RADIO RECEIVER
SERVICING GUIDE

By Robert G. Middleton

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Contents

Preface

This book was prepared with the professional technician (particularly the neophyte) in mind. The coverage includes both solid-state and tube-type receivers, and concentrates on troubleshooting and repair of a-m receivers. Trouble localization is explained in detail throughout, and many notes concerning the use of test instruments are included. The book is functionally divided into the various receiver sections, and subdivided according to symptoms. Most of the possible causes for each symptom are listed, and those troubles most frequently encountered are analyzed. Common variations in circuitry are noted in order to make the troubleshooting procedures as general as possible.

The first chapter explains general troubleshooting and isolating procedures and describes in progressively greater detail how trouble situations are approached and analyzed until the defective component or condition has been pinpointed. Next, a comprehensive coverage of troubles in the rf and mixer stages is given in Chapter 2. Both transistor and tube-type front ends are considered. Considerable attention is given to functional illustration. In Chapter 3, the intermediate-frequency amplifier is analyzed in detail. An explanation of modern integrated circuitry is included. The FET is also discussed. Misalignment conditions causing trouble symptoms are covered, but the reader is referred to the receiver service data for the alignment procedures required by a particular receiver.

Troubles in the audio section (including the detector) are analyzed in the fourth chapter. Both voltage and current detection are given attention, and detector arrangements in the older tube-type receivers are included, as well as those in modern solid-state receivers. Since avc (or agc) can present problems in routine bench work, this subject is allotted a complete chapter. Some of the more elaborate avc and squelch arrangements found in communications receivers are included. Noise-limiter sections are noted also. A complete chapter deals with power supplies, because there is a definite trend to increased complexity in this section of solid-state receivers. Regulated power supplies are much more common now than they were in the past. This chapter also includes practical noise-suppression techniques for auto-radio installations.

The final chapter, which deals with a rare avocation, gives practical pointers on restoring antique radio receivers. Topics include cabinets, audio-transformer problems, tube problems, coil restoration, coherer repair, restoration of carbon detectors, troubleshooting carbon amplifiers, panel repair and replacement,

mineral detector problems, and battery requirements. This is a rather specialized field, because many of the components used in antique radios are not recognized by modern technicians. This area of servicing is comparatively high-paid, since there are very few qualified technicians who can meet the demands of collectors throughout the country.

It is my firm belief and sincerest hope that this book will be a valuable addition to the libraries of all present and future professional radio technicians.

ROBERT G. MIDDLETON

Chapter 1

General Troubleshooting and Isolating Procedures

There is no single procedure for troubleshooting all of the different kinds of receiver failure. However, it is possible to set up a general procedure for each category of receiver trouble. That is, after the nature of the trouble has been determined, the technician can select an appropriate procedure. A good timesaving troubleshooting approach is shown in Fig. 1-1. The first five blocks are concerned with localization of the defect. The last two blocks are steps used in repairing a defect and restoring the circuit to normal operation. In many cases, you will be able to skip some of the first five steps. For example, you may be able to localize the defect without going through Steps 3, 4, and 5. The arrows indicate how some of the localization steps may be skipped. Always employ the last two steps.

GENERAL REQUIREMENTS

Among the basic bench timesavers, the first requirement is a good understanding of electrical and electronic action in the circuit that is being analyzed. Functional block diagrams are very helpful in the analysis of receiver sections. After isolation to a specific block, reference should be made to actual circuits. The next important requirement is a good understanding of the test equipment used on the job. It is as essential to recognize the limitations of a test instrument as it is to know its capabilities. For example, we should know whether a given VOM,

VTVM, or TVM will seriously load a high-frequency oscillator circuit and give a false voltage reading.

Logical Thinking

To be most effective and profitable, troubleshooting must be accurate and swift. Therefore, logical thinking, combined with ingenuity, common sense, and good practices, is required. In most cases, the
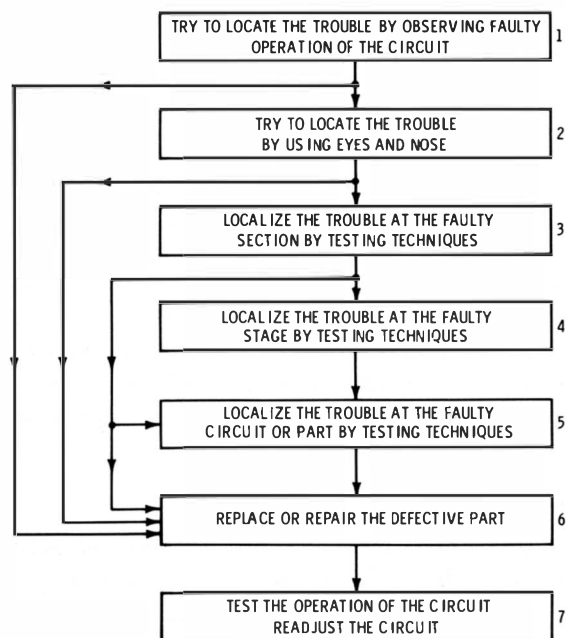

Fig. 1-1. Basic approach to a troubleshooting job.

technician must think for himself and do his job without assistance. Thus, basic maintenance practices are an essential part of the technician's background. Competence is an outgrowth of knowledge and experience. It is a hard fact that competence is not acquired overnight. A technician with experience is professionally limited if he has had no training in theory. Similarly, a "pure theory man" is seriously handicapped if he has had no practical experience. Practical experience can be gained only by working with equipment over considerable lengths of time. In summary, to be a good troubleshooter requires a happy combination of practical experience and pure circuit theory.
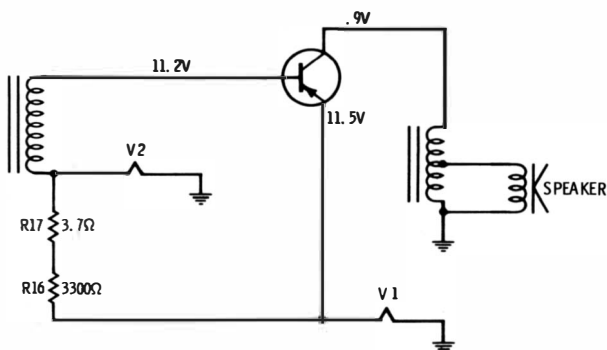

Fig. 1-2. Practical analysis of this circuit requires a logical approach.

Let us consider an example of logical thinking on the job. With reference to Fig. 1-2, the audio-output stage becomes suspect when we fail to hear a "thump" as an auto radio is switched on. In a typical case history, the trouble was caused by a burnt base resistor. An ohmmeter check was inconclusive, because of the parallel path through the transistor to ground. Therefore, to insure a correct check of the base resistor, one leg of the resistor was disconnected from the printed-circuit board or chassis tie point to make the resistance measurement. In the example of Fig. 1-2, the base resistor should measure 3.7 ohms; however, it often increases greatly in value or opens up in case the transistor shorts. Since this is a defect that may not show up on visual inspection, logical analysis is our follow-up analytical tool. Note that the base or emitter resistor in this stage of an auto radio is often listed as a fuse.

Necessity for Service Data

It is probably true that very few technicians know everything about the various radio receivers that cross their bench for repair. Although we are all familiar with the general block diagram for a superheterodyne receiver, there is much more to be known. A block diagram assists us at the outset, but there are circuit details that require additional knowledge if we are to analyze trouble symptoms rapidly and correctly. To get this additional knowledge, we consult the receiver service data. It is our source of information which describes the receiver in full technical detail. The circuit diagram is supplemented by tube socket voltages, resistance charts, and the resistances of transformers and coils. It also shows pictorially the location of each component part and lists acceptable replacements. Component localization is particularly needed in the case of printed-circuit boards.

BASIC TROUBLESHOOTING PROCEDURE

Both tube-type and solid-state radio receivers are serviced in most shops. Let us start by considering the basic troubleshooting procedure for tube-type sets—this procedure also applies to the tube sections in hybrid receivers. Before testing the tubes, look to see whether any of the heaters are glowing. Next, check to see whether B+ voltage is present. In case the supply voltages are all right, proceed to check the tubes. Either a tube tester (Fig. 1-3) or the tube-substitution method may be used. If a tube tester is available, first turn off the power and then remove and test the tubes one at a time. Substitute new tubes only for those that test defective. If a tube is suspected of being intermittent, it should be tapped lightly while being checked, to help show up the intermittent condition.

Fig. 1-3. Typical tube tester.

If the tubes are being checked by substitution, and the set begins to operate normally, discard the last tube removed and return the other original tubes to their sockets. Some circuits, such as oscillators in short-wave sets, might operate with one good tube, but not with another. (See Fig. 1-4.) This can happen because of the difference in the interelectrode capacitance of the tubes, which may play a large part in determining the oscillating frequency. Therefore, if a tube does not operate in a high-frequency oscillator circuit, do not discard it until it is known to be definitely bad. Beginners should note that by rocking or rotating a tube, the pins may be bent, the weld wire may be broken where the pin enters the glass, or even if the weld is not broken, a high-resistance joint may be produced.
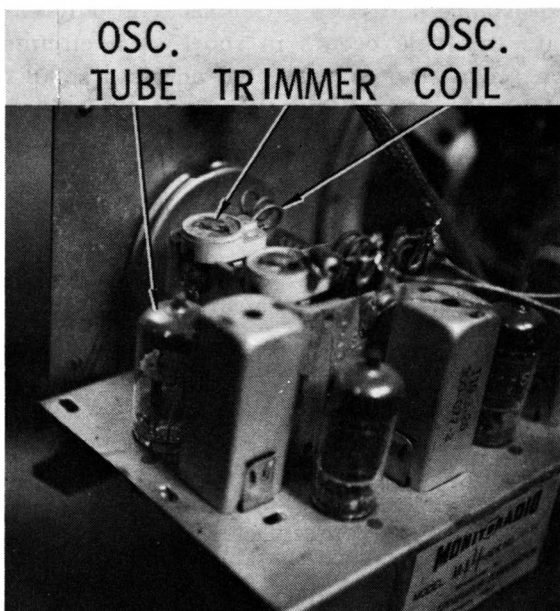

Fig. 1-4. View of oscillator coil, trimmer, and tube in 108–136 MHz receiver.

In case a replacement tube becomes defective immediately, we must check the component parts in the associated circuit. Note that although it usually happens that only one tube fails at a time, it is possible for a chassis to develop two or more defective tubes simultaneously. In such a case, substituting tubes one at a time and reinserting the original tube before substituting for a second time will not pinpoint the defective tube. The original tube may have been defective, but might not show up because another defective tube prevents its normal operation. To correct this trouble, install new tubes and keep putting in new tubes until normal operation is restored. Then, the last tube replaced is defective and should be discarded.

To determine whether another original tube is bad, return an original tube to its socket. If there is a noticeable change in operation, discard the last original tube installed. Another method is to install all new tubes and then replace them with the original tubes, one at a time. When a trouble symptom is noted, discard the last original tube installed. We seldom leave a new tube in a socket, if the receiver operates satisfactorily with the original tube. If tube replacement does not restore the receiver to normal operation, further troubleshooting is necessary. A tube should not be discarded unless a tube tester or other instrument shows it to be defective, or if it can be seen that the tube has a broken glass envelope, an open filament, or a broken base pin. Do not discard a tube merely because it has been in operation for a long time. The final proof of tube quality is indicated by satisfactory operation in the receiver.

Checking Series Heaters

Series heater strings present a different approach, because an open heater in one tube will cause all other heaters in the string to remain cold. Most technicians remove the tubes one at a time and check the heaters for continuity with a tester such as is illustrated in Fig. 1-5. If a chassis is being checked at the bench, the tube with the open heater can be localized by measuring the voltage across the tube heater terminals with all the tubes in their sockets. All good tubes in the string will measure zero volts

Courtesy Paco Electronics Co., Inc.
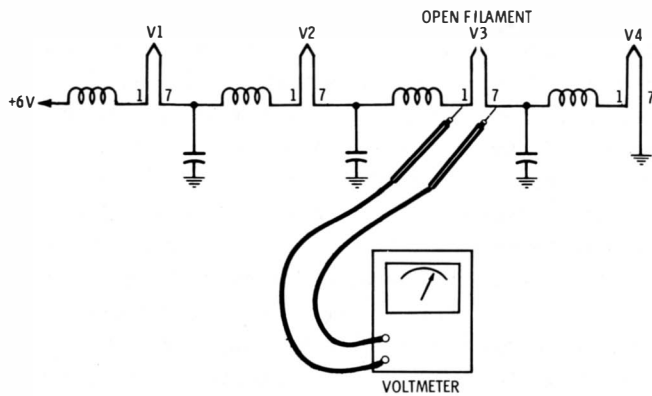Fig. 1-5. Filament continuity tester.

Fig. 1-6. Finding open filament with a voltmeter.

across their heaters, but the one that is burned out will have the full supply voltage dropped across the terminals, as shown in Fig. 1-6. In this example, the voltage drop across each filament will be 1.5 volts when the defective tube is replaced.

Occasionally, an old-type receiver will have series-parallel heater circuits, which often have shunting resistors across some heaters in the series circuit to maintain the current at correct value in each tube. This type of circuit can be deceptive, because the voltage measured across a burned-out heater may be nearly the same as the voltage across a good tube. That is, the shunt resistor provides continuity. Therefore, heater-voltage measurements should be made carefully when checking series-parallel heater circuits.

Testing Components

After the trouble has been narrowed down to a section and then to a stage by the use of test equipment or a shortcut method, the trouble must then be pinpointed to the defective component. This procedure requires testing of resistors, capacitors, inductors, and sometimes connections at terminals or various conductors. A VOM is the basic instrument that is used, although it has certain limitations that should be kept in mind. From a statistical standpoint, fixed capacitors are the most common troublemakers in radio circuits; therefore, we will start our procedural discussion with pinpointing of capacitor defects.

There are several ways in which a capacitor can fail. It may open up, or it may become short-circuited. Again, a capacitor may develop various amounts of leakage. Its capacitance may change (an electrolytic capacitor is the most common offender). Any capacitor may become intermittent, and develop a defect as a result of temperature change or mechanical vibration. Some capacitors become intermittent due to voltage surges. It is very easy to check
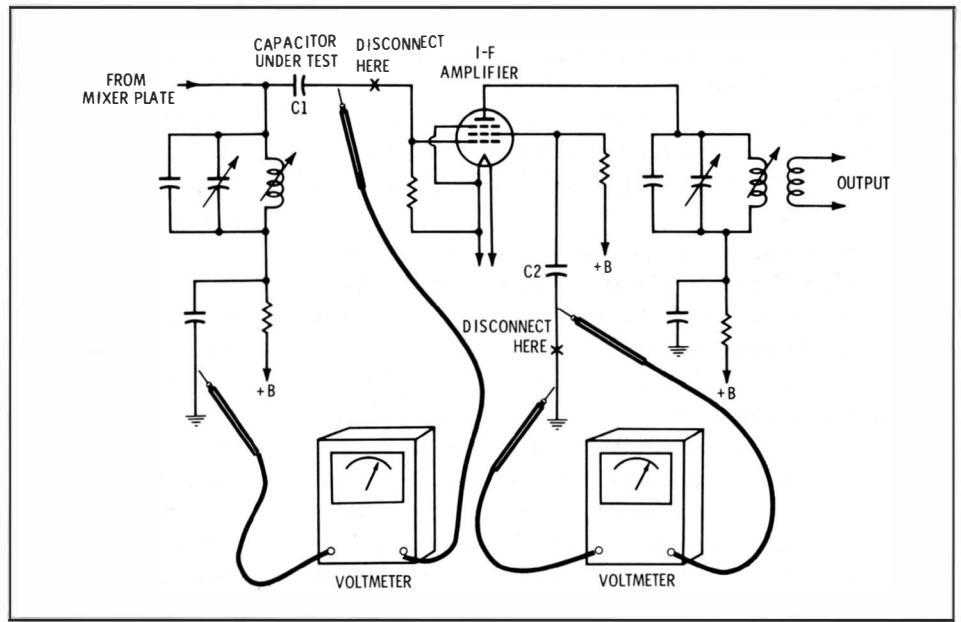
for an open capacitor; we merely bridge the suspect with a known good capacitor. If the circuit operation returns to normal, the diagnosis is confirmed. In the case of an electrolytic capacitor, it is important to observe correct polarity in the test. Also, when working with solid-state receivers, it is advisable to turn off the receiver before connecting the test capacitor into the circuit. This precaution ensures that an abnormal surge, which might damage a transistor, will not be produced.

Shorted capacitors are also comparatively easy to pinpoint. In this discussion, a shorted capacitor is defined as a capacitor that measures zero ohms on the R × 1 range of a VOM. Practically all capacitors in radio circuits operate in circuits that have at least a few ohms of resistance. Therefore, we can usually pinpoint a shorted capacitor by measuring the resistance across its terminals. The only exception to this rule occurs in short-wave circuits in which a capacitor is connected across a small coil. In such a case, the coil resistance is so nearly zero that a useful test cannot be made without disconnecting the capacitor from the coil. That is, we disconnect one end of the capacitor from its circuit and check its resistance with an ohmmeter. If a zero reading is obtained, we know that the capacitor is short-circuited. Note that a shorted capacitor has zero capacitance; similarly, an open capacitor has zero capacitance. Consequently, there is no point in attempting to measure their capacitance values.

Leaky capacitors can often be pinpointed on the basis of changes in circuit voltages that they produce. However, if a leaky capacitor happens to be in shunt with a coil, the most useful clue is the fact that the coil will tune very broadly and will not peak up normally. To confirm the suspicion of a leaky capacitor, most technicians use the disconnect method shown in Fig. 1-7. Of course, this method is inapplicable when the capacitor operates in a circuit that is at ground potential. However, in such a case, we can use a capacitor checker (Fig. 1-8) and apply working voltage across the capacitor. This test can be supplemented by a capacitance measurement, to determine if an otherwise good capacitor may have lost a substantial portion of its rated capacitance.

A *variable-tuning capacitor* or air trimmer can become shorted or leaky. To test for either condition, we disconnect one end of the capacitor from its circuit and check as previously explained for fixed capacitors. It is good practice to vary the capacitor over its complete range while testing, to show up possible defects at particular points. If a variable-tuning capacitor is contaminated with dust, dirt, or grime, it should be well cleaned. A trick of the trade

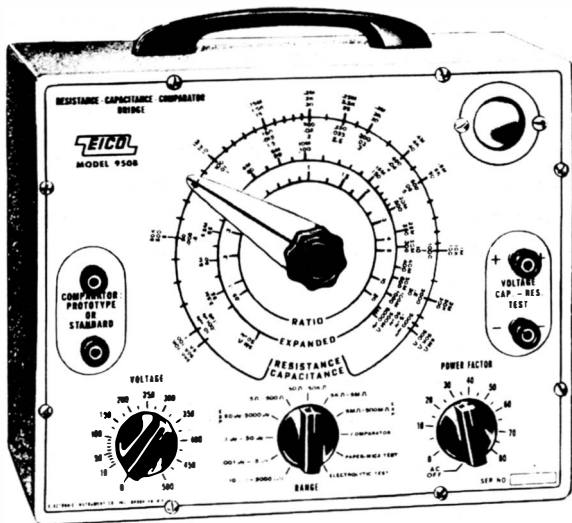**Fig. 1-7. Method for checking capacitors with a voltmeter.**

that is occasionally useful consists in connecting a variable-tuning capacitor across a B+ supply. This procedure will burn out any foreign matter that might be producing leakage between the stator and rotor plates.

Resistors are easy to check for rated value with an ohmmeter, unless the resistor happens to be intermittent. Whenever a component is suspected of being intermittent, it should be analyzed by tapping it while it is connected to the ohmmeter (or other test instrument). It is often helpful to heat the terminals of the component somewhat with a soldering gun and to follow up by chilling it with a suitable spray. These procedures will often speed up the occurrence of an otherwise stubborn intermittent. Beginners should remember that before checking a suspected resistor with an ohmmeter, they should examine the circuit to see whether it is necessary to disconnect one end of the resistor. Remember that diodes and transistors, as well as other resistors or coils, can provide branch-current paths.

In Fig. 1-9, resistor R4 is shunted across the grid winding of transformer T1. If we make a continuity measurement across R4, the low-resistance path through T1 in parallel with R4 will produce a low-resistance reading although R4 might be open. Therefore, we must disconnect one end of R4 before attempting to measure its resistance. On the other hand, plate-load resistor R5 has no resistive component connected in parallel, and we can measure the resistance of R5 without disconnection. Similarly, we can measure the resistance of R6 without disconnection. However, resistance measurements of R1, R2, or R3 must be made with one end of the resistor disconnected. Experienced technicians know that there are occasional exceptions to the foregoing

Fig. 1-8. Capacitance checker.

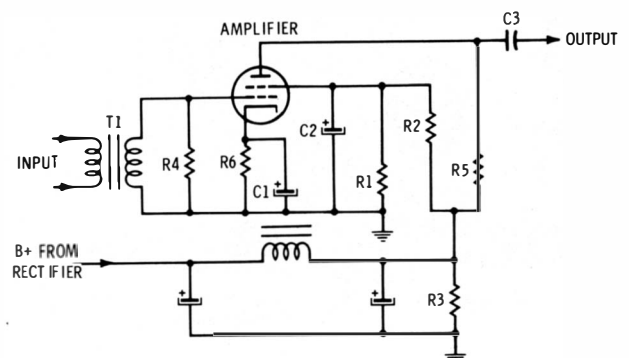**Fig. 1-9. Audio amplifier circuit.**

rules. For example, if C1 happens to be shorted, the resistance of R6 will measure zero unless one end of the resistor is disconnected. Again, if one end of R2 is disconnected, its resistance can always be measured accurately. However, if we next measure the resistance of R1, the reading will be in error if C2 is leaky or shorted.
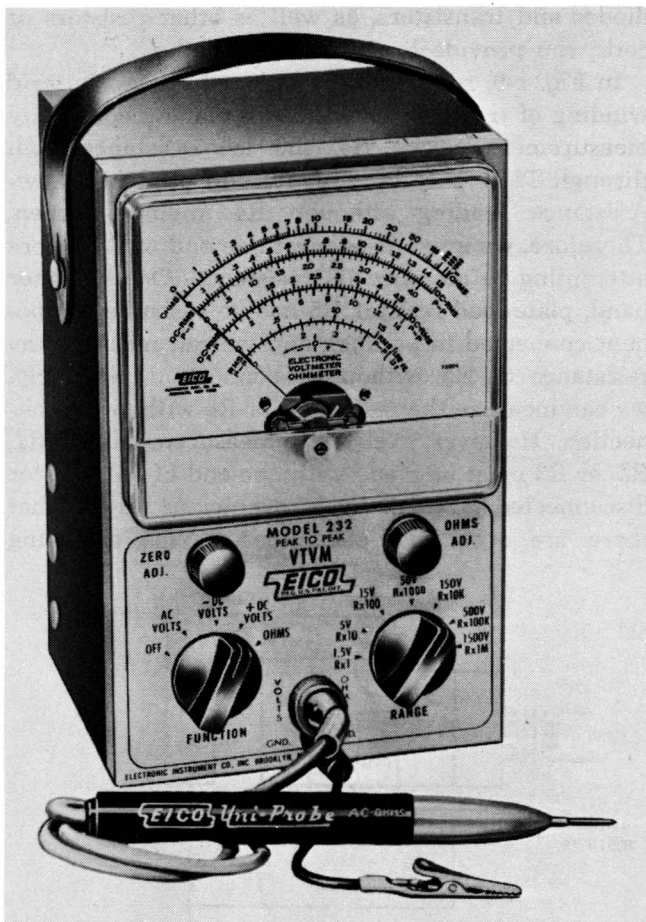
Resistance values can be measured with a Wheatstone bridge. For example, many capacitor checkers, such as the instrument illustrated in Fig. 1-8, have a built-in Wheatstone bridge and provide several resistance scales on the front panel. However, bridge operation is comparatively slow, and practically all technicians use ohmmeters for routine resistance measurements. We use a bridge primarily to check the accuracy of an ohmmeter if it is suspected of defective operation. Various types of ohmmeters are used at the bench, and the ohmmeter function of an instrument is usually accompanied by dc and ac voltage functions (see Fig. 1-10). Beginners should note that it is important to use the right scale in a resistance measurement. If a high range is used to measure a low-resistance value, it is impossible to

make an accurate measurement. By the same token, if a low range is used to measure a high-resistance value, the accuracy of measurement will be poor.

