in Figs. 11-9 and

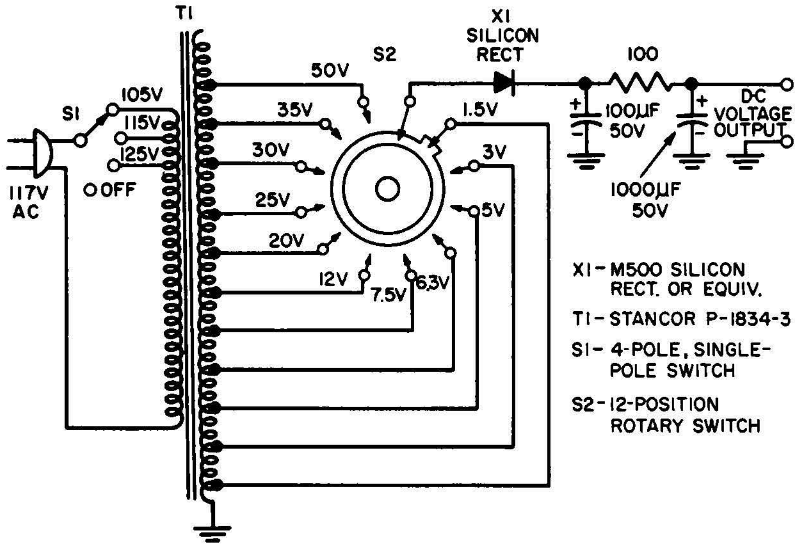


Fig. 11-8. Power supply for servicing transistorized equipment.

11-10, may prove to be a very valuable time-saver. The unit can be used to check the r-f, i-f, and audio sections of a receiver to determine where a signal is being blocked because of a circuit defect, or where noise or oscillation is being introduced. Hence, it can quickly locate the stage where the defect exists. The unit contains a substitute loudspeaker and audio output transformer to check these components by substitution.

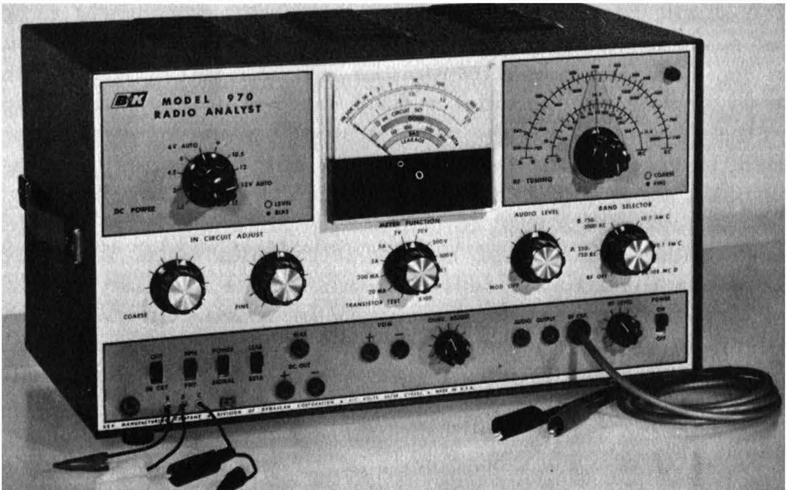


Fig. 11-9. B & K model 970 Radio Analyst (including a d-c power supply, volt-amp-ohmmeter, signal generator, and transistor tester).

Fig. 11-10. Signal tracer (Eico model 150).

Transistor Curve Tracers. Transistor curve tracers provide a more precise indication of the characteristics of transistors and diodes and are therefore very useful in the laboratory. Although it is questionable whether their relatively high cost is worth their use in a service shop, shops doing work on equipment for which a close match is required between transistors may wish to purchase this instrument. It will provide a precise indication of the transistor gain, leakage current, breakdown voltage, and input capacitance. However, transistor curve tracers that do not include the oscilloscope must be connected to an oscilloscope having a d-c input. Furthermore, interpretation of the displayed curves requires a good technical understanding and experience.

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