In the measurement of high-resistance values, it is necessary to avoid touching the test prods or clips, because body resistance will cause the meter to read a subnormal value. You will find that some resistors have different values when they are hot, compared with their cold resistance values. This is particularly true of special resistors such as Globars used in many old-model receivers. In the case of *variable resistors*, such as potentiometers, defects may occur at certain spots; therefore, it is good practice to observe the resistance variation as the control is turned through its range. Beginners should also note that any fixed resistor has a certain tolerance (often ±20 percent). The resistor has a normal value if its resistance falls within the given tolerance range. For example, a 100,000-ohm ±20 percent resistor is within rated limits if we measure a resistance value in the range of 80,000 to 120,000 ohms. Note that an ohmmeter also has a certain accuracy rating; however, the operating tolerance of a service-type ohmmeter is considerably narrower than the tolerances on resistors used in receiver circuits.

Coils and transformers include rf and audio chokes, power transformers, audio transformers, i-f transformers and coils, voice coils, and any component that is wound with wire, except wire-wound resistors. Coils and transformers are ordinarily checked for resistance values and compared with the values specified in the receiver service data. As in testing resistors, one end of a coil might need to be disconnected for test. Remember that a coil with normal winding resistance might be short-circuited to the core, or have leakage resistance to the core. Fig. 1-11 shows a typical power-transformer schematic. Chart 1-1 tabulates the test points, normal resistance readings, and the points to check for shorts.

The condition of low-voltage, power-transformer windings is often difficult to determine because winding resistances may be so low that the readings appear as short-circuits on an ordinary ohmmeter. Large service shops can justify the cost of a lab-

Courtesy EICO Electronic Instrument Company, Inc.
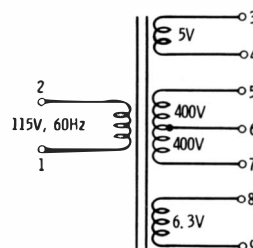**Fig. 1-10. A typical VTVM.**

Fig. 1-11. Typical power-transformer schematic.

Chart 1-1. Power-Transformer Resistance Tests

Test points	Normal indication (ohms)	Test for short to:
Primary 1, 2	5 to 10	Frame (ground) Terminals 3, 4, 5, 6, 7, 8, 9
5-volt filament 3, 4	less than one	Frame Terminals 5, 6, 7, 8, 9
High-voltage 5, 6	50 to 100	Frame Terminals 8, 9
High-voltage 6, 7	50 to 100	Frame Terminals 8, 9
6.3-volt filament 8, 9.	less than one	Frame

type, low-range ohmmeter, such as is illustrated in Fig. 1-12. This type of instrument is also very useful in checking for cold-solder joints, deteriorated switch contacts, poor grounds, and general analysis of low-resistance circuits. Another typical trouble condition in a low-resistance winding is shorting between turns or layers.

Signa

Signal tracing and signal substitution are used in trouble localization procedures. In the case of signal substitution, the speaker serves as an output device, and the point of signal injection is changed progressively. For example, we may feed a signal from an audio oscillator to the output terminal of the last audio stage. If there is no sound from the speaker, we know that the trouble will be found in the speaker or in the output transformer. Many technicians make preliminary tests with a pencil-type noise generator, such as is illustrated in Fig. 1-14, inasmuch as the signal frequency is of no concern.

Fig. 1-12. A useful low-range ohmmeter.

Next, we fed the signal into Point 1 (Fig. 1-13). If there is no sound from the speaker, we know that the trouble is in the audio stage or in the power supply.

In case the speaker and the audio section are operative, the next step in signal substitution is to feed a modulated i-f signal into Point 2 (Fig. 1-13). Either an a-m signal generator or a noise generator can be used (Fig. 1-14). If there is no sound from the speaker, we know that there is a defect in the detector section. However, in case the trouble is before the detector, we feed modulated signals into the preceding stages, working toward the antenna. When a point is reached that provides no sound output, the

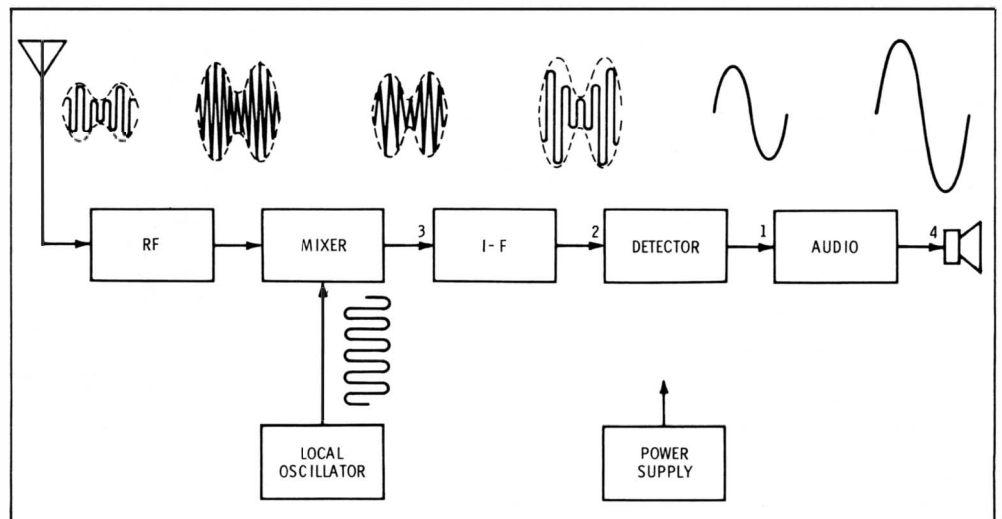**Fig. 1-13. Block diagram of a superheterodyne receiver.**

Fig. 1-14. Pencil-type noise generator.

defect will be found in the last stage tested. Note that a harmonic generator, instead of a noise generator, may be used in the foregoing tests because they are practically equivalent. Also, the harmonic generator is a compact type of instrument, and is often used instead of a signal generator in preliminary test work.

Signal tracing is also used in trouble-localization procedures, but the method employed is different. That is, the point of signal application remains the same, but we move the output indicator from point to point, working toward the speaker. For example, with reference to Fig. 1-13, we might feed a modulated rf signal into the rf stage, using an a-m generator, noise generator, or harmonic generator. In turn, we would trace the test signal through the receiver, section by section, using a signal tracer, such as is illustrated in Fig. 1-15. Note that a broadcast signal can also be used in this test; the signal generator serves as a tuning indicator for setting the tuning dial of the receiver.

Although an oscilloscope, such as is illustrated in Fig. 1-16, has a formidable appearance to the technician apprentice, it is the most informative type of signal tracer. A scope shows the comparative amplitude of a signal and displays waveform distortion. An analysis of the distortion characteristics will often pinpoint the trouble in a circuit. Basic normal waveforms using an a-m generator signal source are shown in Fig. 1-13. When a scope is used in the high-frequency receiver sections, a demodulator probe must be used instead of a pair of test leads (or direct cable). A suitable demodulator probe is shown in Fig. 1-17.

Transistor Circuit Testing

A junction transistor (Fig. 1-18) can be compared with a triode tube in that it has three electrodes.

However, a transistor is much smaller than a tube. A basic comparison of transistor and tube configurations is shown in Fig. 1-19. Note that a transistor may be either a pnp type or an npn type. The characteristics of these two types are the same, except that the supply-voltage polarities are reversed. Basic transistor tests can be made with an ohmmeter; the $R \times 1000$ range is suitable. Procedure is as follows:

1. Taking the transistor leads by pairs, we will find one pair of leads that has a comparatively high resistance in both directions (high-resistance value using either polarity of the ohmmeter test leads). This pair of transistor leads consists of the collector and emitter electrodes; the remaining lead is the base electrode.

2. Checking from the base to either one of the other electrodes, we will find that the front-to-back ratio (resistance ratio with ohmmeter test leads reversed) is very high. With the ohmmeter connected to read forward (low) resistance, the transistor is a pnp type if the negative ohmmeter lead is connected to the base. On the other hand, the transistor is an npn type if the positive ohmmeter lead is connected to the base.

Fig. 1-15. A typical signal tracer.

Fig. 1-17. Schematic diagram of a detector probe.

example, the beta of a good transistor might be rated in the order of 95 to 100. The leakage current of a transistor is measured by measuring the collector current that flows when the collector-base junction is reverse-biased. A good transistor has a very small value of leakage current.

Since the majority of receivers have the transistors soldered into their circuits, in-circuit transistor testers are widely used. These are discussed in detail subsequently. It is often possible to make an in-circuit test of a transistor with a dc voltmeter, as shown in Fig. 1-21. In this example, the voltmeter is connected to measure the collector-emitter voltage. A control-action test is made by short-circuiting the base to the emitter. If the voltmeter reading responds by jumping up to the supply-voltage value, the resistor has normal control action. This test is based on the fact that a junction transistor normally

Courtesy Simpson Electric Company
Fig. 1-16. Service-type oscilloscope.

3. Comparing the forward-resistance values from the base to each of the two other electrodes, we will find that one of the forward-resistance values is substantially less than the other. (Use the R × 10 range of the ohmmeter to obtain a readable deflection). The lower reading identifies the emitter electrode; conversely, the higher reading identifies the collector electrode.

Various types of transistor checkers are used at the service bench. All of these instruments provide two fundamental measurements: the value of current gain provided by the transistor and the leakage current value between collector and base. A small transistor tester is illustrated in Fig. 1-20. The current gain of a transistor is also called its beta value. Beta is defined as the ratio of collector-current change to base-current change with the transistor connected in the common-emitter configuration. For
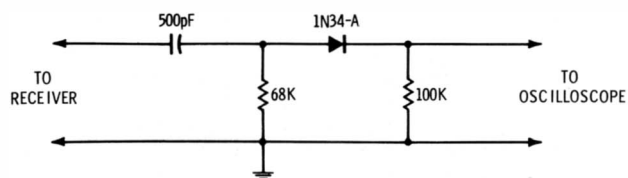

Courtesy Raytheon Manufacturing Co.
Fig. 1-18. Typical junction transistors.

(A) *Common emitter—common cathode.*

(B) *Common base—common grid.*

(C) *Common collector—common plate.*

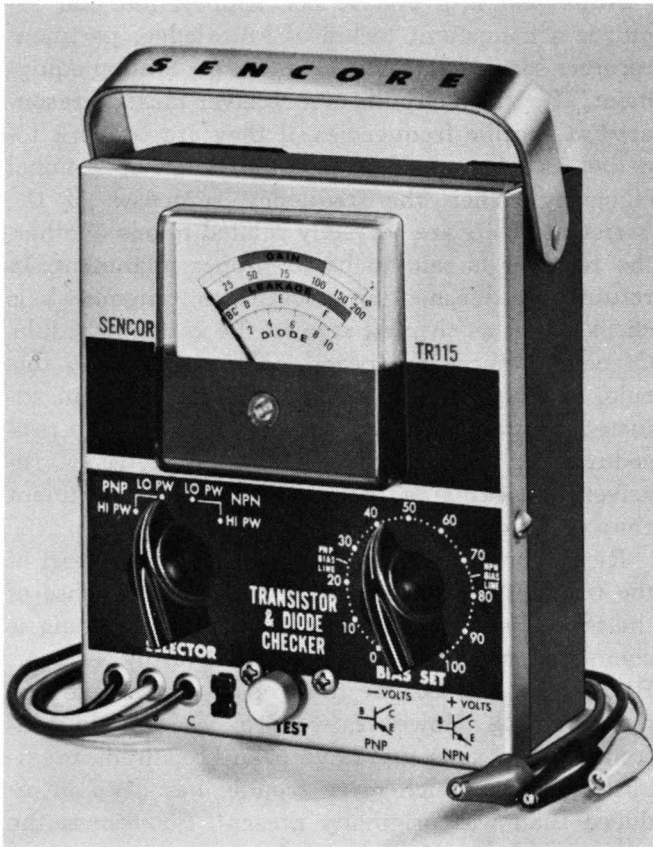**Fig. 1-19. Tube and transistor circuit configuration.**

goes into collector-current cutoff when the base and emitter are at the same potential. Of course, if the transistor operates in a circuit in which the collector voltage is normally the same as the supply voltage, another type of test must be made. Fig. 1-22 illustrates a "turn-on" test, which is made by shunting a 10-k resistor from collector to base. If the collector voltage then falls to a lower value, we know that the transistor is workable. This test employs the principle of bleeding a small amount of forward bias voltage from the collector to the base.

GENERAL TROUBLESHOOTING PROCEDURE

The quickest and most logical method of troubleshooting is to follow an organized plan. All servicing procedures are based on the observation of symptoms, the combination of which may tell an experienced technician exactly where the trouble is located. The first rule, therefore, is to observe and analyze. When certain symptoms occur in the absence of others, various impossible, as well as improbable, causes can be eliminated at the outset. For

example, if a multiband receiver operates on all bands but one, we immediately discard the possibility of a blown fuse, or the possibility of a defective power-supply rectifier, because either of these defects would prevent the receiver from operating on any band at all. The standard sequence of troubleshooting operations is as follows:

1. Encourage the customer to explain when the trouble started, what he observed, and whether the trouble has been steady or intermittent.
2. Make a preliminary operating test and a visual inspection, and clean the chassis if required.
3. Follow up with instrument tests to isolate the trouble to a specific section of the receiver.
4. Make any additional tests that will help to localize the defective circuit (try to avoid the "shotgun" approach).
5. After the defective component has been pinpointed, repair or replace it, as the appropriate course of action may be.
6. Give the receiver a thorough check-out before it is finally released from the bench.

Courtesy Sencore

Fig. 1-20. A simple transistor tester.

A visual inspection is often supplemented by specific odors, sounds, or physical characteristics. For example, if the odor of "rotten eggs" occurs when the receiver is turned on, an experienced technician looks for a burning selenium rectifier. If the power transformer vibrates loudly and heats up rapidly, he

(A) Two-battery circuit.

(B) One-battery circuit.

Fig. 1-21. Short-circuit transistor test.

knows that there is short-circuited winding. If a resistor appears to be scorched, it might crumble to dust when tapped. Visual inspection will often turn up defective connectors or plugs, blown fuses, certain blown-out tubes, broken cords, tripped circuit breakers, abnormal meter indications (chiefly in hi-fi or ham receivers), badly burned resistors, exploded electrolytic capacitors, arcs, and smoke due to overheating. Switches and dials are also inspected for obvious faults, loose setscrews, and so on.

Localization means to trace the trouble to a certain stage in a section; localizing trouble to a sub-chassis or to a portion of a main chassis is also called *sectionalization*. Before pulling a chassis, we make certain that power is being supplied by the power cord, the antenna lead is not broken, the trouble is not caused by an overlooked defect, and the defect is definitely due to a condition that cannot be corrected without removing the chassis. For example, it might be observed that a connecting lead to the speaker is loose, or that a speaker plug is not fully inserted.
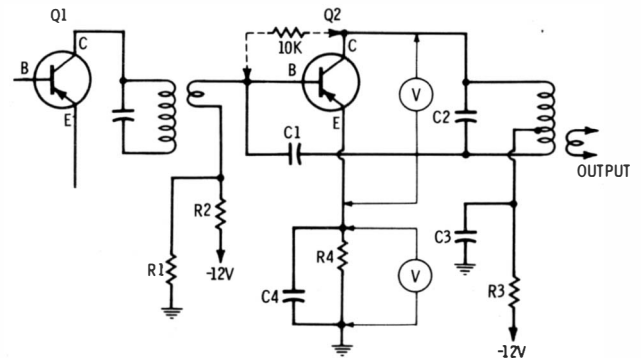

Fig. 1-22. Turn-on test of a transistor.

After a chassis has been pulled, check for B+ voltage first. If the voltage is zero, or seriously subnormal, it is good practice to make a resistance measurement at the point where the dc voltage from the power supply is fed to the various stages. This is done in order to find out whether there is a short-circuit or a very low resistance in the power-supply circuit. This trouble is usually caused by defective filter capacitors. On the other hand, assuming that the B+ supply voltage is normal, we proceed to use signal-tracing or signal-substitution techniques to determine whether it is the rf, oscillator, i-f, detector, audio, or speaker section that is defective. Preliminary localization is followed by dc voltage measurements at the plate, grid, screen-grid, and cathode terminals in a tube-type circuit. In a transistor circuit, we make dc voltage measurements at the collector, base, and emitter terminals.

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If dc voltage measurements are inconclusive in a tube-type circuit, it is often helpful to make *resistance measurements,* with reference to a resistance chart in the receiver service data, or on the basis of analysis of the circuit diagram. It is less helpful to make resistance measurements in a transistor circuit, because the transistor junctions represent nonlinear resistances which have widely different values under variations of test conditions. For example, an ohmmeter applies an unknown voltage in a circuit, and another ohmmeter will apply some other value of unknown voltage. Even if the applied voltage is measured, it is very difficult to analyze a transistor circuit to deduce its apparent resistance. The majority of defective transistors can be spotted on the basis of abnormal or subnormal terminal voltages.

If the complaint is weak output from the receiver, and preliminary tests do not turn up the trouble, *stage-gain measurements* must be made. This check is made by applying a signal at one stage and noting the output level; the same signal is then applied at the preceding stage, and the resulting increase in output level is observed. In case of doubt, the normal amount of gain for a given stage can be determined by testing another receiver of the same or similiar type. Step-by-step methods for measuring gain are explained subsequently under pertinent chapter headings. After a weak stage has been localized, the cause of subnormal output must be determined. If there is no defective component in the circuit, we check out the remaining possibilities. For example, a capacitor might have been replaced previously with a new capacitor that has an incorrect value. A replacement component might have been wired into the circuit incorrectly. Or, the trouble might be caused simply by stage misalignment.

Alignment is a precise bench operation that requires a competent technical knowledge, pertinent receiver service data, and accurate generating equipment. The tuned circuits of a receiver must be resonated at specific frequencies, if they are to work together as a team and provide maximum operational efficiency. When the frequency responses of the various circuits are correctly related to one another, the receiver is said to be in proper alignment. In routine troubleshooting procedures, alignment is checked out as the last step in the bench schedule. Of course, there are occasional exceptions to this rule, as when the tuned circuits have been misadjusted by inexperienced persons. Step-by-step procedures for the alignment of various types of receivers are explained subsequently under pertinent chapter headings.

Repair, or component replacement, is not a part of the troubleshooting procedure in the strict sense of the term. Repairs are made after troubleshooting is completed, and before final checkout of the receiver. Beginners often assume that repairs are simple and undemanding. However, we are occasionally confronted by chassis that have been "repaired" previously, and in which more trouble has been introduced than was originally present. Sometimes the new trouble is obvious, such as a sloppy solder connection that produces a short-circuit between printed-circuit conductors. Or, the new trouble may be less obvious, such as that caused by a diode that has been wired into the circuit with incorrect polarity. Again, the new trouble might be due to an incorrect inductance value—beginners often assume that coils which have the same value of winding resistance must necessarily have the same value of inductance. Of course, this is an elementary error.
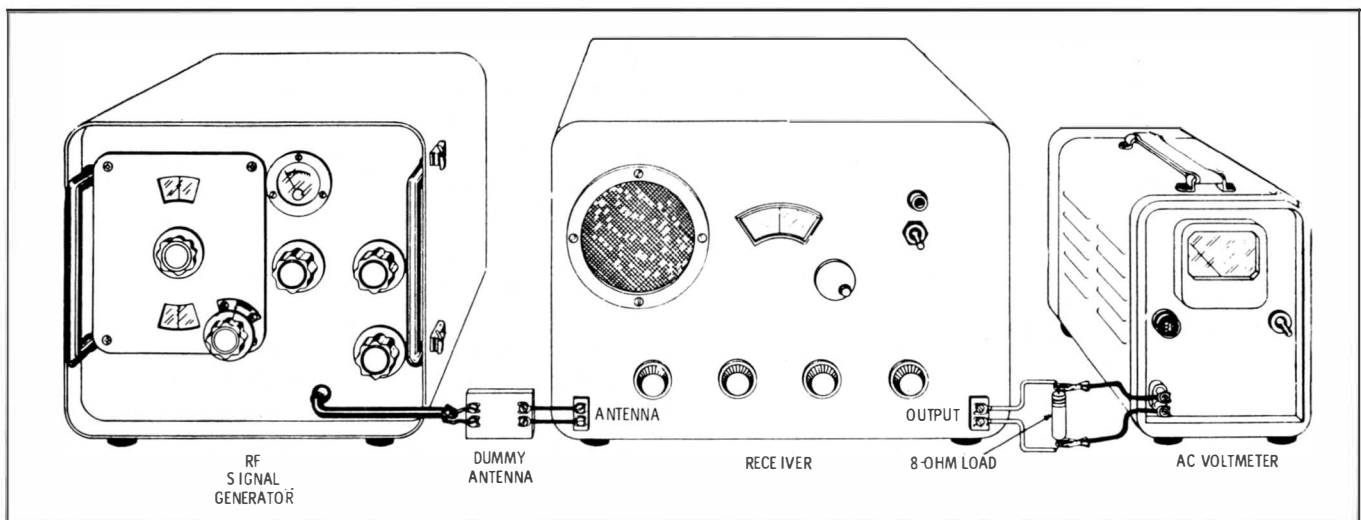

Fig. 1-23. Checking receiver sensitivity by measuring output power.

Therefore, one of the subsequent chapters explains good repair practices.

Testing after repairs is essential, because a receiver may not necessarily be free of faults after the defective parts are located and replaced. For example, a replacement tube or transistor in a short-wave receiver might cause the receiver to "go dead" even though all components are now in good condition. The trouble in this situation is due to a changed value of interelectrode or junction capacitance, which detunes the associated circuit so that it fails to operate as a member of the team. In turn, the final alignment procedure will provide normal receiver operation. When high-performance receivers, such as communication receivers, are being checked out, a good technician will complete the job ticket with a sensitivity measurement, such as is shown in Fig. 1-23. This requires a lab-type signal generator with a carrier-level meter and an accurately calibrated microvolt attenuator.

Stage Gain

Stage gain is usually measured in terms of voltage at the service bench. A typical example is illustrated in Fig. 1-24. An output meter or scope is connected at the plate of the audio-output stage. Working back toward the grid of the rf amplifier, we progressively inject an input signal at suitable frequency. To obtain an accurate measurement, the signal-input level
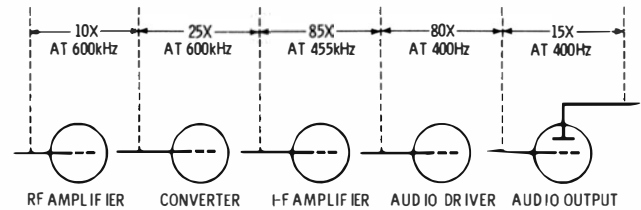

Fig. 1-24. Normal voltage gain for each stage of a small a-m receiver.

should be maintained below the level at which appreciable agc voltage is developed (this is the same precaution that is followed in alignment procedures). Accurate measurements also require the use of a lab-type signal generator, as in the measurement of output power. Note that the total gain of a receiver is equal to the product of its individual stage gains. For example, the total gain of the receiver in Fig. 1-24 is equal to $10 \times 25 \times 85 \times 80 \times 15$, or approximately 25×10^6 times.

Chapter 2

Troubles in RF and Mixer Stages

Isolation of troubles in individual stages entails the same basic procedures, regardless of the particular type of stage. That is, after the defect is known to be in a certain stage, dc voltage and resistance measurements will, in most cases, pinpoint the defect to an individual component. General information concerning voltage and resistance measurements is included in the following discussion. Localization of trouble to an rf or mixer stage can be accomplished in various ways; either signal-tracing or signal-substitution techniques may be used, as explained in the foregoing chapter. The most professional method involves the use of a service-type scope with a demodulator probe. Troubles in rf and mixer stages are usually associated with the following symptoms:

1. Dead receiver.
2. Weak output.
3. Distorted output.
4. Incorrect dial indication.
5. Drifting off-frequency.
6. Poor selectivity.
7. External interference.
8. Intermittent operation.

GENERAL DISCUSSION

Rf and mixer stages may employ either transistors or tubes. One or more bands may be provided. The antenna signal may be fed directly to a mixer in simple receivers, or one or more rf (preselection) stages may precede the mixer in elaborate receivers. Technically, a *mixer* is a separate tube, transistor, or diode that heterodynes the incoming antenna signal with a local-oscillator signal generated by a tube or transistor operating in an oscillator circuit. On the other hand, a *converter* is a tube or transistor that combines oscillator and mixer action in one device. In any case, heterodyne detector action is involved, and this section of the receiver is sometimes called the *first detector.*

Fig. 2-1 shows the ac waveforms that are normally present in mixer and converter stages. In this example, the antenna signal F2 has a frequency of 1 MHz, and the local oscillator generates a signal with a frequency of 1.5 MHz. The mixer device is operated on a curved portion of its characteristic. We find four frequencies in the mixer output: Two of the output frequencies are the same as the input frequencies— they simply feed through the mixer device. The third output frequency is equal to the sum of the input frequencies (2.5 MHz in this example). The fourth output frequency is equal to the difference of the input frequencies (0.5 MHz in this example). The alert reader will perceive that there is also a dc component in the mixer output, due to detector action of the mixer device.

We observe in Fig. 2-1 that a converter provides the same output frequencies as a mixer. The only difference here is that a converter device does double duty as both a detector and an oscillator. Now, with reference to Fig. 2-1A, let us suppose that the local oscillator fails, with the result that the 1.5-MHz frequency disappears. Then, we will find only one frequency in the mixer output; this will be the 1-MHz antenna signal. This is an important fact of
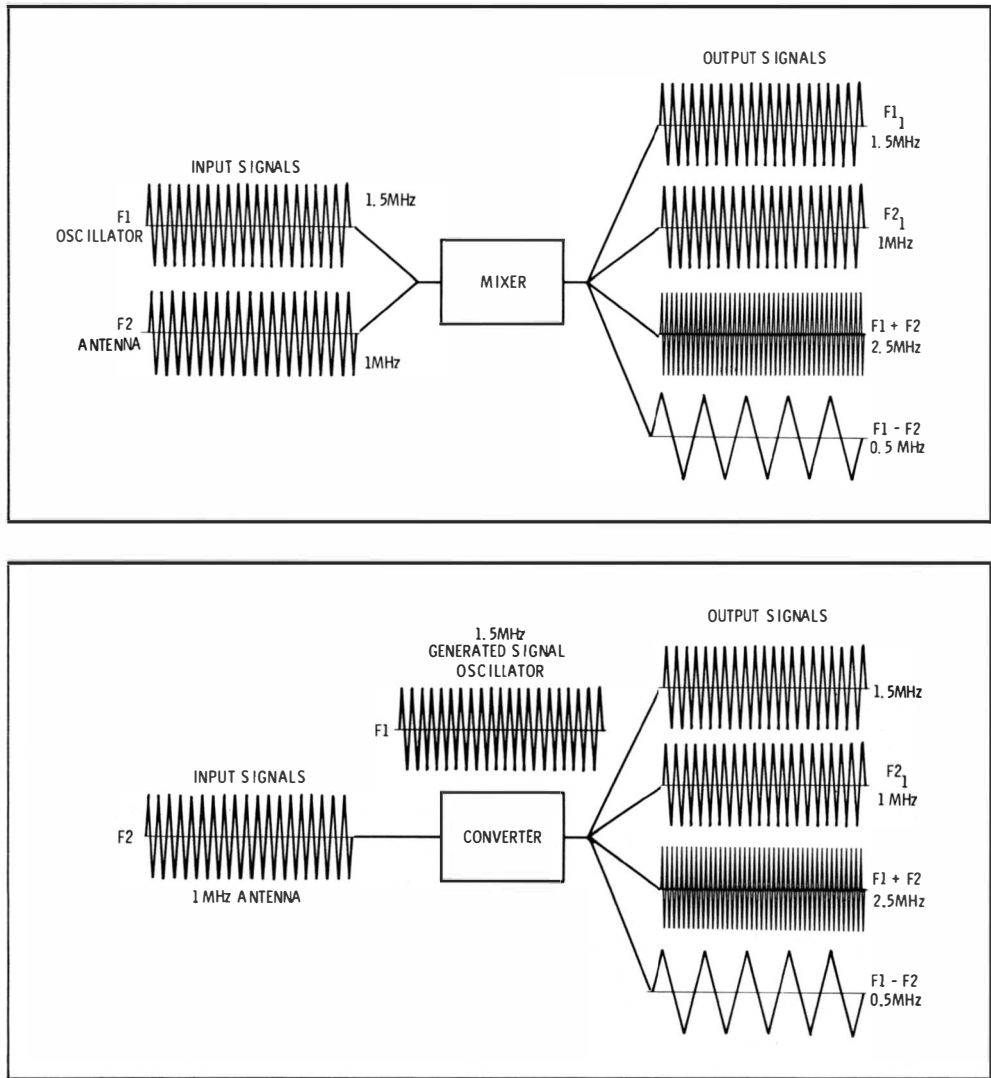
INPUT SIGNALS

F1 OSCILLATOR 1.5MHz

F2 ANTENNA 1MHz

MIXER

OUTPUT SIGNALS

$F1_1$ 1.5MHz

$F2_1$ 1MHz

F1 + F2 2.5MHz

F1 - F2 0.5 MHz

(A) Mixer stage.

INPUT SIGNALS

F2 1 MHz ANTENNA

1.5MHz GENERATED SIGNAL OSCILLATOR

F1

CONVERTER

OUTPUT SIGNALS

1.5MHz

$F2_1$ 1 MHz

F1 + F2 2.5MHz

F1 - F2 0.5MHz

(B) Converter stage.

Fig. 2-1. Input and output waveforms of a mixer and a converter.

circuit action, because oscillator failure is a fairly frequent cause of receiver trouble. Next, let us consider the situation in which the local oscillator is operating, but in which an incorrect value of bias voltage is applied to the mixer device. If the changed bias causes the device to operate in Class A, detector action is stopped. In turn, we will find only two frequencies in the mixer output: the 1-MHz antenna signal and the 1.5-MHz oscillator signal. By the same token, if the bias voltage shifts so that only a small amount of detector action occurs, the mixer output will have 0.5-MHz and 2.5-MHz signals, although these signals will be quite weak.

In case the antenna signal F2 in Fig. 2-11 is amplitude modulated, we will find the following signals in the mixer output:

1. A feedthrough amplitude-modulated signal (F2, MHz).

2. A cw feedthrough oscillator signal (F1, 1.5 MHz).
3. An amplitude-modulated sum frequency (F1 + F2, 2.5 MHz).
4. An amplitude-modulated difference frequency (F1 − F2, 0.5 MHz).
5. An audio-frequency signal produced by detection of the a-m signal F2.

In most superheterodyne receivers, only the difference frequency is of interest, and all of the other frequencies are normally filtered out by the tuned circuits in the i-f amplifier. If the mixer device is a transistor, the oscillator frequency may be fed into the base, emitter, or collector circuit, as shown in Fig. 2-2. To continue the previous example, the rf signal would have a frequency of 1 MHz, the oscillator signal 1.5 MHz, and the i-f output signal 0.5 MHz. T1 would be tuned to 1 MHz, and T2 would be
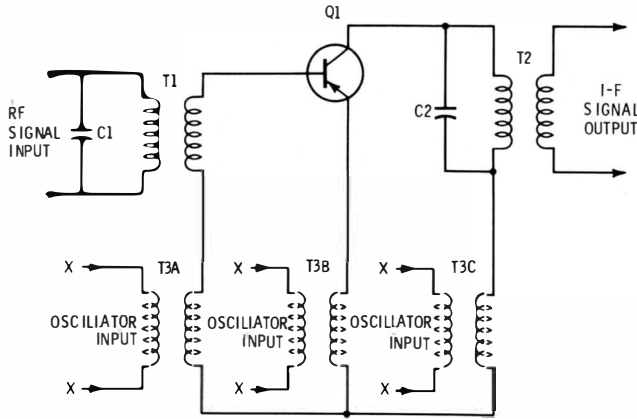
Fig. 2-2. Methods of injecting an oscillator frequency into a mixer stage.

Fig. 2-3. Schematic diagram of mixer showing typical values of components.

tuned to 0.5 MHz. It follows from previous discussion that this circuit would operate in exactly the same manner if we reduced the oscillator frequency to 0.5 MHz, since the difference frequency would again be 0.5 MHz. However, this would be an undesirable mode of operation for the mixer, because we would have a strong feed-through oscillator signal passed by T2, which would tend to overload the following i-f amplifier stages.

Another important way of viewing the circuit action in Fig. 2-2 is to consider its operation when the oscillator is tuned to 1.5 MHz, with an incoming rf signal of 2 MHz. In such a case, the difference frequency is again 0.5 MHz, and the 2-MHz rf signal results in the production of a 0.5-MHz i-f signal. The 2-MHz rf signal in this example is called the *image frequency* of the mixer circuit. In normal operation, T1 is tuned to accept a 1-MHz signal, and thereby rejects a 2-MHz signal that might be picked up by the antenna. But let us suppose that there is a defect in T1 so that its resonant frequency is incorrect and falls at 1.5 MHz. In such a case, the 1-MHz and 2-MHz rf signals have equal strengths in the mixer circuit, and the result is a severe case of *image interference*.

Another practical trouble situation occurs when there is no defect in T1 (Fig. 2-2), but image interference nevertheless occurs because of *poor selectivity*. In other words, when T1 is tuned to 1 MHz, the response at 2 MHz will be quite small, but there is nevertheless some response. Now, if we are tuned to a weak 1-MHz station, and a strong 2-MHz station is also operating in the vicinity, it is quite possible that sufficient 2-MHz signal will enter the mixer circuit that objectionable image interference will occur. There are two approaches to reduction of this type of image interference. If a loop antenna is used, it may be possible to orient the loop toward the 1-
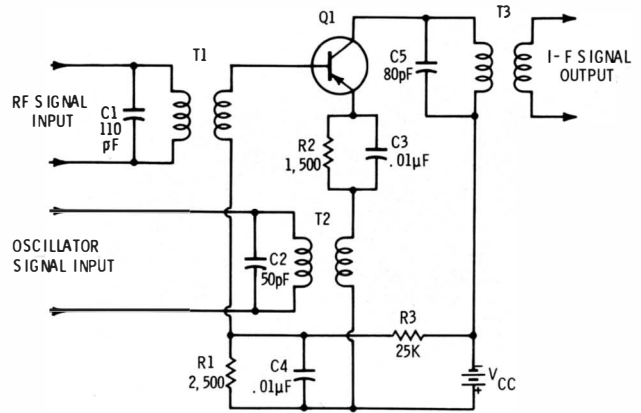
MHz station and away from the 2-MHz station. The same principle applies to dipole-type antennas used with short-wave receivers. The other solution is to use a more elaborate receiver that has one or more rf (preselection) stages, so that better selectivity is available.

Fig. 2-3 shows a schematic diagram for a mixer stage with typical component values. Emitter injection is used to couple the oscillator signal into the mixed transistor. Resistor R1 provides emitter-base bias, and R3 is a voltage-dropping resistor. C4 operates as a base-bypass capacitor, to avoid loss in mixer-stage gain. R2 is an emitter self-bias resistor that provides bias stability over an appreciable temperature range. C3 is an emitter bypass capacitor that is used to avoid reduction in mixer-stage gain. Fig. 2-4 shows a schematic diagram for a converter stage. Note that the oscillator signal is developed in the collector circuit by means of a tuned coil with feedback from the base circuit. The collector connections are tapped down on the tuned-circuit coils to provide better selectivity. A converter section is illustrated in Fig. 2-5.

Rf amplifiers are usually operated in a common-emitter configuration. Since the base and collector circuits are tuned to the same frequency, the stage may become unstable or oscillate, if the collector-
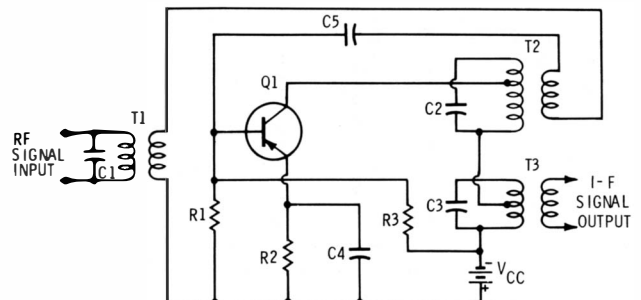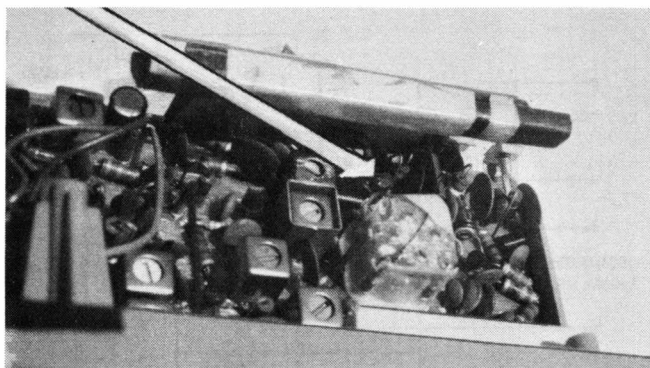

Fig. 2-4. Schematic diagram of a converter.

Fig. 2-5. Arrow points to converter transistor in a small receiver.

(A) Schematic diagram.

(B) Bridge representation of schematic at (A).

Fig. 2-7. Common-emitter amplifier using bridge arrangement to prevent oscillation.

base junction capacitance is sufficient. Two methods are commonly used to stabilize a tuned ampler and thereby avoid trouble due to regeneration or oscillation. For example, the configuration shown in Fig. 2-6 employs partial emitter degeneration. Capacitor C_N and resistor R_{N1} and R_{N2} form a *unilateralizing network*. This means that the circuit will pass a signal only from left to right, in normal operation. Let us consider the circuit action that is involved.

Transformer T1 in Fig. 2-6 couples the input signal to the base-emitter circuit. Resistor R1 forward-biases the base-emitter junction. Coupling capacitor C1 prevents shorting of the base-bias voltage by the secondary of T1. Transformer T2 couples the output signal to the following stage. Capacitor C3 blocks the dc battery voltage from resistor R_{N1}, and also couples a portion of the collector current i_{c2} to the emitter. Inductor L1 is an rf choke; it prevents flow of rf energy in the dc supply circuit. Note that if L1 were not used, i_{c2} would not be coupled to the emitter. The signal flow is as follows.

When the input signal is rising and aiding the forward bias in Fig. 2-6, collector current i_c increases in the direction indicated. Inside the transistor, a portion of the collector current is coupled to the base-spreading resistance (internal base resistance) through the collector-base junction capacitance. This
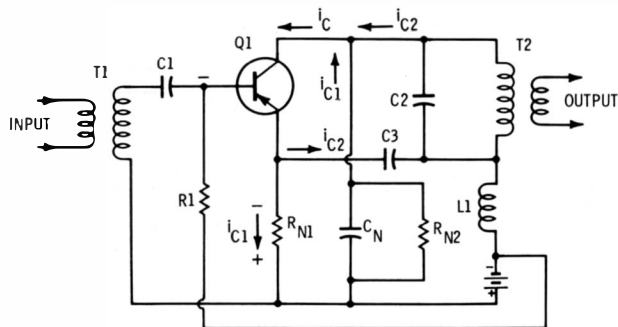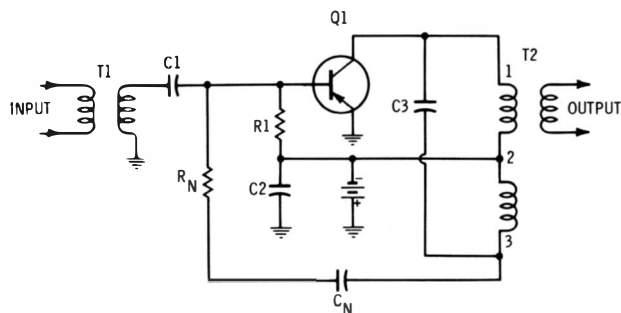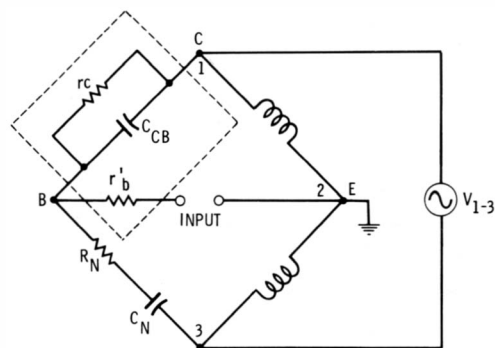

Fig. 2-6. Common-emitter amplifier with partial emitter degeneration.

action is analogous to feedback of signal voltage from plate to grid of a tube, via plate-grid interelectrode capacitance. The signal voltage developed across the base-spreading resistance aids the incoming signal, and thus develops positive feedback. To offset this positive feedback, a portion of the collector current i_{c1} is caused to flow through resistor R_{N1} and the parallel combination of capacitor C_N and resistor R_{N2}. The signal voltage developed across R_{N1} is a degenerative voltage equal and opposite to the signal voltage developed across the base-spreading resistance. Thus, the net voltage feedback in normal operation is zero, and the amplifier is unilateralized. Note that the values of C_N, R_{N1}, and R_{N2} depend upon the internal values of the collector-base junction capacitance, the base-spreading resistance, and the collector resistance. Therefore, if we do not use an exact-replacement type of transistor, trouble due to regeneration or oscillation may be introduced in the repair procedure.

The other method of tuned-amplifier stabilization entails bridge unilateralization, as exemplified in Fig. 2-7. This is accomplished by using the T2 transformer winding 2-3 and the network comprising R_N and C_N. Transformer T1 couples the input signal to the input signal to the base-emitter circuit. Winding 1-2 on transformer T2 couples the output signal to the following stage. The transistor is forward-biased

by resistor R1. Capacitor C1 prevents shorting of the base-bias voltage by the transformer T1 secondary. Capacitor C2 bypasses the collector battery and places terminal 2 of transformer T2 at ac ground potential. The circuit action can be followed by showing the bridge arrangement that is represented, as shown in Fig. 2-7B.

1. This bridge action does not involve T1, C1, C2, C3, R1, T2, or the collector battery.
2. Points B, C, and E on the bridge represent the base, collector, and emitter terminals, respectively, of the transistor. The parts shown in dashed lines are the transistor internal feedback elements. Points marked 1, 2, and 3 correspond to the terminals of the transformer T2 primary. The signal voltage developed across terminals 1 and 3 of transformer T2 is represented by a voltage generator with an output voltage v_{1-3}.
3. When the bridge is balanced, no part of the voltage v_{1-3} appears between points B and E. The amplifier is then unilateralized, or neutralized. The bridge is balanced when the ratio of voltages between points B and C and points B and 3 equals the ratio of the voltages between points C and E and points E and 3. In addition, the same phase shift is introduced by the network between points B and 3.
4. In many applications, use of capacitor C_N is sufficient to prevent oscillation in the amplifier; resistor R_N is omitted in such a case.

Trouble will obviously occur if the neutralizing capacitor becomes leaky or opens up. Use of a replacement transistor that has different values of junction capacitance can also upset the neutralizing circuit. The most critical requirements occur in tuned amplifiers that have a high Q (narrow bandwidth), high gain (high value of transistor beta), and a high value of collector-base junction capacitance.

Tube-type mixers and oscillators provide the same signal-processing function as their transistor counterparts; however, dc voltages in tube circuits are much higher than in transistor circuits. Details of circuit action are different, in that a transistor is a low-impedance (current-operated) device, whereas a tube is a high-impedance (voltage-operated) device. This is a difference in degree, rather than of kind. Nevertheless, the distinction is considerable, and it affects our troubleshooting approaches and test methods. Ordinary triodes and pentodes make excellent mixers, particularly at high frequencies. A tube-type mixer functions as a conventional plate

detector, and is biased approximately to plate-current cutoff. With reference to Fig. 2-8, the rf input circuit is tuned to the incoming signal frequency. The oscillator circuit is tuned above the radio frequency by an amount equal to the intermediate frequency. In some cases, the oscillator may be tuned below the radio frequency. Finally, the i-f transformer in the plate circuit of the mixer is tuned to the difference frequency between the rf circuit and the oscillator circuit. To provide single-control tuning, the rf and oscillator tuning capacitors are ganged on the same shaft.
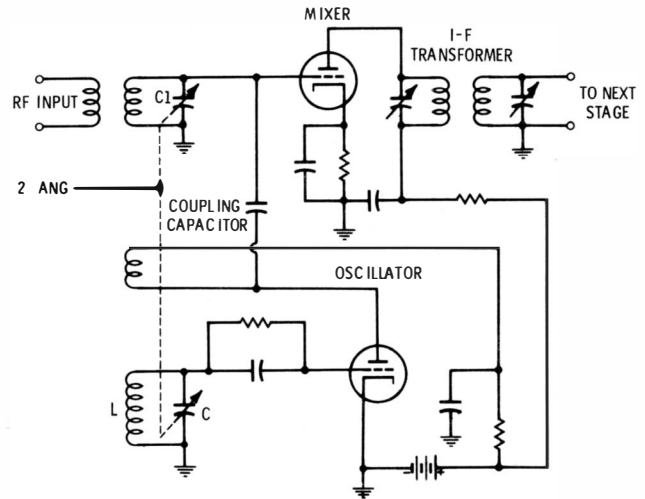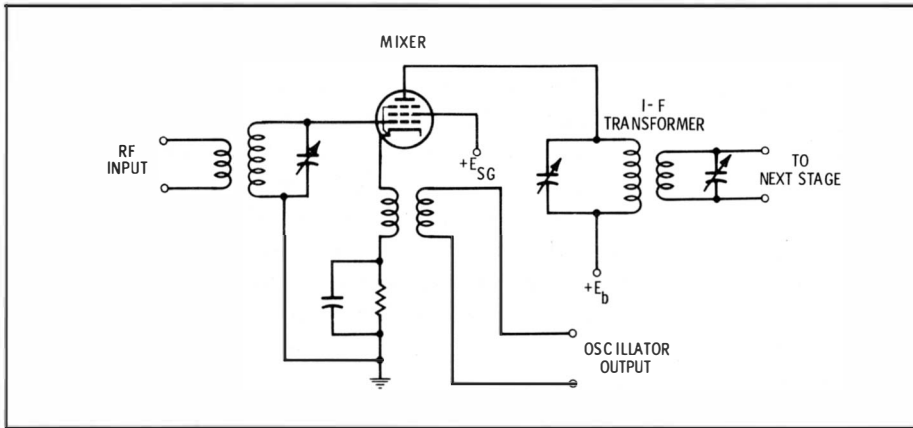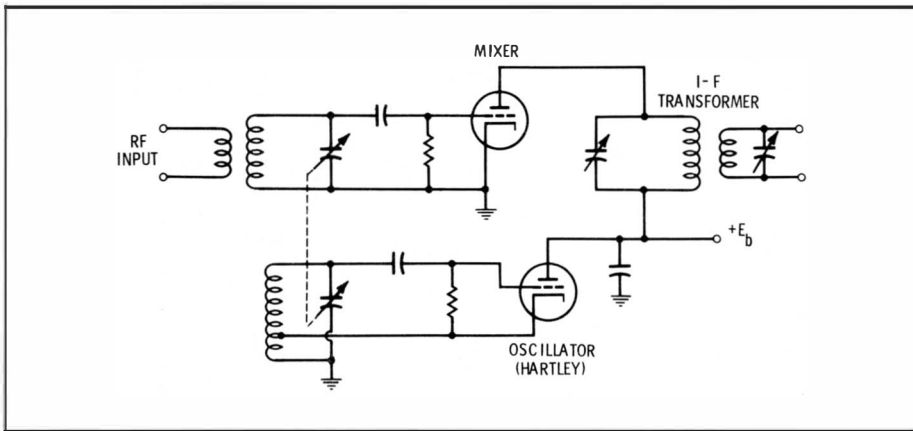

Fig. 2-8. Triode oscillator and triode mixer.

In the example of Fig. 2-8, the oscillator circuit employs tickler feedback. We will find various other types of feedback used in different receivers. One of the conditions for optimum mixer operation is the *proper injection*. The arrangement in Fig. 2-8 normally draws only a small amount of power from the oscillator. This is the function of the coupling capacitor connected between the oscillator plate and the mixer grid. Obviously, if this capacitor opens up, little or no oscillator voltage will be injected into the mixer tube. This is an example of *grid injection*. Note that if an incorrect replacement is made, and the coupling capacitor has too large a value, the mixer tube will be overloaded (overdriven), with a resulting reduction in mixer gain and loss of normal selectivity.

In other receivers, we will find oscillator injection circuits such as is illustrated in Fig. 2-9. In A, the oscillator output is inductively coupled to the cathode of the mixer. This is an example of *cathode injection*, which is quite common. One of its advantages is its comparative freedom from *pulling*. In other words, a strong signal in the rf grid circuit does not interact with the oscillator circuit appreciably,

(A) *Cathode injection.*

(B) *Injection by inductive coupling.*

Fig. 2-9. Simple frequency mixers showing different injection methods.

which would result in an objectionable shift in the oscillator frequency. Next, in B, we see an example of oscillator injection by inductive coupling between the mixer and oscillator tuned circuit. This is the same injection method shown in Fig. 2-8; however, another type of oscillator circuit is employed in Fig. 2-9B.
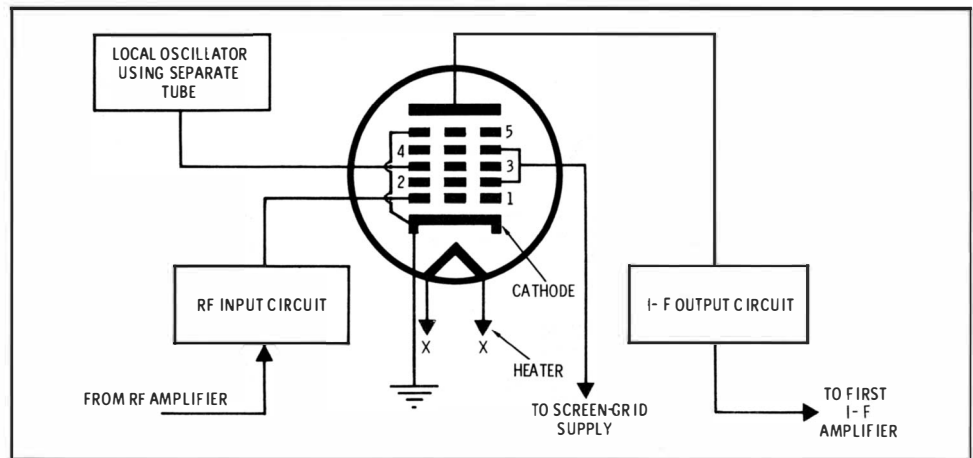
A plate detector type of mixer normally has high conversion gain and a good signal-to-noise ratio. Of course, incorrect bias, due to capacitor or resistor defects, can reduce its gain figure and impair the signal-to-noise ratio. The chief disadvantage of a triode or pentode mixer is its tendency to interact with the oscillator section, even in normal operation, if a strong interfering signal is present that has a frequency close to the oscillator frequency. That is, interaction denotes a tendency of the oscillator frequency to shift and *lock in* on the interference frequency. This pulling action is especially annoying at higher frequencies of reception, because the radio and oscillator frequencies then differ by only a small percentage. For this reason, pentagrid mixer tubes are preferred in high-performance receivers.

Isolation of the local oscillator from the rf input circuit is obtained in a pentagrid mixer tube by

means of two independent control grids; one grid processes the rf signal, and the other grid processes the oscillator signal. With reference to Fig. 2-10, Grids 1 and 3 are the control grids. Grid 1 is also called the *inner grid,* and has a remote cutoff characteristic. Grid 3 is the *injection grid,* and is used for modulating the electron stream in the tube. It has a sharp cutoff characteristic. Grids 2 and 4 are screen grids, and Grid 5 is a suppressor grid. In normal operation, a change in frequency of the rf signal on Grid 1 has practically no effect on the oscillator frequency.

Fig. 2-11 shows a typical configuration for a pentagrid mixer with a separate local oscillator. The oscillator output is coupled from the grid of the oscillator tube to the injection grid of the pentagrid mixer tube. We will find this arrangement used extensively in multiband and short-wave receivers, in which problems of oscillator pulling are more marked than in broadcast-band receivers. Note that some of the advantages of a separate oscillator and pentagrid mixer can also be provided by a *triode-heptode* converter tube, which combines both types of tubes in a single envelope, as seen in Fig. 2-12. A pentagrid mixer (heptode section) is built into the same en-

Fig. 2-10. Basic pentagrid mixer circuit.

velope with a triode. These two sections share a common central cathode. The oscillator grid is tied internally to the mixer injection grid 3. Because the oscillator section uses only a small portion of the cathode, its efficiency is less than if separate tubes were used. However, the triode-heptode is compact, and we will find it used often in older-model portable receivers.

The disadvantages of the triode-heptode are largely overcome in the *triode-hexode* converter tube (Fig. 2-13), which contains a triode oscillator section and a hexode (four-grid) mixer section in the same envelope. An entirely separate electron stream is used for the oscillator and the mixer section. This provides good oscillator efficiency. A typical frequency-converter circuit using a triode-hexode tube is shown in Fig. 2-14. In normal operation, good isolation is provided between the oscillator

and mixer sections. We will find this tube used extensively in older-model high-frequency and multiband receivers.
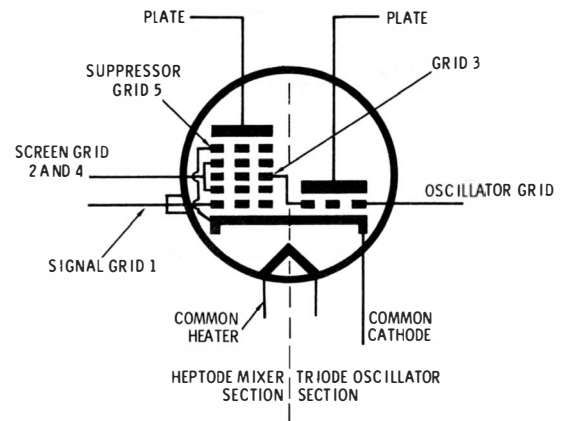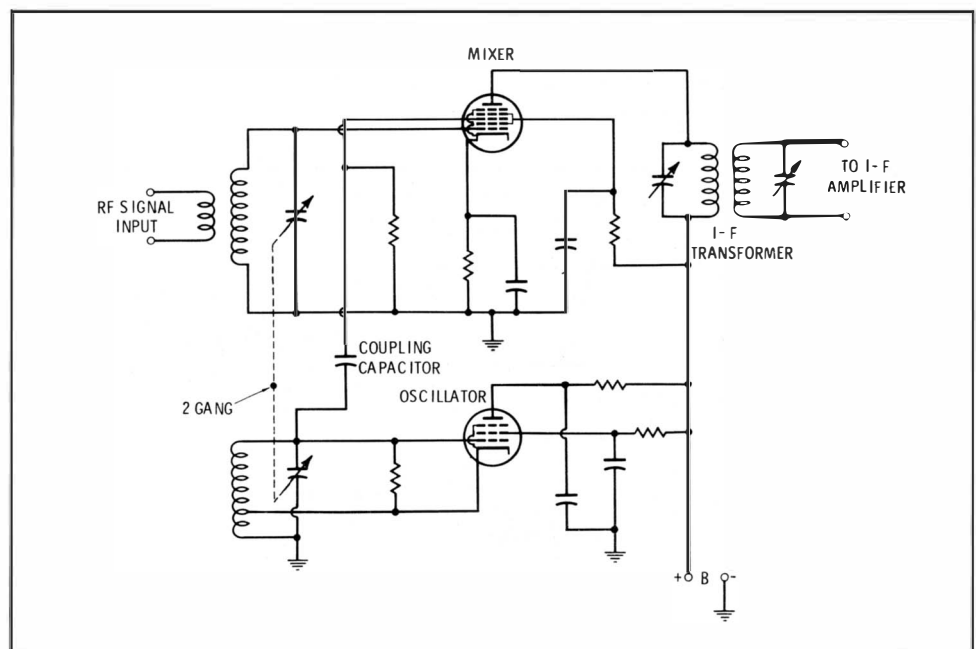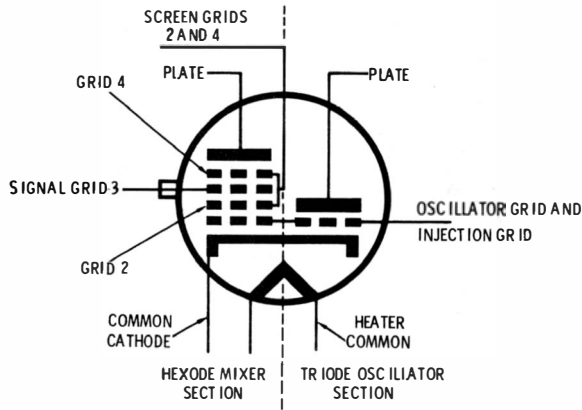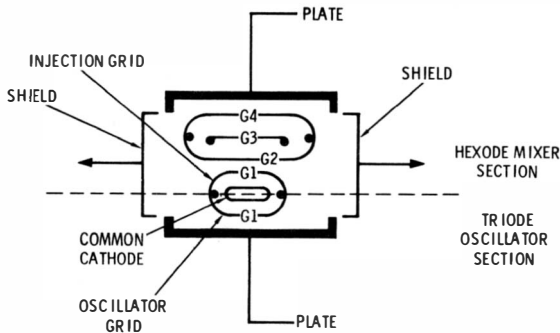

Fig. 2-12. Triode-heptode converter tube.

Fig. 2-11. Pentagrid mixer with separate local oscillator.
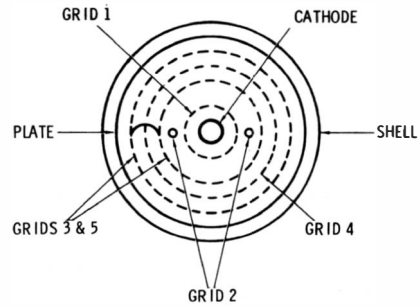
(A) *Tube symbol.*

(B) *Basic construction.*
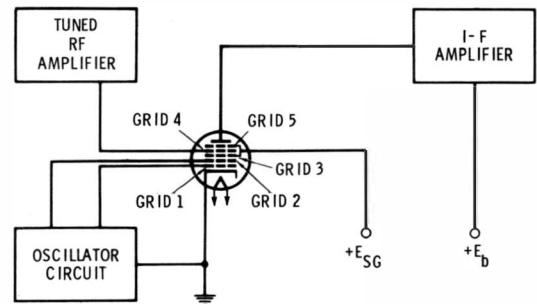
Fig. 2-13. Triode-hexode converter tube.

A *pentagrid converter* tube (Fig. 2-15) combines the functions of the oscillator and frequency mixer in a single section, with coupling between the oscillator and mixer grids obtained by the common electron stream. Five grids are utilized. The cathode, Grid 1, and Grid 2 are connected to an external circuit which functions in the same manner as a conventional triode oscillator. That is, Grid 1 serves as the control grid for the oscillator, and Grid 2 (which consists simply of two vertical rods in the electron

stream) serves as the oscillator plate. Most of the electrons from the cathode bypass the two positive oscillator plate rods (Grid 2), and proceed to Grid 3, which serves as an electrostatic shield. Since the electron stream is varying its intensity at the operating frequency of the oscillator electrodes, the function of oscillator injection has been accomplished. Some of the electrons strike the screen and produce secondary electrons, but most of them pass through to the rf signal Grid 4, which is negatively biased.

Thus, a space-charge of retarded electrons is formed between Grids 3 and 4; the space charge serves as a *virtual cathode* so far as the mixer section of the tube is concerned. In normal operation, the number of electrons that the plate is able to draw

(A) *Basic construction.*

(B) *Circuit.*

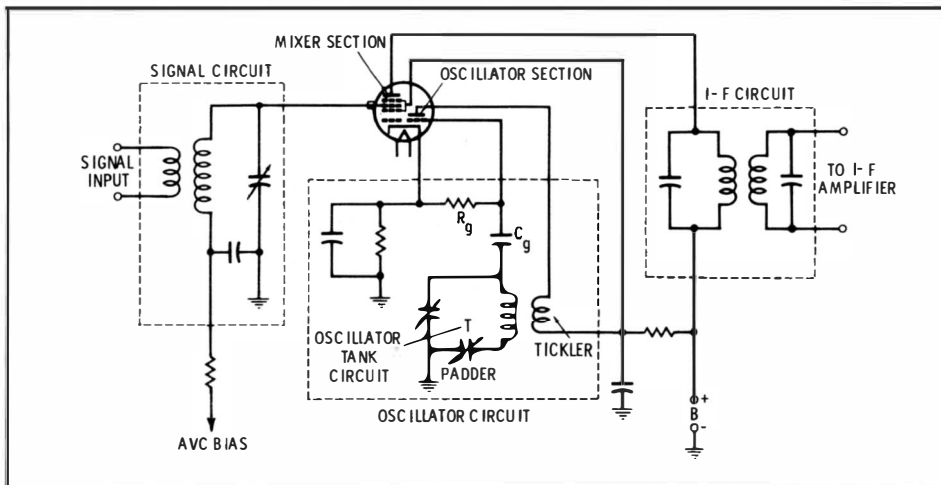**Fig. 2-15. Pentagrid converter tube.**

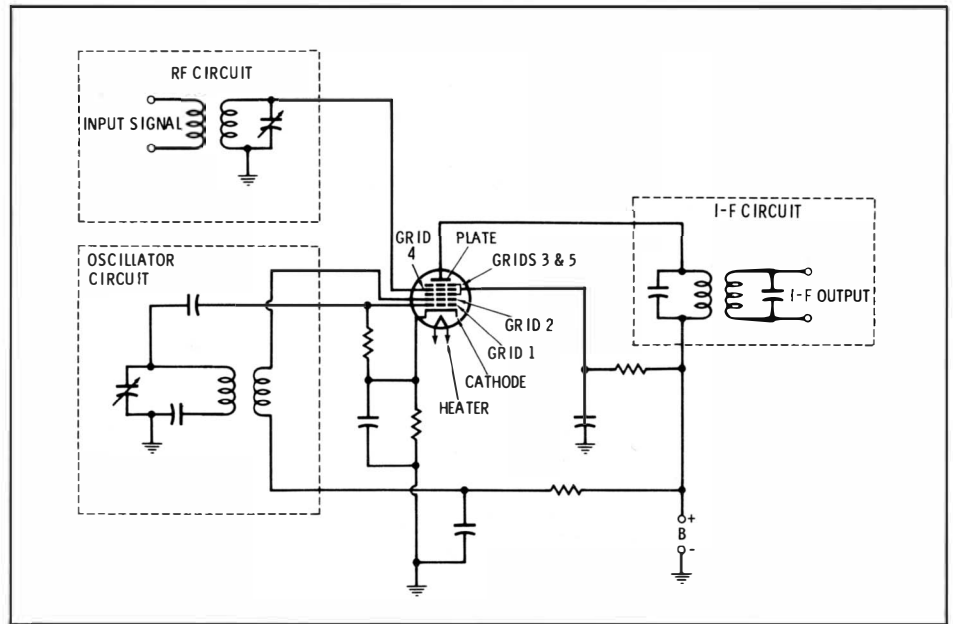**Fig. 2-14. Typical triode-hexode converter circuit.**

Fig. 2-16. Pentagrid converter circuit.

away from the virtual cathode depends on the rf signal voltage applied to Grid 4. In turn, the electron current arriving at the plate is modulated by both the oscillator and the rf signal voltages. Between the rf signal grid and the plate is placed another screen, Grid 5, which is connected internally to Grid 3. Grids 3 and 5 together accelerate the electron stream and shield Grid 4 from the other electrodes. A typical pentagrid converter circuit is shown in Fig. 2-16.

Frequency Tracking

Technicians are routinely concerned with problems of frequency tracking. The mixer and oscillator circuits of a superheterodyne are said to *track* when they maintain a constant frequency difference (the intermediate frequency) throughout the tuning range. Since the oscillator circuit is usually set to a higher frequency than that of the rf and mixer circuits, less capacitance and inductance are employed in the oscillator circuit. From the standpoint of frequency variation, the percentage of frequency change produced by the oscillator tuning capacitor must be smaller than that produced by the rf and mixer tuning capacitors. Often, a smaller coil and a smaller capacitor with specially shaped plates are used in the oscillator circuit. Although special shaping of the plates provides good tracking over a single frequency band, this method cannot be used in multiband receivers.

When tuning capacitors of the same size are used in the oscillator and mixer circuits, a smaller oscillator coil is used, and proper tracking is obtained by means of *trimming* and *padding* capacitors. With ref-

erence to Fig. 2-17, the trimmer is connected in parallel with the oscillator tuning capacitor, and the padder is connected in series. At the *high-frequency* end of the tuning range, the oscillator tuning capacitor is set to its minimum value. The parallel trimmer has approximately this same minimum value, and it is aligned to obtain the correct resonant frequency at the high end of the band.
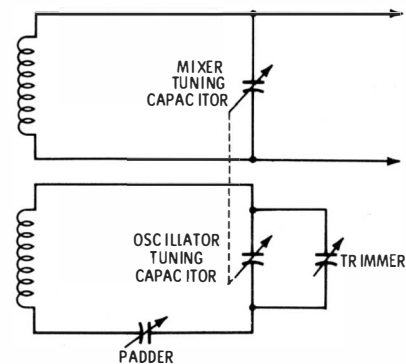

Fig. 2-17. Use of padder and trimmer for tracking purposes.

At the *low-frequency* end of the tuning range, the oscillator tuning capacitor is set to its maximum value. Therefore, the capacitance of the small parallel trimmer is negligible. However, the series padder has a value comparable to the maximum value of the tuning capacitor, and its adjustment affects the resonant frequency substantially. By correct alignment adjustments of the trimmer and padder capacitors, reasonably good tracking can be obtained over the entire band. In the case of a multiband receiver, we will usually find separate trimmer and padder capacitors for each band.

One of the more vexing types of service problems concerns oscillator stability. An oscillator circuit must have a high degree of frequency stability. This requires good original design, because design deficiencies cannot be corrected at the service bench. Frequency stability is impaired by marginal component defects, such as leaky capacitors and transistors, or absorption of moisture by coils. Oscillator stability is a particularly difficult problem in high-frequency receivers, and we will sometimes find
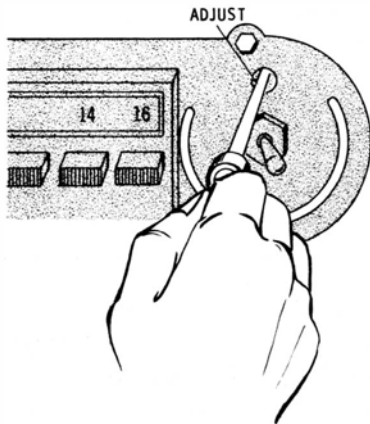

Fig. 2-18. Antenna-circuit tracking adjustment.

crystals used instead of tuned circuits in the oscillator section. Drift in oscillator frequency causes the reproduced signal to weaken, become distorted, and perhaps to disappear completely until the tuning dial of the receiver is reset. Temperature variation and line-voltage fluctuation contribute to frequency drift in unstable oscillator circuits.

Antenna-Circuit Tracking

In the case of auto radios, a small antenna is used and operation must be maintained, if possible, under very weak signal conditions. To obtain maximum receiver sensitivity, an antenna-coil trimmer capacitor is often provided, as shown in Fig. 2-18. The
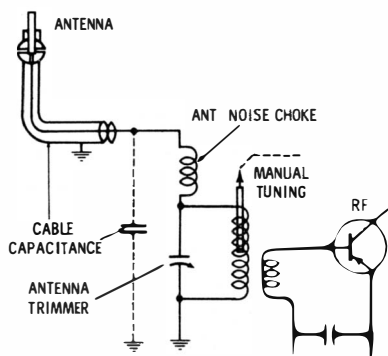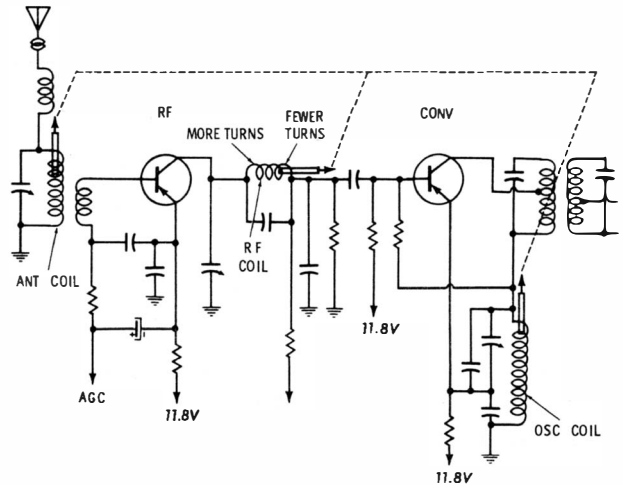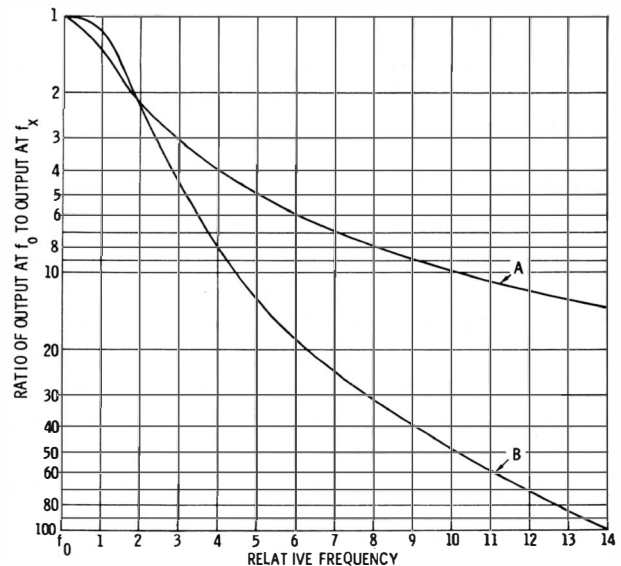

Fig. 2-19. Antenna-coil circuit is most efficient when trimmer is peaked.

circuit affected by adjustment of this trimmer capacitor is shown in Fig. 2-19. This alignment adjustment is made by tuning the receiver to a very weak station, or noise, in the range from 800 to 1400 kHz. The trimmer is then adjusted for maximum signal or noise output. This adjustment is made with the antenna at normal height, such as 30 inches. If a definite peak is not found, it is most likely that the antenna is defective and needs replacement.

(A) Align antenna, rf, and oscillator coils for good tracking.

(B) Advantage normally provided by rf preselection.

(C) Bandwidth of tuned circuit is equal to the number of cycles from f_1 to f_2.

Fig. 2-20. Tracking adjustments in an auto radio.

Next, let us consider the tracking adjustments that are made in the rf and converter arrangement of an auto radio, as shown in Fig. 2-20. We are concerned with three tuned circuits; the coils are usually specially wound in order to spread out the stations on the upper half of the a-m tuning dial. Since the coils are not wound uniformly, the tracking procedure is slightly more complicated than otherwise. Fig. 2-21 illustrates the distinction between good and poor tracking. When a tracking error is present, reception is weakened, and interference often occurs. To track the circuits, we proceed as follows:
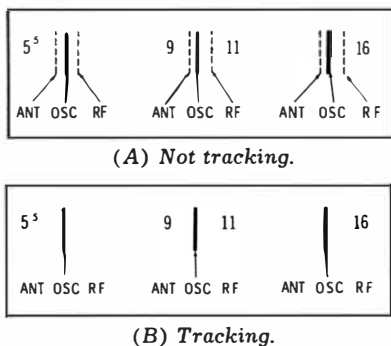

(A) *Not tracking.*

(B) *Tracking.*

Fig. 2-21. Good and poor tracking.

1. Couple the output from an a-m signal generator to the receiver antenna connector or jack through a suitable dummy antenna. Three typical dummy antennas used in auto-radio work are shown in Fig. 2-22. Consult the receiver service data.
2. Connect an ac voltmeter across the speaker for output indication.
3. The oscillator slug is usually adjusted at an approximate standard depth, as shown in Fig. 2-23. For example, 1⅜ inches from the back of the slug to the rear of the coil is often specified as a starting point. This distance is measured with the dial tuned to its extreme high-frequency end. The slug setting should be checked at the start, because an incorrect setting may necessitate a complete realignment.
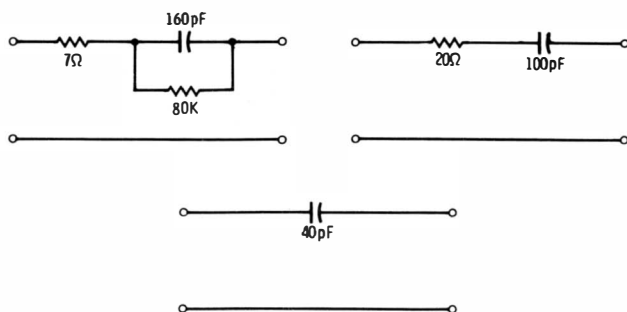

Fig. 2-22. Dummy antennas for auto radio tests.

4. With the receiver tuned to the high-frequency end, set the signal generator to 1615 kHz (the frequency may be a little different for various receivers and models). Set the volume control to maximum. Then, using a weak test signal, tune the oscillator, rf, and antenna trimmers for maximum output.
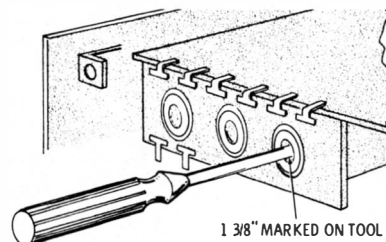

Fig. 2-23. Adjusting oscillator slug in auto radio.

5. Turn the signal-generator dial to 600 kHz, and tune the receiver for maximum output. Using a weak signal, the antenna and rf slugs are now peaked for maximum output. If considerable slug adjustment is required, Step 4 should be repeated. Then, recheck Step 5.

Troubleshooting Requirements

Many receivers are of the transformerless "hot-chassis" type. The basic bench requirement for servicing this design is an isolating transformer. Line isolation ensures that the technician will not receive a shock when the chassis is touched. It also prevents "fireworks," in the event that two transformerless chassis are connected to a common ground. If the isolating transformer has an adjustable output-voltage control, it will be more useful while checking certain types of intermittent troubles. Note that an autotransformer is not an isolating transformer; isolation from the line is provided only by a transformer that has separate primary and secondary windings.

A bench power supply is also a fundamental troubleshooting aid. Fig. 2-24 illustrates a regulated power supply used in troubleshooting transistor radio receivers. Regulation ensures that the output voltage will not fluctuate or drift from its set value. The provision of a current meter is helpful in preliminary trouble analysis. Before a transistor receiver leaves the bench, its operation should be checked at reduced supply voltage (to simulate aging batteries). In the case of auto radios, a similar condition occurs when a car is driven at slow speed with a heavy load on the electrical system. As the supply voltage decreases, the local oscillator tends to drop out, with a resulting "dead radio" symptom. An

auto radio normally performs satisfactorily over a supply-voltage range from 9 to 12 volts.

Resistance measurements must always be made with the power switch of the receiver turned off, and with the filter capacitors discharged. Otherwise

Courtesy Heath Co.
Fig. 2-24. Regulated power supply.

the ohmmeter is likely to be burned out. Common causes of trouble in the rf, mixer, or converter sections are open, leaky, or shorted capacitors, burned resistors, and cracked printed-circuit boards. If a pocket-type transistor radio goes dead after having been dropped, the most likely defect is a cracked

printed-circuit board. A magnifying glass is helpful in a visual inspection, and an ohmmeter is used to confirm the suspicion of an open conductor. The beginner should be on guard to avoid false conclusions in continuity tests due to parallel branch-current paths. It is often necessary to disconnect a component or a lead in order to make a valid continuity test.
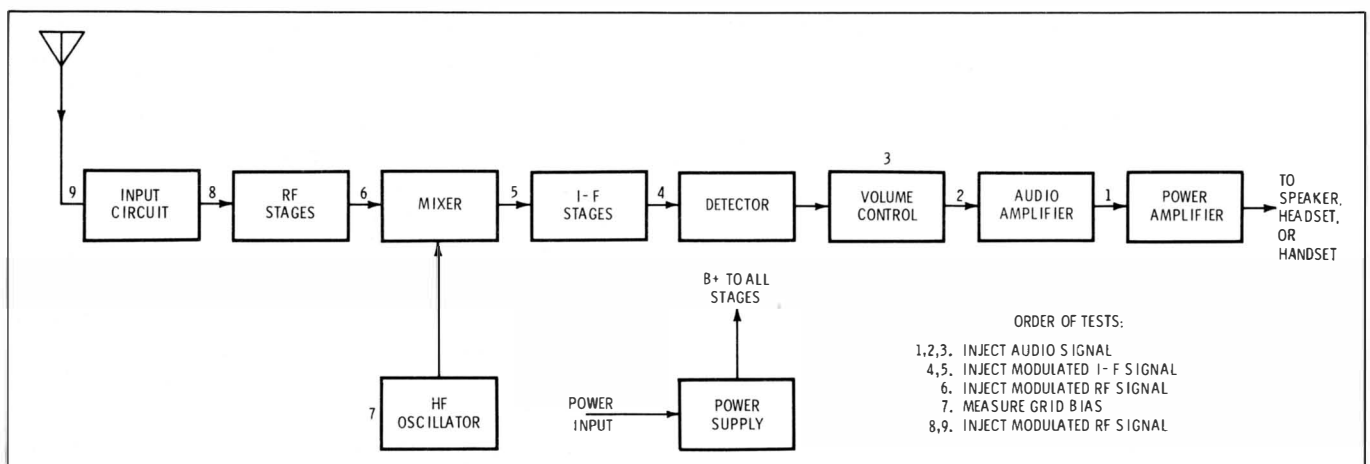
ANALYSIS OF COMMON SYMPTOMS

An analysis of the common trouble symptoms listed earlier in this chapter is presented in this section.

1. "Dead" Receiver

When the trouble symptom is a "dead" receiver, the defect may be located in almost any section. Therefore, it is necessary to localize the trouble before making component tests in the rf or mixer stages. An experienced technician can often make a shrewd guess about the general location of a defect by listening to the noise output (or lack of it) from a "dead" receiver. When the volume control is turned to maximum, a particular model of receiver (and similar models) will have a recognizable normal noise level. If a receiver arrives at the bench with this normal noise output, but with a "dead" job tag, the experienced technician checks the local oscillator immediately. The standard procedure is to connect the output from a signal generator to the antenna terminal, if no preselection is employed. Otherwise, the generator signal is applied to the mixer through the oscillator coupling capacitor. If the oscillator is not working, this signal substitution will provide normal or near-normal operation of the receiver when the generator is tuned to the nominal frequency of the oscillator. (See Chart 2-1.)

Chart 2-1. Basic Trouble Localization Tests

As noted previously, the B+ voltage is measured at the output in the case of a "dead" receiver with no noise output. If the B+ voltage is normal, or nearly so, and the agc voltage is all right, the trouble can be localized easiest by means of signal-tracing or signal-substitution procedures. To repeat an important point, tubes are prime suspects in tube-type receivers, but capacitors are the most likely troublemakers in solid-state receivers. In the case of a multiband receiver, the beginner should remember to carefully check operation on each band. Obviously, if a receiver has five bands, and only the broadcast band is "dead," an important step in localization has been taken at the outset.

Possible causes of a dead-receiver complaint, due to defects in the rf, mixer, or oscillator sections, are as follows:

a. Defective fixed capacitor.
b. Damaged resistor (often caused by a tube with shorted elements).
c. Defective or erratic bandswitch (see Fig. 2-25).
d. Break in printed-circuit wiring.
e. Open or shorted transistor.

Note that the local oscillator in a transistor receiver can be checked by the voltage-variation test,
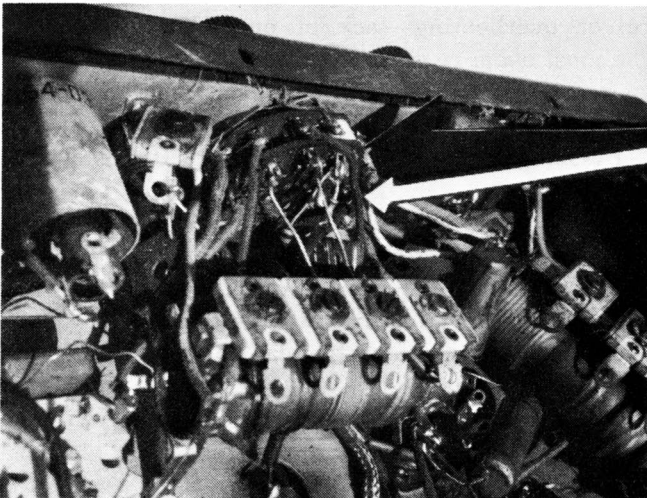

Fig. 2-25. Arrow points to bandswitch in a small a-m receiver.

as well as by signal substitution. A voltage-variation test is made as shown in Fig. 2-26. The dc voltage at the emitter of the oscillator transistor can be expected to change slightly as the tuning control is turned through its range. This is because an oscillator circuit usually has greater output at some frequencies than at other frequencies. On the other hand, if the dc voltage remains unchanged, it can usually be assumed that the oscillator is not work-

ing; we suspect an open or leaky transistor or an open oscillator coil. In case the unchanged value of dc voltage is very low, or zero, there is probably an open-circuit to the emitter junction inside the transistor. (This observation applies also to the other transistors illustrated in Fig. 2-26). A quick check
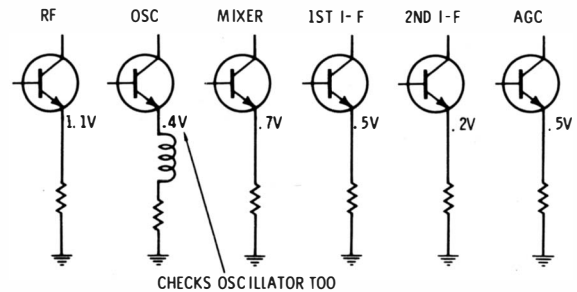

Fig. 2-26. Emitter test for open transistor and dead oscillator.

can be made by bridging a new transistor across the suspected one; if the oscillator starts to operate, the suspicion is confirmed.

2. Weak Output

Weak output can be caused by defects in almost any section of a receiver. Therefore, the trouble must first be localized by means of comparison, signal-tracing, or signal-injection tests. Note that if reception is normal (or nearly so) when the receiver is first turned on but slowly fades, with stations gradually disappearing from one end of the dial and on down until the other end is "dead" also, the converter transistor is a prime suspect. In this situation, it is usual for the high-frequency end to cut out first. If the converter transistor is not defective, capacitors in the converter circuit are the next logical suspects. Misalignment in the front end is seldom a cause of weak output, unless the receiver has been tampered with by some inexperienced person.

Possible causes of weak output are as follows:

a. Leaky transistor.
b. Defective bypass capacitor.
e. Cracked printed-circuit board (such as open antenna-lead conductor).
d. Cold-soldered joint (check with low-range ohmmeter).
e. Misalignment of tuned circuits.

3. Distorted Output

Distortion occurs most commonly in high-level stages; however, certain types of distortion can be caused by defects in the front end of a radio receiver. The most common source is regeneration,

which makes tuning excessively sharp and cuts the sidebands. In most cases, the trouble will be found in the rf amplifier; look for an open screen capacitor in tube-type chassis and incorrect replacement types of transistors in solid-state sets. Another type of distortion that occurs in front ends is excessive noise. This trouble is usually caused by a defective transistor; however, a deteriorated resistor can also be the troublemaker. Sometimes, a high noise level is not due to a component defect, but to a coil terminal that is bent so that it barely touches the chassis or shield can.

Possible causes of distorted output due to front-end defects are:

a. Incorrect type of replacement transistor.
b. Loose or missing coil shields.
c. Open screen capacitor (tube-type chassis).
d. Defective decoupling capacitor between front end and power supply.
e. Incorrect type of replacement loop antenna.

Note that some receivers are designed to operate with high-Q ferrite loops, whereas other receivers normally employ air loops with moderate Q values. If we replace an air loop with a high-Q ferrite loop, the sensitivity of the receiver will be considerably increased. However, we may also find that increased Q value causes distortion due to sideband cutting. Occasionally, the increase in circuit Q will cause a front end to "take off" and oscillate.

4. Incorrect Dial Indication

Dial indication is determined basically by the local-oscillator frequency. In turn, oscillator misalignment is suspected when the dial indication is incorrect. However, the same symptom can be caused by an incorrect oscillator-coil replacement, an incorrect oscillator variable-capacitor replacement, or incorrect lead lengths (high-frequency bands only). Beginners should also be on the alert for loose pointers and scale plates mounted incorrectly. In economy-type receivers, there is a reasonable tolerance on dial-indication accuracy, which should be kept in mind.

Possible causes of incorrect dial indication are:

a. Dial cord strung incorrectly (certain receivers only—see Fig. 2-27).
b. Dial plate shifted in position.
c. Local oscillator misaligned (check receiver service data).
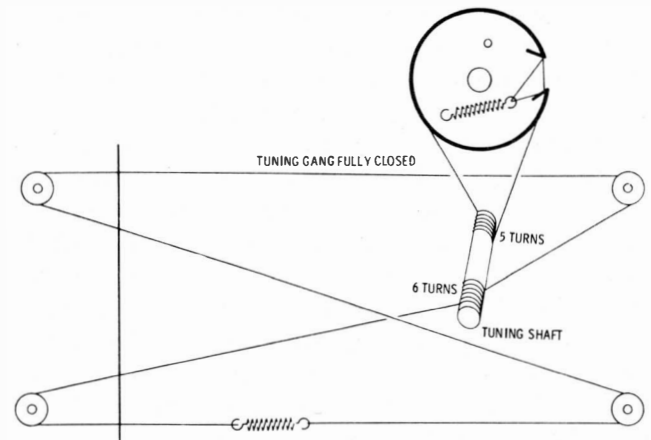d. Incorrect type of replacement oscillator coil.
e. Loose dial pointer.

Fig. 2-27. Typical dial-cord stringing arrangement.

5. Off-Frequency Drift

Drift in the dial indication is a result of drift in oscillator frequency. In the case of a solid-state receiver, the oscillator transistor should be suspected first. Drift is more of a problem on high-frequency bands than on low-frequency bands. High-performance receivers are often designed with temperature-compensating capacitors in the oscillator circuit. It is important to use exact replacements, and to mount the replacement capacitor in the same position as the original. Sometimes, frequency drift is due to receiver overheating—lack of normal ventilation is the most usual reason. The same observation applies to receivers operated in locations exposed to fog, mist, or spray.

Possible causes of off-frequency drift are as follows:

a. Unstable oscillator transistor.
b. Marginal defect in an oscillator tube.
c. Leaky capacitor in oscillator circuit.
d. Worn or loose mechanical parts in tuning assembly.
e. Operation of receiver in an excessively humid location.

6. Poor Selectivity

Poor selectivity is not always due to receiver defects or misadjustments. For example, if the customer connects some types of a-m receivers to an excessively high and long external antenna, it may be impossible to prevent powerful local stations from "feeding through" when the receiver is tuned to a weak station. There is particular need for a suitable antenna installation when using a receiver with no rf stages (preselection). Of course, any receiver will develop poor selectivity if a component defect throws

a tuned circuit off-resonance, or if it has the effect of substantially reducing the circuit Q value. Poor selectivity is almost certain to occur if the tuned circuits have been misadjusted for any reason.

Possible causes of poor selectivity in an a-m receiver are as follows:

a. Excessively high and long external antenna (some receivers only).
b. Incorrect replacement type of loop antenna.
c. Incorrect replacement type of rf transformer.
d. Open or leaky capacitor in rf or oscillator circuit.
e. Defective rf transformer—shows up as inability to align or as an abnormally broad peak.
f. Previous sloppy alignment job.

7. External Interference

All external-interference complaints are not necessarily legitimate. For example, economy-type receivers tend to radiate. If several receivers are operated from the same antenna in an apartment house, it is possible for various receivers to interfere with one another. Even separate antennas may permit interference, if the antennas are erected close together on the same roof. In some locations, external interference is very difficult to control, as in neighborhoods adjacent to powerful broadcast stations.
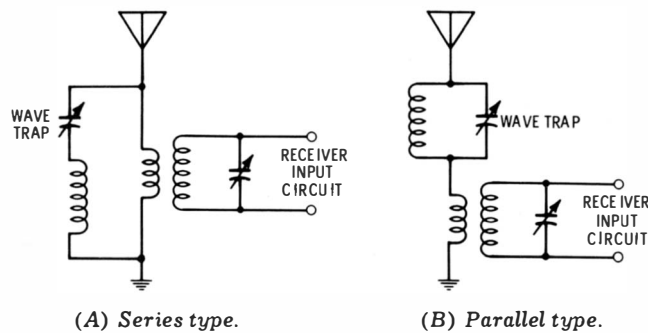

(A) Series type. (B) Parallel type.

Fig. 2-28. Basic wave traps.

Some reduction of interference is often possible by use of wave traps, as shown in Fig. 2-28. When an external-interference complaint is justified, it is almost certain to be associated with poor selectivity. Accordingly, refer to the preceding topic.

8. Intermittent Operation

In tube-type receivers, unstable or erratic capacitors are the most common causes of intermittent operation. In solid-state receivers, deteriorating transistors are also ready suspects. Since an intermittent condition is often slow to make an appearance, monitoring procedures are widely used. For example, spe-

cialized oscilloscopes are available for intermittent analysis. However, conventional scopes and meters will also serve the purpose. It is advisable to energize the receiver with a steady signal from an a-m generator and to monitor the outputs at the rf amplifier and mixer or converter (assuming that we know that the trouble is in the front end). Let us consider a case history: An auto radio had a trouble symptom of stations disappearing progressively, starting at the high end of the band. Ordinarily, this symptom would point to a defective converter transistor. However, in this case, transistor replacement did not cure the trouble. Heat tests of various components then pinpointed the trouble to an unstable emitter bypass capacitor (C14 in Fig. 2-29).
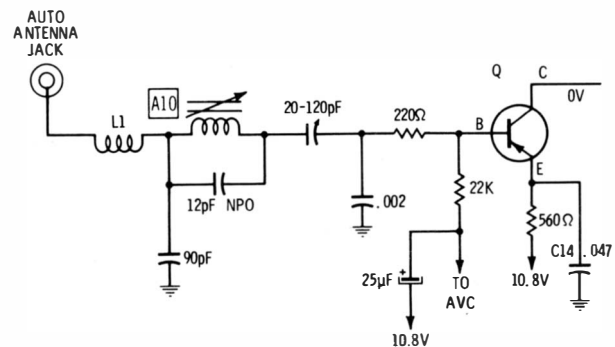

Fig. 2-29. Defective C14 causes misleading symptoms.

Possible causes of intermittent operation due to defects in the front end are:

a. Oscillator "drop out" due to fluctuating supply voltage or a defective transistor.
b. Thermally intermittent capacitor; an intermittent condition can often be intensified by heating the capacitor pigtail with a soldering gun.
c. Mechanically intermittent capacitor—can often be localized by tapping.
d. Microscopic break in printed-circuit conductor; inspect under magnifying glass; flex board slightly to determine whether a change in operation occurs.
e. Marginal defect in tuned coil or transformer; tap with tuning rod or pencil; press assembly gently from side to side; press each terminal to determine whether a change in operation occurs.
f. Cold-solder joint; tapping will usually localize.

Sometimes the replacement of a transistor soldered to a printed-circuit board is made easier by leaving intact ¼ inch of the wire leads of the old transistor. Cut off the excessive lead lengths from the new tran-
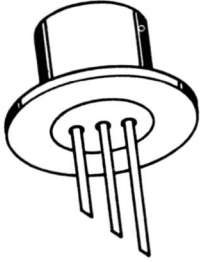
Fig. 2-30. Clip transistor leads to uneven lengths for easy replacement.

sistor and form a small loop in each lead. Slip the loops over the lead stubs of the old transistor and solder them in place. Of course, this is an expedient, to be used in difficult situations. It is preferable to install the new transistor directly in place of the defective one. When you use a small soldering iron and desoldering tools to remove a transistor, clean out the mounting holes with a toothpick or a pointed tool. Leave the leads on the new transistor uncut and carefully work the leads through the mounting holes in the board. Solder the leads in place, and then cut off the excess lead lengths with a small pair of side cutters. Sometimes it is helpful to precut the leads on the new transistor to progressive lengths, as shown in Fig. 2-30. Finally, when an exact replacement type of transistor is not available, a reliable substitution guide should be consulted.

Chapter 3

Servicing Intermediate-Frequency Amplifiers

To a major extent, the selectivity and gain of the complete receiver are determined by the characistics of the intermediate-frequency amplifier. This receiver section contains from one to three tuned stages, and utilizes high-beta transistors or high-gain pentodes. In addition to providing high gain and sufficient selectivity between adjacent channels, an i-f amplifier must provide adequate fidelity to reproduce the modulation of the signal satisfactorily. The i-f amplifier differs from an rf amplifier in several ways: The i-f amplifier operates at a lower, fixed frequency, and at very high gain (when the incoming signal is weak). In turn, it is free from variable-tuning and tracking problems, although it can develop characteristic trouble symptoms.

Common trouble symptoms caused by defects in the i-f section are:

1. Dead receiver.
2. Weak output.
3. Distorted output.
4. Interference.
5. Noisy reproduction.
6. Intermittent reception.

GENERAL DISCUSSION

Coupling in i-f amplifiers is usually obtained by means of coupled resonant circuits. Fig. 3-1 exemplifies the locations of the tuned i-f circuits in a small a-m receiver. With reference to Fig. 3-2, A illustrates the basic elements of a tuned i-f circuit, comprising primary and secondary inductances L_p and L_s, primary and secondary winding resistances R_p and R_s, and adjustable tuning capacitors C_p and C_s. Next, the curves in B show how the response of the tuned transformer depends upon the degree of coupling. When the coupling between the primary and secondary is loose (separation of the coils is considerable), the output is small but the response curve is sharply peaked, as seen at (1). As the cou-
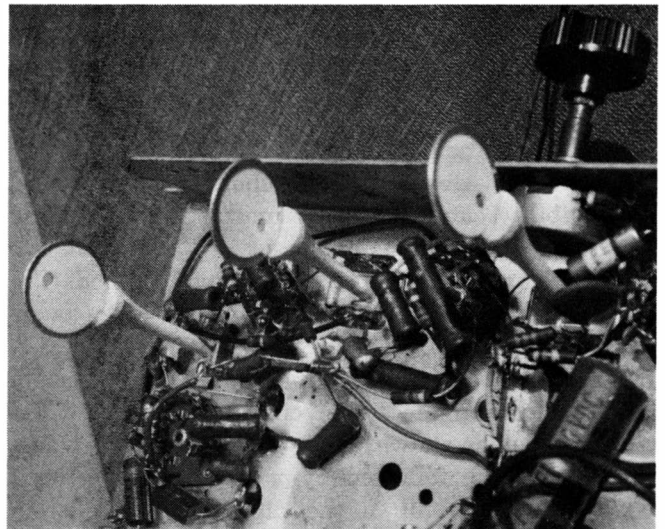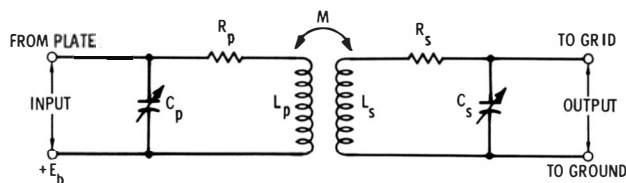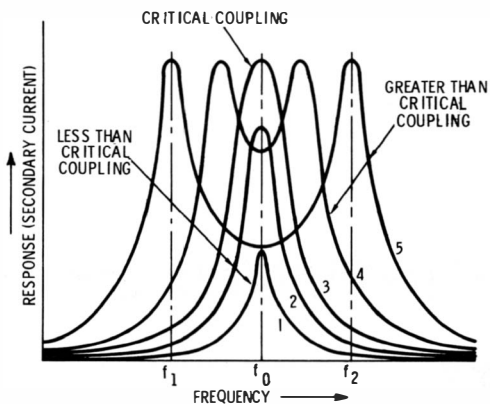

Fig. 3-1. Markers indicate location of tuned i-f circuits in a small a-m receiver.

(A) Basic elements of the circuit.

(B) Response curves.

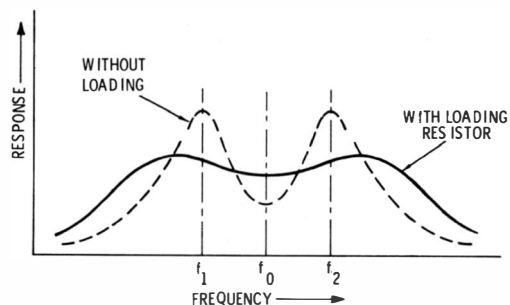**Fig. 3-2. Characteristics of coupled resonant circuits.**

(A) Effect of loading.

(B) Combined response of two i-f stages.

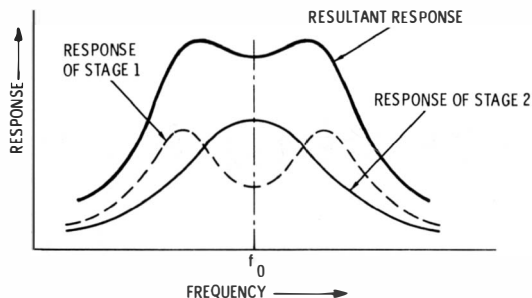**Fig. 3-3. Two methods of smoothing response curve.**

pling is increased somewhat, the output becomes greater and the response curve becomes broader, as seen at (2). As the coupling is increased to its *critical* value, maximum output with a single-peak response curve is obtained, as seen at (3).

When the coupling is increased beyond the critical value, the peak output remains the same, but the response curve begins to display two humps. This is called a *double-peaked curve,* as seen at (4) in Fig. 3-2B. In between the two peak-output frequencies, the response decreases, and the curve is said to *sag.* With extremely tight coupling, the peaks in response are very widely separated, and the response at f_o becomes almost negligible. We will find certain types of receivers in which the effective coupling is adjustable by the operator, in order to obtain optimum bandwidth under various conditions of problem reception. To anticipate subsequent discussion, under conditions of severe adjacent-channel interference, intelligibility can often be optimized at the expense of fidelity by judicious choice of i-f bandwidth.

In high-performance receivers, two methods are employed to smooth out the dip or sag of an over-coupled response curve. As shown at A in Fig. 3-3, the peak responses are reduced at the expense of gain by *loading* the tuned circuits with shunt resistance. Or, as shown at B, an overcoupled transformer may be followed by a single tuned circuit which serves to fill in the dip. Alternatively, an overcoupled transformer can be followed by an undercoupled transformer to fill in the dip. The coils

of an i-f transformer are contained in a shield can, with small trimmer capacitors or with adjustable ferromagnetic cores for alignment adjustments. These cores are often called *slugs,* and the coils are said to be *permeability tuned.* You will find i-f coils surrounded by a ferrite cup, as shown in Fig. 3-4. If the cup works loose from the paper coil form, a slight jar can change a "hot" receiver into a weak one.

The gain of an i-f stage depends upon its bandwidth. That is, if the bandwidth of a stage is doubled, its gain will be approximately halved. Most i-f amplifiers employ transistors connected in the common-emitter configuration, although there is an occasional exception. A comparison of transistor stage-
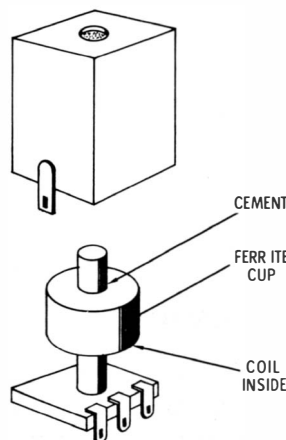

Fig. 3-4. Loose collar shifts frequency.

VOLTAGE GAIN: 270 TIMES
CURRENT GAIN: 35 TIMES
POWER GAIN: 40dB
INPUT RESISTANCE: 1.3K
OUTPUT RESISTANCE: 50K

(FOR GENERATOR INTERNAL RESISTANCE OF 1K)

(A) Common emitter.

VOLTAGE GAIN: 380 TIMES
CURRENT GAIN: 0.98
POWER GAIN: 26dB
INPUT RESISTANCE: 35 OHMS
OUTPUT RESISTANCE: 1 MEGOHM

(FOR GENERATOR INTERNAL RESISTANCE OF 1K)

(B) Common base.

VOLTAGE GAIN: 1
CURRENT GAIN: 36 TIMES
POWER GAIN: 15dB
INPUT RESISTANCE: 350K
OUTPUT RESISTANCE: 500 OHMS

(FOR GENERATOR INTERNAL RESISTANCE OF 1K)
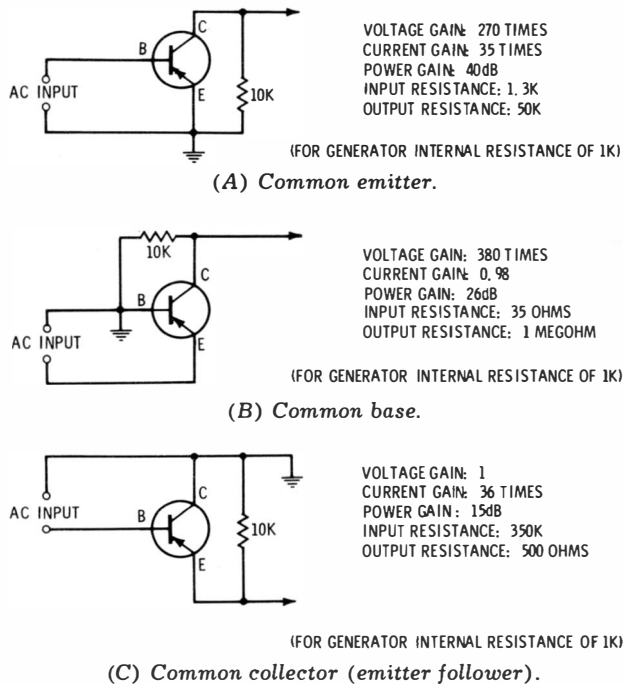
(C) Common collector (emitter follower).

Fig. 3-5. Three basic amplifier configurations for a triode transistor.

gain values for the common-emitter, common-base, and common-collector configurations is seen in Fig. 3-5. Pentodes are generally used in tube-type i-f stages, as shown in Fig. 3-6. They are generally of the remote-cutoff type to permit automatic gain control. Two or three stages of i-f amplification are ordinarily used, although an economy-type receiver may have only one i-f stage. The *overall gain* of an i-f amplifier is equal to the product of the individual stage gains. If two identical i-f stages are used, for example, the overall gain is equal to the square of the gain provided by one stage. For three identical stages, the overall gain is the cube of the gain of a single stage.

Etched Circuit Boards

Many i-f trouble symptoms are caused by defects in etched circuit boards. Some boards are lettered on one side with the placement marking of components. From this same (top) side, we can see the conductor paths on this type of board, by the use of backlighting. However, most boards, as exemplified in Fig. 3-7, have no markings. In any case, the receiver service data is essential. In some ac-dc chassis, where tubes with high heater voltages are used, heater terminals may become so hot that they open up. In such a case, a practical repair consists of bridging the etched conductor with a heavy copper wire that has ample current-carrying capability. Defective joints to etched conductors are sometimes caused by "rocking" tubes and applying excessive pressure. Judicious soldering of the defective joint is then required.

When replacing a defective resistor or capacitor, it is good practice to first cut the old component in half with a pair of diagonal cutters. Then, the component can be crushed until it falls free of its pigtails. Then form a loop at the end of each pigtail. With the leads on the new component cut to suitable lengths, they can be slipped through the loops for easy soldering and a firm connection. Be careful, however, not to overheat the joint, or the old loops may be melted from the board. Another approach, if you can get at the board from below, is to melt the solder out of the hole and solder the new pigtail directly into the etched wiring. It is often helpful to stick a wood toothpick through the melted solder to clear the mounting hole. Soldering tools with suction devices for removing old solder are available.

A defective wafer-type tube socket can be removed by first cutting the center support off and then snipping away the wafer material. Finally, each
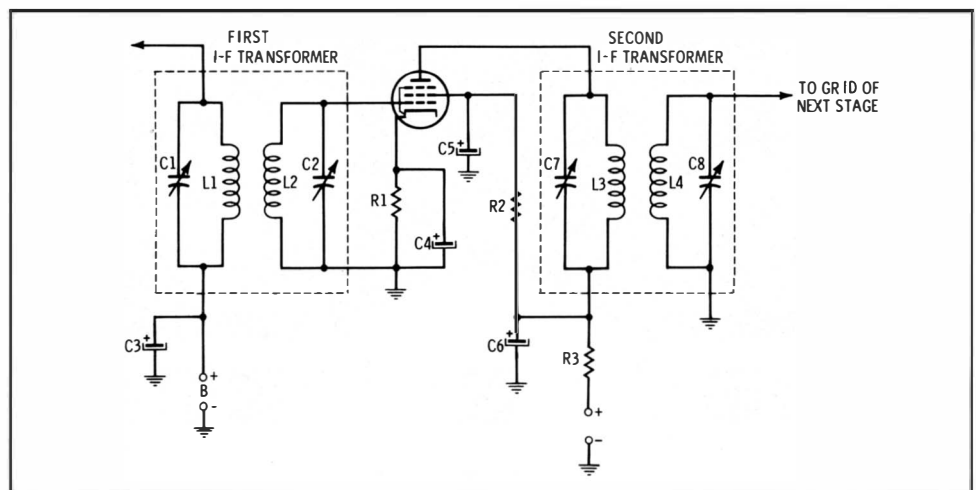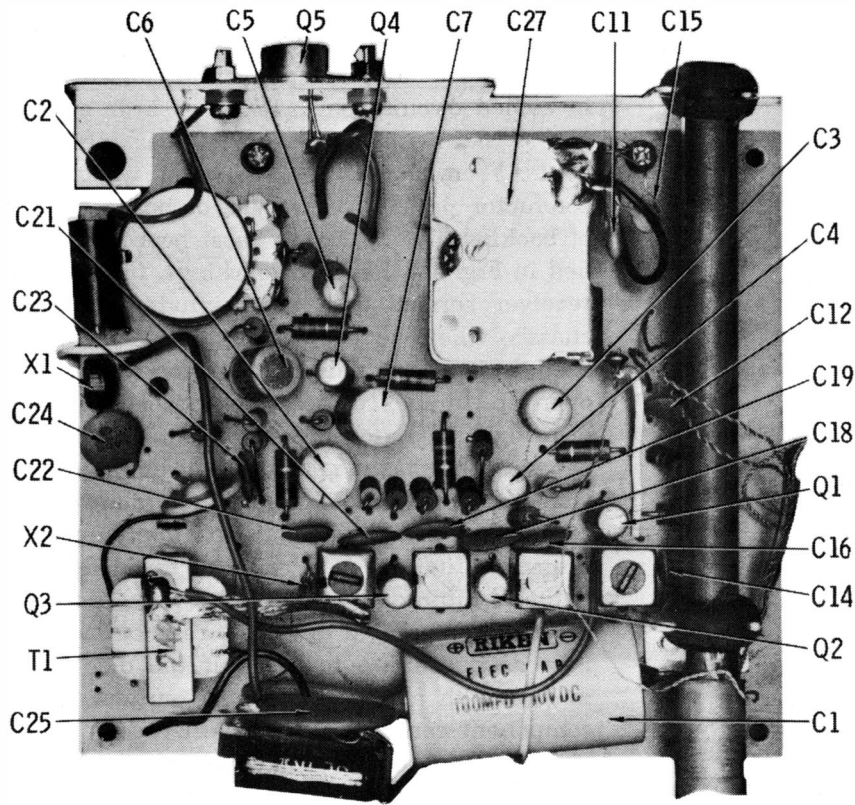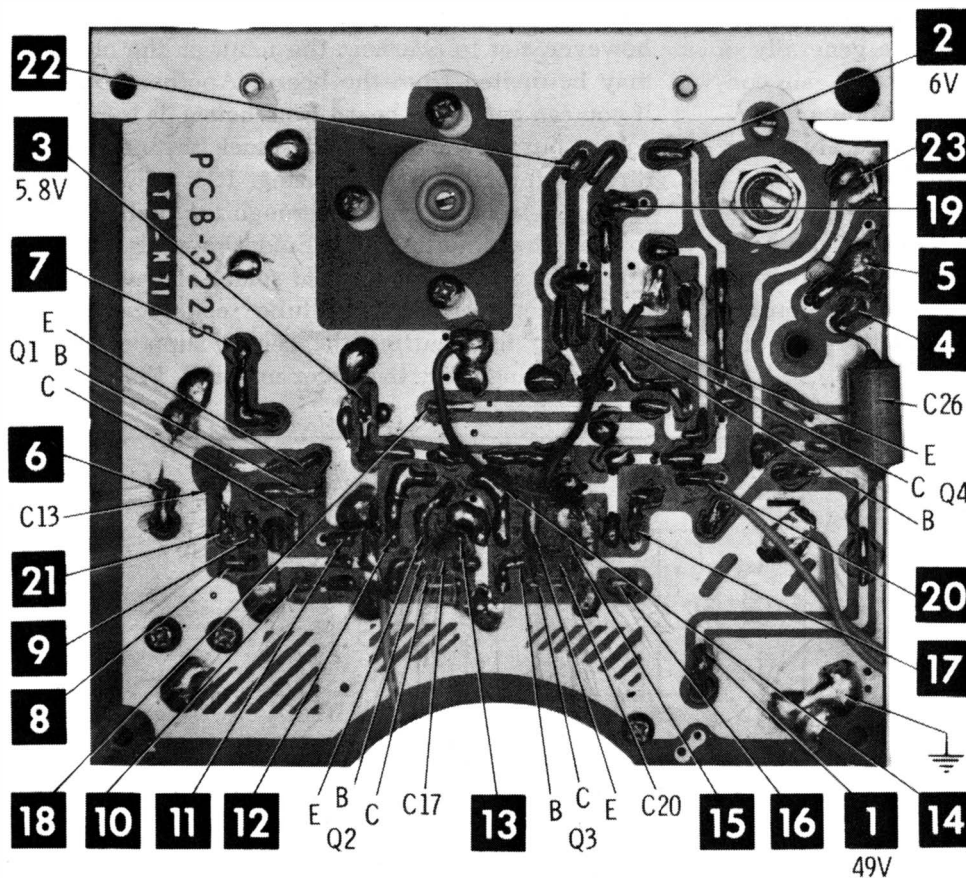
Fig. 3-6. Typical one-stage i-f amplifier circuit.

(A) Top view.

(B) Bottom view.

Fig. 3-7. Small etched circuit board.

pin connection can be unsoldered from the etched board. Molded sockets are a bit harder to remove. It is advisable to place the tip of the soldering iron under each pin and pry upward; the solder can then be drawn away from each pin connection. Next, unsolder the center ground terminal; use a screwdriver to pry upward around the socket. Use care to avoid damaging the board. If all the old solder has been loosened or removed, the socket will now drop out, and a new one can be installed in its place.

As noted previously, most transistor radio boards are damaged by the accidental dropping of the receiver. The damage can usually be repaired by using No. 14 solid copper wire to hold the sections together. Broken conductors are then bridged with hookup wire run directly between the pertinent solder joints. Beginners should note that some etched boards are covered with green enamel that must be scraped away to permit a good connection. As would be anticipated, heavy components are the first to break loose. In marginal situations, intermittent trouble symptoms result. The same basic techniques apply in auto-radio repair. However, in some cases, we will find boards etched on both top and bottom. More heat is required to unsolder the etched wiring on both top and bottom. If a conductor is accidentally damaged, replace it with bare hookup wire.

Intermittent breaks may be almost invisible, although their presence is obvious when the board is flexed slightly. Microscopic breaks can be pinpointed by using a suitable test lead. Two insulated test prods can be soldered at the ends of a flexible wire; sharp points are ground on the tips of the prods to provide good connection to the etched conductors under test. We can check between soldered joints by pushing the sharp points into the etched wiring. As soon as we bridge the broken section, the intermittent break will disappear and the receiver will operate normally. Then, a length of bare hookup wire may be connected in parallel with the defective conductor.

To disassemble a pocket portable radio, a collection of miniature tools is needed. Among the essentials are small Phillips screwdrivers, a set of jeweler's screwdrivers, and an assortment of small-size spindrivers. An appropriate spanner wrench (terminal wrench) is necessary for removing the nut from tiny earphone jacks. The two standard sizes are $5/16$ and $1/2$ inch. A magnifying fluorescent light is very helpful in tracing circuits. Special test-instrument probes consisting of phonograph needles soldered into miniature alligator clips are necessary to avoid accidental short circuits. Small tweezers or miniature long-nose pliers are needed to manipulate components and pigtail leads. The soldering iron should be rated at not more than 50 watts. A jeweler's eye loupe is almost as useful as a "third hand." A desk-stand magnifying glass is not as convenient, because it often requires repositioning.

Field-Effect Transistors

Field-effect transistors are used in various radio receivers. The FET has certain characteristics that make it superior to conventional transistors in particular applications. Since the FET has an extremely high input impedance, its action is comparable to that of a vacuum tube, which is in sharp contrast to the low input impedance of junction transistors. Thus, we state that the FET is a voltage-operated device. The FET has three electrodes called the *drain,* the *gate,* and the *source.* These electrodes are comparable, respectively, to the plate, grid, and cathode of a vacuum tube. As would be anticipated, the characteristics of the FET are quite similar to those of triode tubes.

Let us consider the operation of the FET, starting with a simple junction diode, as shown in Fig. 3-8. With no bias applied, electrons and holes are uniformly distributed throughout the n and p material. Forward bias causes charge carriers to flow to the junction, where they neutralize and permit conduction of forward current. On the other hand, reverse bias sweeps the charge carriers away from the junction, and the resulting depletion layer operates effectively as an insulator to prevent conduction of current.

Fig. 3-9 shows a cross section of an n-channel junction FET. A positive voltage is applied to the drain, and a negative control voltage is applied to the gate. When the gate voltage is zero, current conduction occurs from the source to the drain, as shown in Fig. 3-10. However, an increasing negative voltage on the gate reduces the current, because the depletion layer restricts the current as it becomes larger. In normal operation, the gate is reverse-biased, so that the operation is quite similar to that of a triode tube. A p-channel junction FET operates in the same manner, except that the bias voltages are reversed. This is the same distinction that is observed in pnp and npn junction transistors.

Another type of FET, called the MOSFET, is designed so that at zero gate voltage, drain-current conduction either will or will not occur. If a MOSFET permits current at zero gate voltage, it is called a *depletion* type; on the other hand, if current is stopped at zero gate voltage, it is called an *enhancement* type. Fig. 3-11 shows the cross section of a depletion-mode MOSFET (n-channel version). Note
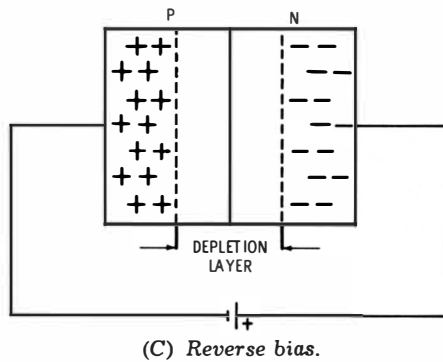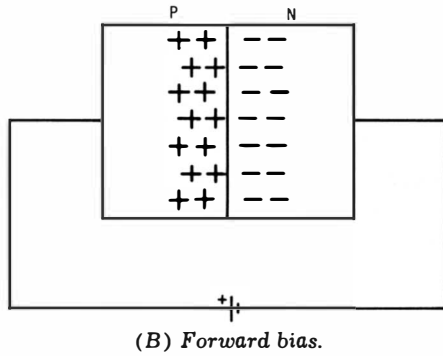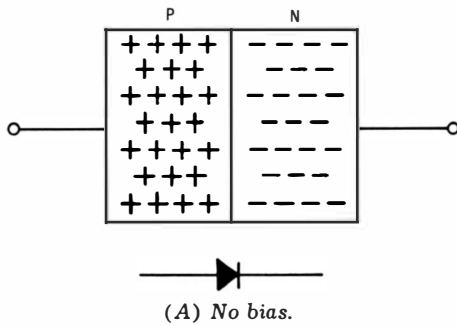
(A) No bias.

(B) Forward bias.

(C) Reverse bias.

Fig. 3-8. Pn junction characteristics.

that it has an additional connection called the *substrate,* which is usually connected to ground. "Channel" terminology derives from the fact that when the device is conducting, a channel of n-type material occurs between the n-type drain and the source. The basis of MOSFET operation is the capacitance
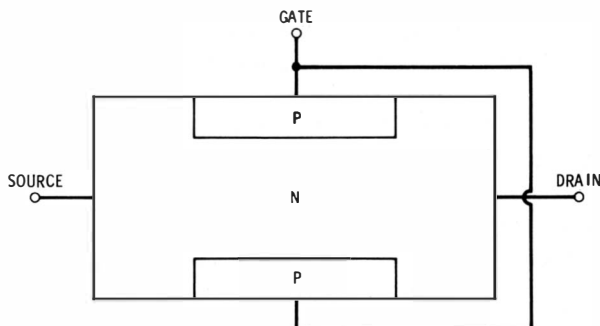

Fig. 3-9. N-channel junction FET.

formed by the metal gate, the silicon-dioxide insulator, and the silicon semiconductor.

Since an ideal capacitor conducts no direct current, the gate electrode has zero leakage current whether a positive or a negative signal voltage is applied. On the other hand, the grid of a triode tube draws current when driven positive. When the gate voltage is zero, as shown in Fig. 3-11A, the existing n-channel conducts electrons from the source to the drain. If a negative gate voltage is applied, the MOS
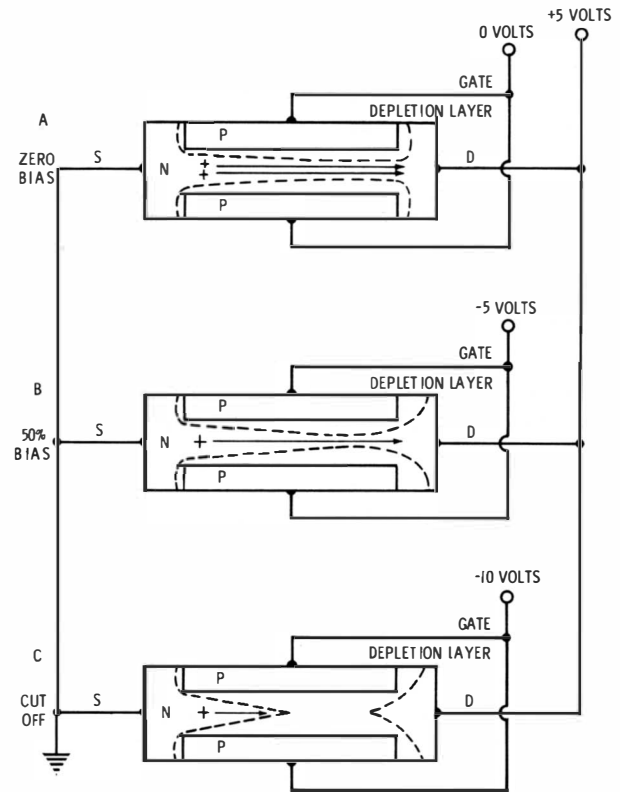

Fig. 3-10. Effect of bias on J-FET.

capacitor charges. This causes holes to be drawn toward electrons in the gate, thus forcing electrons out of the n-channel, as shown in Fig. 3-11B. Because the channel is now smaller, there is less current from source to drain. If sufficient negative voltage is applied to the gate, enough electrons are forced out of the channel to produce *pinch-off,* as shown in Fig. 3-11C. An npn junction is formed, but it does not conduct current because the pn junction is reverse-biased.

The *enhancement type* of MOSFET (Fig. 3-12) operates in a manner opposite to the depletion type. When the gate voltage is zero, there is no current-conducting channel. On the other hand, when the gate is positive, electrons are drawn toward the gate, thereby setting up an n-channel. Current then flows from source to drain in accordance with the
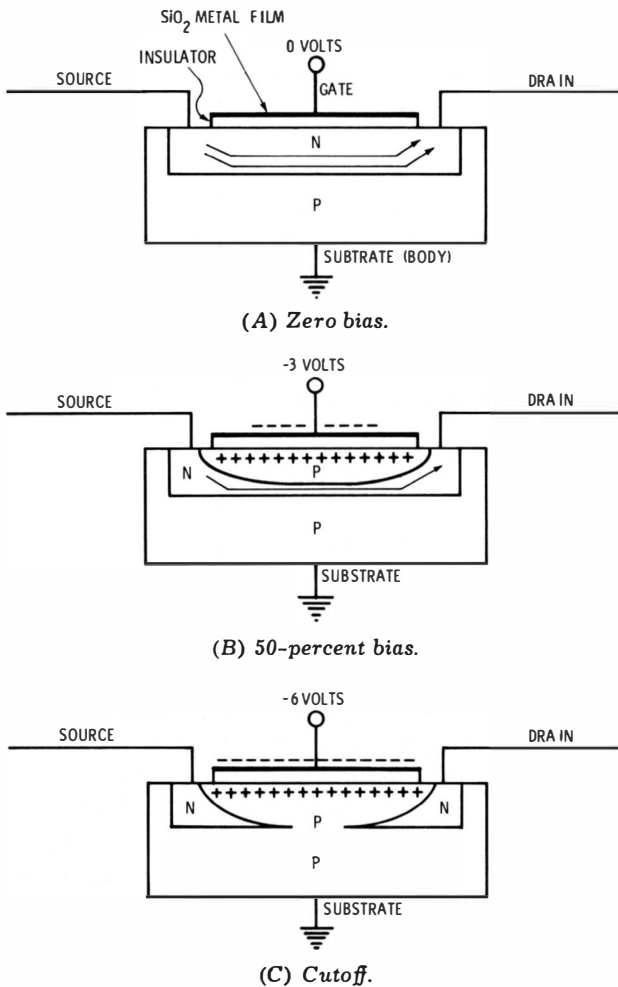
(A) Zero bias.

(B) 50-percent bias.

(C) Cutoff.

Fig. 3-11. N-channel depletion MOSFET.

(A) Zero bias.

(B) 50-percent bias.

(C) On.

Fig. 3-12. N-channel enhancement MOSFET.

value of positive gate voltage that is applied. Since the input impedance to the gate is extremely high, static electricity due to strong stray fields can build up enough voltage to damage the FET when it is not connected into a circuit. Therefore, the leads are usually shorted until the FET is connected into its circuit.

Integrated Circuits

Integrated circuits represent an important direction in semiconductor technology. Integrated and monolithic circuits consist of integral solid-state units that include transistors, resistors, semiconductor diodes, and sometimes capacitors. The components of an integrated circuit are formed simultaneously during manufacture. This technique tends to introduce factors that are not present when a circuit is wired with separate components. Fig. 3-13 shows the configuration of an integrated amplifier. The transistors in an integrated circuit are similar to conventional transistors, but more capacitance is involved because of the compact construction.
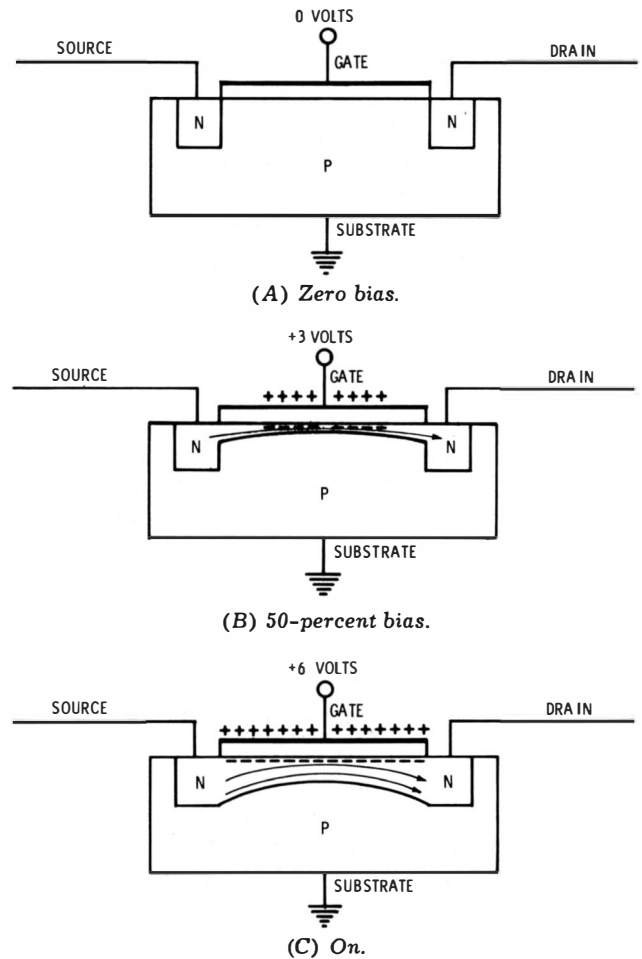
Resistors used in an integrated circuit are basically semiconductor material, which is necessarily temperature-dependent to a greater extent than the material used in an ordinary composition resistor.
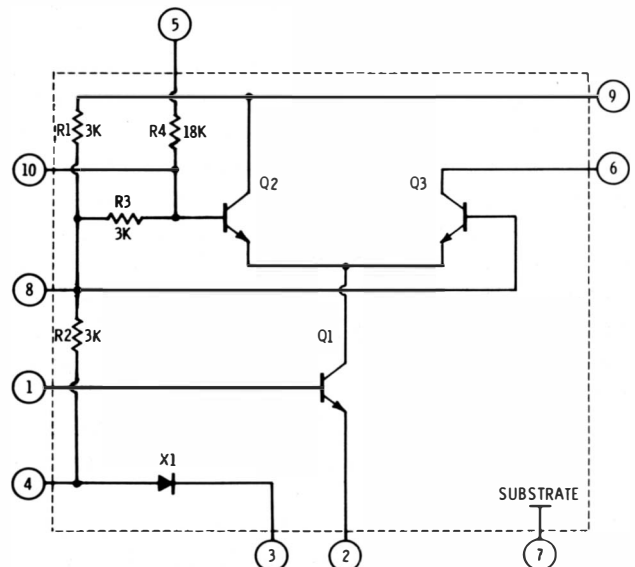

Fig. 3-13. An integrated amplifier package.

Therefore, it is advantageous to employ circuits that are based on resistance ratios rather than on absolute resistance values. In other words, the tolerance on an integrated resistor is greater than the usual tolerance on a composition resistor. Dependence on resistance ratios makes it desirable to use more than one transistor in a stage, as seen in Fig. 3-13. This arrangement provides stable IC operation, in spite of the fact that the absolute resistance values drift more or less. Advantage is taken of the fact that the percentage of drift is practically the same for each resistor.

An integrated circuit is typically manufactured from a silicon wafer of p-type substance. If a pair of n-type regions are diffused into the p-type substance at separate places, two diodes are formed. The p-type material that is common to these diodes is called the *substrate*. This substrate provides electrical isolation between the two n-type regions. Next, if a p-type region is diffused into each of the n-type regions, the base of a transistor is formed. Finally, if another n-type region is diffused into each of the p-type regions, a pair of transistors is formed, as shown in Fig. 3-14. Note that the p-type substance provides electrical isolation between the two transistors. Metalized contacts are made to the electrodes of the transistors.
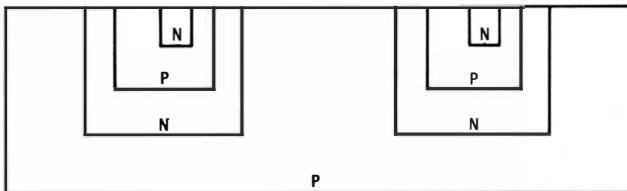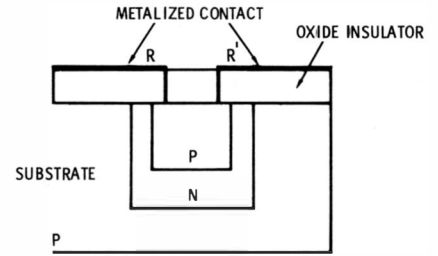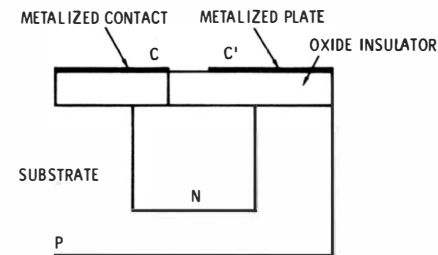

Fig. 3-14. A pair of npn transistors diffused into a p-type substrate.

In Fig. 3-14, the upper n-type regions are emitters, the interleaved p-type material forms bases, and the lower n-type regions are collectors. To form a resistor, the upper n-type region is not used; instead, two separate contacts are made to the p-type substance. The amount of resistance provided by the p-type substance depends on its length, width, and depth. The lower n-type regions serve to provide electrical isolation between the p-type resistor and the substrate. When capacitors are to be formed, only the initial n-type region is used. An oxide layer is employed as the dielectric. Cross sections of an integrated resistor and of an integrated capacitor are shown in Fig. 3-15.

An IC unit used in a 455-kHz i-f amplifier is shown in Fig. 3-16. Transistors X_1, X_3, X_4, and X_6 are connected as a pair of dc-coupled common-emit-

(A) Resistor.

(B) Capacitor.

Fig. 3-15. How integrated resistors and capacitors are formed.

ter/common-collector amplifiers, and provide a voltage gain of approximately 60 dB. Fig. 3-17 shows how the IC units are connected for two stages of 455-kHz i-f amplification. The rf feedback choke is self-resonant at 455 kHz. For precise bandwidth control (such as 10 kHz), a tuned i-f transformer may be used to couple the signal source to the first IC unit. Since we have no access to the interior of an IC, trouble analysis is restricted to terminal voltage and current measurements, as exemplified in Fig. 3-18. Voltage measurements, which can be made with a scope, include i-f signal amplitudes. Note that
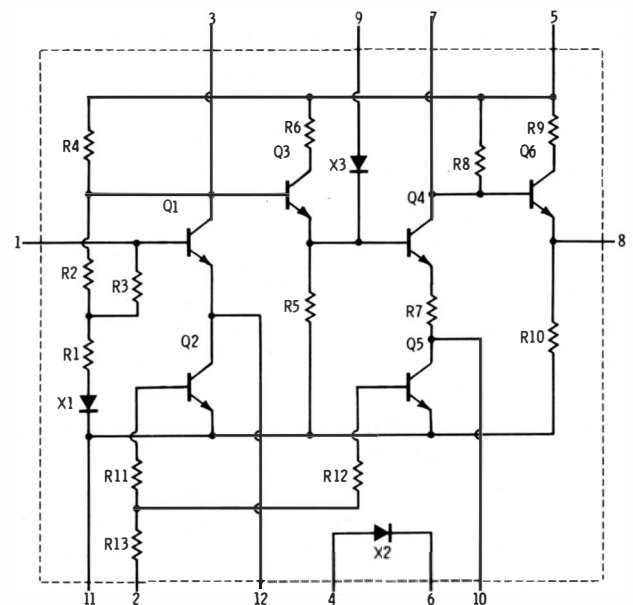

Fig. 3-16. Schematic diagram of the RCA CA3021 integrated circuit.

Fig. 3-17. Connections of the RCA CA 3021 IC in a 455-kHz amplifier.

measurement of the current drawn by Terminal 9 requires opening of the circuit for insertion of a milliammeter.

Sealed Slugs

Radios subjected to considerable vibration, such as car radios, may have i-f transformers sealed with wax to prevent alignment adjustments from shift-ing. If realignment is attempted by forcing a sealed slug to turn, the transformer is likely to be damaged and may require replacement. The correct procedure in this situation is to heat a metal screwdriver or other metallic rod and transfer sufficient heat to the slug to soften the wax. Then, the slug can be turned back and forth as the wax cools and will remain free, so that realignment can be made

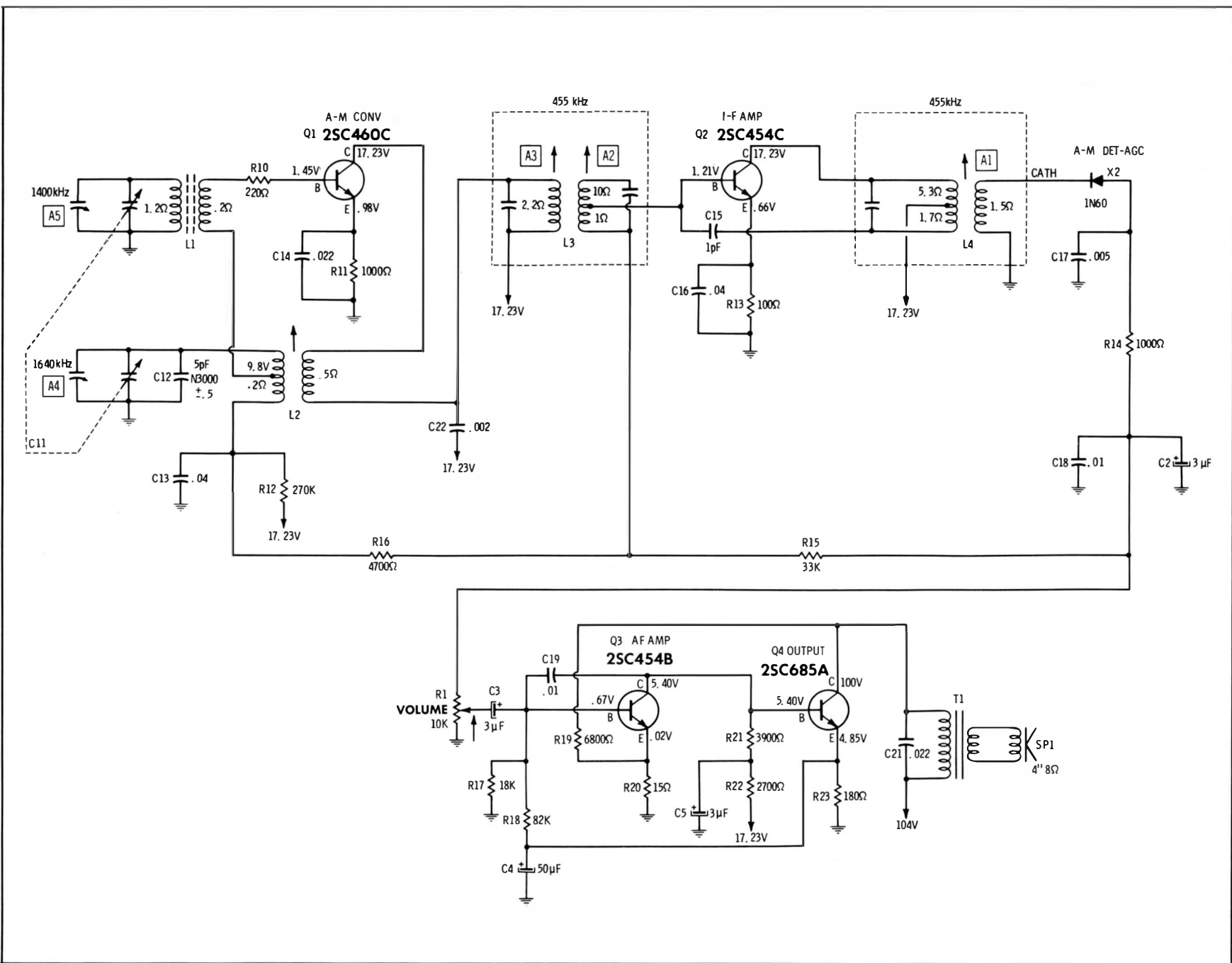Fig. 3-18. Voltage and current values for a typical IC.

Fig. 3-19. Receiver circuit with neutralization in the i-f stage.

without damage to the transformer. As another practical precaution, be sure to check the receiver service data before assuming that a particular shield encloses an i-f transformer—some manufacturers use identical shield cans for the i-f and the local-oscillator coils.

I-f coil windings occasionally open up, as the result of accidental connection across the supply voltage. Case histories show that an apparently open winding has been due to failure to solder a coil lead to a terminal. Intermittent operation and noisy reception can be caused by a bent terminal that barely touches the shield. Defects of this kind are evident on visual inspection after disassembly of an i-f transformer. Shields must be properly grounded; a loose shield often develops noise, as well as impaired reception. Most i-f transformers are designed for operation at either 455 kHz or 262 kHz. The latter type is found chiefly in auto radios. When an i-f transformer must be replaced, consult the receiver service data for suitable replacement sources.
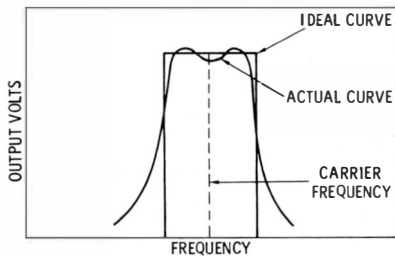
I-F Regeneration and Oscillation

I-f regeneration or oscillation is caused by positive feedback from the output circuit to the input circuit. With reference to Fig. 3-19, positive feedback occurs from the collector to the base of Q2 via the collector-base junction capacitance. However, the undesirable effect of this feedback is can-
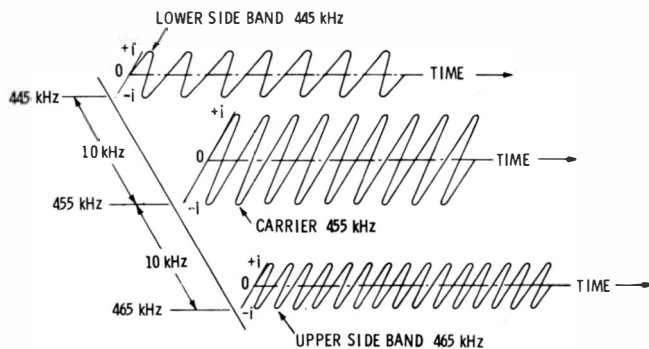
celed, or neutralized, by capacitor C15. This neutralizing capacitor feeds back a voltage from collector to base which is 180 degrees out of phase with the voltage fed back via the junction capacitance. In case C15 opens up, the stage will become unstable, and may break into oscillation. The same trouble symptom can be caused by an incorrect type of replacement transistor that has more junction capacitance than the original. It is helpful to analyze the characteristics of a regenerative i-f stage, as follows.

Distortion is the most common customer complaint when an i-f stage is regenerative. Basically, the trouble is due to sideband cutting, as a result of subnormal bandwidth. That is, regeneration causes the i-f response curve to become narrow and sharply peaked. Let us consider the intermediate frequencies produced by a 10-kHz audio tone. As shown in Fig. 3-20, the 455-kHz carrier is flanked by an upper sideband of 465 kHz and by a lower sideband of 455 kHz. In an ideal receiver, the i-f amplifier would have a rectangular response "curve," with a bandwidth of 20 kHz to accommodate both sidebands. In practice, however, an ideal response curve can only be approximated by means of a double-humped response curve. In turn, there is a certain amount of sideband cutting (attenuation) in normal operation when high-frequency audio tones are being transmitted.

Next, with reference to Fig. 3-21, we observe that alignment with a single-peaked response curve produces still more sideband cutting. In this example, the bandwidth of the single-peaked response attenuates tones substantially higher than 3 kHz. This is approximately the maximum degree of sideband cutting that can be tolerated by most broadcast listeners. In the majority of practical situations, an experienced technician will align a receiver to provide curve A, rather than curve B in Fig. 3-21. The reason for this choice is that a-m receiver alignment involves a compromise. Broadcast stations are allocated 10-kHz apart; therefore, if a receiver has sig-

(A) *Comparison of ideal and actual frequency-response curves.*

(B) *Sideband frequencies in amplitude-modulated wave.*
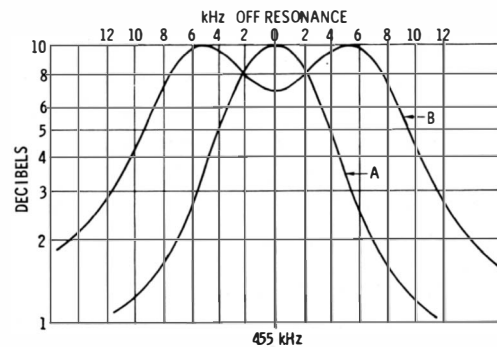
Fig. 3-20. Frequency-response curves.

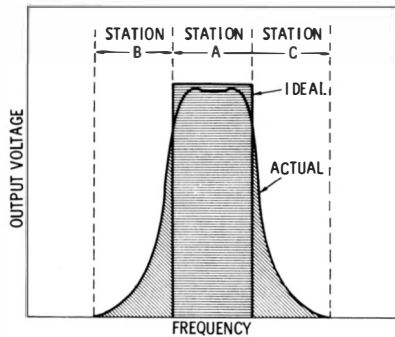**Fig. 3-21. Sideband cutting.**

Fig. 3-22. Selectivity depends on the steepness of the frequency-response curve.

nificant response for 10-kHz audio tones, adjacent-channel interference is very likely to occur. This relationship is shown in Fig. 3-22.

In case an i-f stage becomes regenerative, the response curve will have much narrower bandwidth than curve A in Fig. 3-21. Accordingly, distortion due to sideband cutting becomes very objectionable. This distortion takes on various forms, depending on the exact tuning of the front end. For example, when the local oscillator is tuned to produce an i-f carrier of 455 kHz (center i-f frequency), sideband cutting has the effect of developing a "boomy" audio signal, with poor intelligibility. That is, only the low-frequency components of the signal are passed by the i-f amplifier. On the other hand, if the local oscillator is tuned to produce an i-f carrier of about 457 kHz, one of the sidebands and most of the carrier are eliminated. The result is a "tinny" audio signal with poor intelligibility.

Regeneration is least troublesome when the receiver is tuned to a strong signal, because the agc (or avc) bias causes the i-f amplifier to operate at comparatively low gain, so that the amount of feedback is minimized. On the other hand, when the receiver is tuned to a weak station, the i-f amplifier operates at high gain, and distortion due to regeneration becomes most troublesome. In severe cases, the i-f amplifier will break into sustained oscillation, which blocks signal passage and results in a "dead" receiver. This condition is easily checked by measuring the output voltage at the detector with a dc voltmeter. When the i-f amplifier is oscillating, we will find a high dc voltage present at the detector output. Regeneration is best checked with a signal generator. When the bandwidth of the i-f amplifier is measured, we will find a comparatively narrow response in case regeneration is present.

In-Circuit Transistor Testing

As noted previously, defective transistors can usually be pinpointed by means of dc voltage measure-

ments, and by comparing the measured values with those specified in the receiver service data. This is basically an in-circuit type of test. It has also been explained how "turn-on" and "turn-off" tests can be made in-circuit. We will now consider how the ac beta of a transistor can be measured in-circuit with the use of a suitable tester. Although this type of instrument is somewhat more complicated than a VOM, for example, it can be a time-saver when the bench man clearly understands how to use it. First, the leads of the in-circuit ac-beta transistor tester are connected as illustrated in Fig. 3-23. Then, the BETA CAL control is adjusted to bring the pointer to the BETA CAL calibration mark on the scale plate, as shown in Fig. 3-24. This sets the collector current to a normal value of about 2 mA.
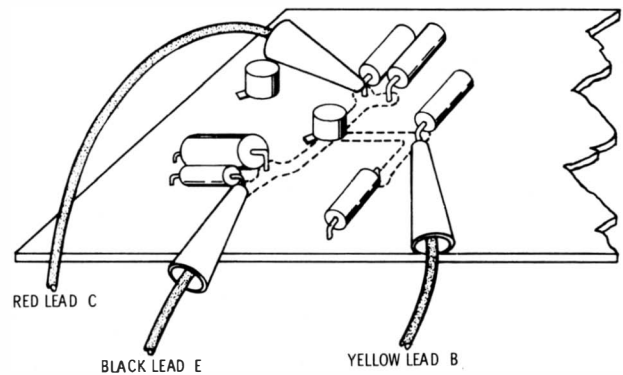

Fig. 3-23. Connect transistor tester to convenient points that are directly connected to transistor leads.

To measure the beta value of the transistor, the TEST or GAIN button is pressed. This transfers the meter to the base circuit, as shown in Fig. 3-25, and we are essentially reading the amount of base current that it took to give 2 mA of collector current. Since beta is the ratio of output current to input current, the meter scale can be calibrated in terms of beta values. Next, we measure leakage with the basic test arrangement shown in Fig. 3-26. This is
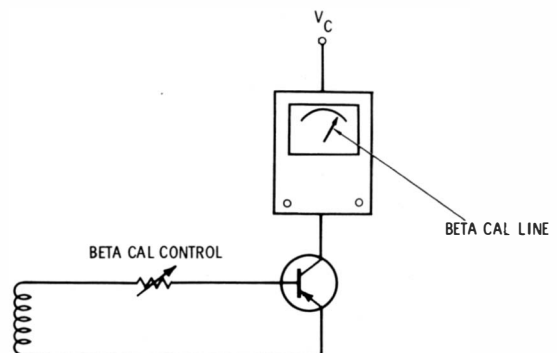

Fig. 3-24. BETA CAL control sets the collector current to a normal, or reference, level of about 2 mA.

a test that must be made out of circuit, because the measurement is impossible to make unless the emitter circuit is open. As a rule of thumb, when reverse bias is applied between collector and base, a low-power germanium transistor normally has a leakage current from 2 to 10 μA, and a power-type transistor normally has a leakage current up to 3 mA. Serious leakage will be evident when an in-circuit beta test is made, because the beta reading will be unacceptably low.
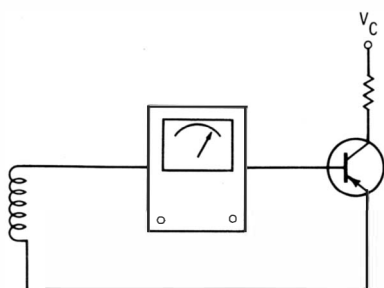

Fig. 3-25. Meter indicates beta by comparing base current to collector current that is produced by it.

A reasonably accurate in-circuit beta measurement can be made in most i-f configurations. Of course, we will find occasional exceptions. Therefore, when it appears that a transistor is defective on the basis of an in-circuit beta measurement, this test should be followed up with an out-of-circuit measurement after the transistor is disconnected. If a normal beta value is then measured, there may be a defective component in the circuit—or we may be concerned with an exceptional circuit arrangement which is not adapted to in-circuit beta measurements. The basic working rules for in-circuit transistor testing are summarized in Chart 3-1.

ANALYSIS OF COMMON SYMPTOMS

An analysis of the common trouble symptoms listed at the beginning of this chapter is presented in this section.

1. Dead Receiver

When both the B+ voltage (or supply voltage) and agc voltage are normal, and signal-tracing or signal-injection tests indicate that the signal is being stopped in the i-f section, it is logical to conclude that there is a defective component to be pinpointed in this section. In the case of a tube-type receiver, new tubes will have been tried before the chassis arrives at the bench. Dc voltage measurements are made first. In doubtful cases, an experienced technician will often feed a signal from an a-m generator into the receiver, and check the i-f circuits with
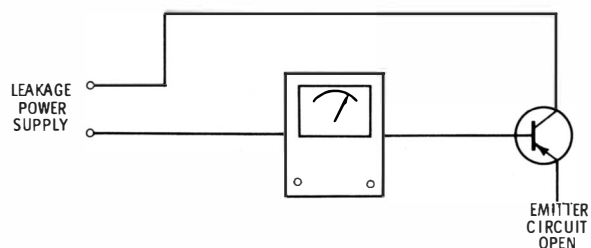

Fig. 3-26. Basic circuit for testing leakage in a transistor.

a scope—this is a particularly useful method of pinpointing open capacitors.

Possible causes of a "dead-receiver" complaint are as follows:

a. Leaky or shorted capacitor in a coupling circuit.
b. Open neutralizing capacitor.
c. Defective transistor.
d. Cracked printed-circuit board.
e. Unsoldered or cold-soldered connection.
f. Defective i-f transformer.
g. Open resistor (not likely, but possible).

2. Weak Output

Weak output can be due to obvious faults, such as subnormal supply voltage to the i-f amplifier or incorrect agc voltage. When low i-f gain is due to a defect in the i-f section, we look for marginal defects that would stop the signal if the defect becomes more serious. For example, a leaky capacitor can weaken the signal, and can stop the signal if it becomes a dead short. Another class of defects will cause reduced i-f gain, but cannot produce a dead-receiver symptom. For example, an open emitter bypass capacitor will weaken the signal; an i-f tuning slug that falls loose or crumbles will weaken the signal, but does not cause signal stoppage.

Possible causes of weak output due to defects in the i-f section are:

a. Transistor with collector leakage.
b. Open emitter bypass capacitor.
c. Leaky capacitor in a coupling circuit.
d. Defective i-f transformer.
e. Misalignment (less likely, but possible).

Sometimes, weak output is not due to a component defect, but to an incorrect type of component. For example, beginners occasionally replace a defective i-f transistor with an audio-type transistor. The replacement transistor will check good on an in-circuit or out-of-circuit test, because service-type instruments do not take the beta cutoff frequency of a transistor into account. However, an audio-type transistor will produce only a weak output in an i-f

Chart 3-1. Transistor Tester Meter Indications For Defective Transistors

Trouble	Meter Indication
Open base, emitter or collector	Cannot **BETA CAL** when transistor is tested out of circuit. In-circuit tester may **BETA CAL** through circuit impedances but no beta reading can be obtained when **GAIN** button is depressed.
Base to emitter short	Tester will **BETA CAL**, but **TYPE** switch must be in wrong position. Beta reading will be all the way to left or greater than infinity with meter pointer vibrating.
Base to collector short	Tester will **BETA CAL**, but when **GAIN** button is depressed, meter indication will not change.
Emitter to collector short	If there is a dead short, tester will not **BETA CAL**. If there is a low resistance short the tester may **BETA CAL**, but the meter needle will vibrate rapidly when checking beta.
Collector and base leads interchanged	Tester will **BETA CAL**, but meter reads to right (a beta of less than one).
Emitter and collector leads interchanged	Tester will **BETA CAL**, but meter may read to right (a beta of less than one). Indicates a very low beta figure. A few transistors may read the same because they are made to have the emitter and collector leads transposed.
Base and emitter leads interchanged	Transistor will **BETA CAL** as opposite-polarity transistor, and no beta reading is obtained when **GAIN** button is depressed.

circuit, because the signal frequency is greater than the beta cutoff frequency of the transistor. In case of doubt, always refer to the receiver service data, or to a transistor substitution guide.

3. Distorted Output

Distorted output can result from malfunctions in the front end or in the audio section, as well as from defects in the i-f amplifier. Therefore, the trouble symptom must be carefully localized before making a definite conclusion. The most straightforward approach is to inject a modulated–i-f signal at the input of the i-f amplifier, and to check the output from the detector with a pair of earphones or with a utility audio amplifier and speaker. In case the output is distorted, it is logical to conclude that the trouble is in the i-f section.

Possible causes of distorted output due to defects in the i-f amplifier are:

    a. Open neutralizing capacitor.
    b. Open decoupling capacitor in the i-f section.
    c. Incorrect type of replacement transistor.

    d. Missing or loose i-f transformer shields.
    e. Open screen bypass capacitor in a tube-type receiver.
    f. Substitution of tube with excessively high G_m.

4. Interference

Only a few types of interference are actually due to i-f defects. For example, feedthrough interference is basically caused by a front-end malfunction that lets a 455-kHz (or 262-kHz) signal pass through the rf and mixer circuits. On the other hand, a missing i-f transformer shield can permit direct pickup of interference by an i-f stage. Image interference occurs at the intermediate frequency, but is caused by inadequate preselection in the front end. On the other hand, a badly misaligned i-f strip will pass spurious mixer output frequencies that would normally be rejected. This trouble symptom is often associated with low gain.

Possible causes of interference due to defects in the i-f section are:

    a. Missing or defective i-f shielding.
    b. Defective capacitor, causing an alignment shift.
    c. Broken or otherwise defective i-f coil slug.
    d. Misalignment due to tampering by a beginner.
    e. Leakage between printed-circuit conductors, or short circuit due to solder splash.

5. Noisy Reproduction

There are two basic types of internally generated noise that we contend with in radio receivers. These are tunable noise and untunable noise. Tunable noise disappears between stations, and becomes apparent when the receiver is tuned to a station. This is basically a modulation of the station signal by a noise source in the receiver; it is the most common type of noise disturbance produced in an i-f amplifier. Untunable noise is not affected by the presence or absence of a station signal. For example, a loose or corroded battery connector can produce untunable noise, whereas a noisy i-f transistor will produce tunable noise only.

Possible causes of noisy reproduction due to defects in the i-f section are:

    a. Noisy transistor.
    b. Cold-soldered contact in i-f circuitry.
    c. Deteriorated resistor.
    d. Highly unstable capacitor.
    e. Foreign matter between printed-circuit conductors.

A noisy stage is localized best by means of a signal tracer or an oscilloscope. A signal tracer will

give an audible indication when noise is present with the signal, and a scope will show when noise "spikes" are present in a signal.

6. Intermittent Reception

As noted previously, an intermittent condition is usually localized best by means of monitoring with dc voltmeters, hf or high-frequency voltmeters, signal tracers, or scopes. The most prevalent problem at the service bench is to speed up the occurrence of the intermittent symptom. This can sometimes be done by tapping various components, heating pigtails with a soldering tool, or by spraying suspected components with a coolant. Transistors must be warmed cautiously to avoid thermal damage. Turning the power switch on and off several times is oc-

casionally helpful. An intermittent transistor will show up on an in-circuit test—the pointer will move erratically on the scale when the transistor is tapped. A tube-type set can be operated at high line voltage to help speed up an intermittent; however, this is not permissible in the case of a solid-state receiver.

Possible causes of intermittent reception due to defects in the i-f section are as follows:

a. Intermittent capacitor.
b. Unstable transistor.
c. Cold-solder joint.
d. Bent terminal that barely touches a shield or other metallic object.
e. Microscopic break in printed-circuit wiring.
f. Defective resistor (less likely, but possible).

Chapter 4

Troubles in the Audio Section

The audio section of a radio receiver includes the load circuit of the detector, the preamplifier (or driver), the output (or power) amplifier, and the speaker(s). This receiver section has a power rating, or output power, that denotes the amount of audio-frequency power that can be supplied to a speaker without objectionable distortion. Note that the input portion of a detector configuration is technically a part of the i-f system, whereas the output portion of the detector is a part of the audio system. The function of the detector is to recover the modulation envelope from the i-f signal. This audio information is stepped up in the preamplifier, which provides an increased audio voltage but comparatively little audio power. An output amplifier is designed to provide audio power amplification, and may supply the output signal at comparatively low voltage.

Common trouble symptoms caused by defects in the audio section are:

1. Dead receiver.
2. Weak output.
3. Distorted sound.
4. Noise and/or hum in the audio signal.
5. Intermittent operation.
6. External interference.

GENERAL DISCUSSION

Most superheterodyne receivers employ a diode detector for demodulation of the i-f signal. Because of the linear characteristic that a diode provides be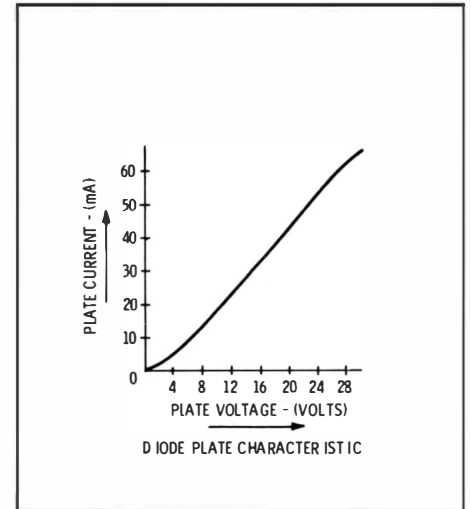tween the modulated input signal and the demodu-lated output signal, high-level signals can be processed with very little distortion. Accordingly, diode detectors are in very wide use. The chief disadvantage of a diode detector is its lack of gain; therefore, all of the gain in the audio section is developed in the circuits following the detector. Another disadvantage of a diode detector is the comparatively heavy loading that it places on the last i-f transformer. This loading reduces the selectivity of the i-f amplifier, but the loss of selectivity is not excessive as long as the detector operates normally.

In practice, either tube-type or solid-state diodes may be used as detectors. Fig. 4-1 shows the basic circuit for a vacuum-tube diode detector. It consists of an i-f signal input circuit, a diode rectifier tube, and an RC filter. The plate-current/plate-voltage characteristic of a typical diode is shown in B. In normal operation, the characteristic is almost linear; however, at low values of heater voltage, the upper portion of the curve will droop and cause nonlinear distortion. Note that the RC section operates as a low-pass filter; it bypasses the i-f component to ground, to avoid possible overload and resulting distortion in the first audio stage. At the same time, the time constant of the RC section (in normal operation) is such that the audio frequency component is passed without high-frequency attenuation.

Diode detectors are basically classified as voltage or current types. With reference to Fig. 4-2, note that the voltage-type detector employs a series-diode arrangement, whereas a current-type detector employs a shunt-diode arrangement. In the case of a current detector, a low-pass RL section must be

(A) *Circuit and waveforms.*

(B) *Diode plate characteristic.*

Fig. 4-1. Action of basic diode detector.

used for filtering, because an RC section would shunt the applied i-f signal to ground. Most a-m broadcast receivers employ voltage detectors; current detectors are found chiefly in high-frequency receivers, such as communication-type receivers. Another example of a voltage detector is seen in Fig. 4-3; the diode section operates as the demodulator. The rectified signal drops across R, and its i-f component is removed by C. Note that the triode grid is connected directly to a tap on the diode load resistor. Thereby, the average rectified cathode current provides a dc bias voltage at the tap which is applied to the grid.

The triode section of the tube in Fig. 4-3 operates as an audio amplifier. A coupling capacitor, C_0, is employed, which normally prevents plate-voltage drain-off by the volume control. Note that if C_0 becomes leaky, a positive bias voltage would be ap-

plied to the grid of the following audio-amplifier tube. Next, let us consider the grid-leak detector circuits shown in Fig. 4-4. These are very efficient circuits, in which the control grid does double duty as the anode of a diode, and as a control element for amplification. Grid-leak demodulation is employed chiefly in compact specialized receivers. Its chief

Fig. 4-3. Diode detector circuit.
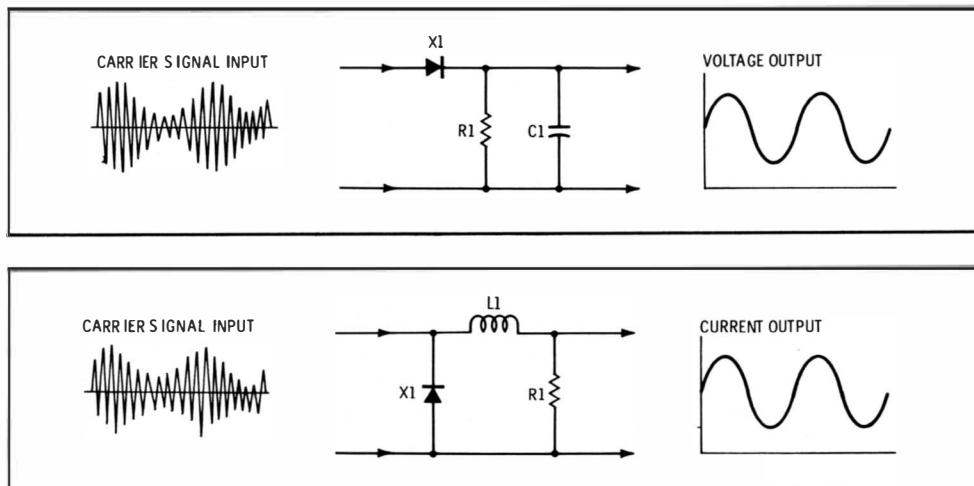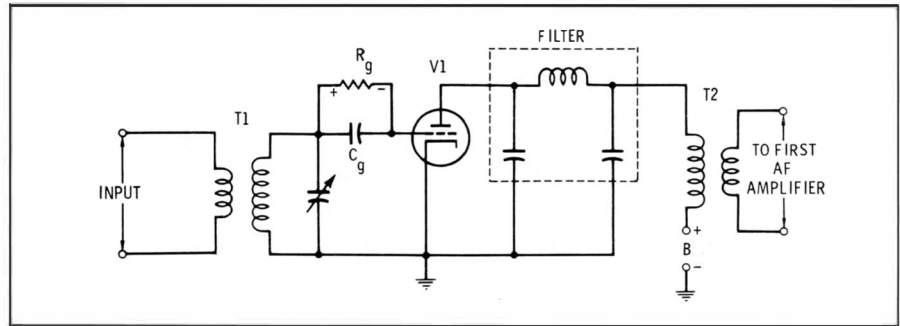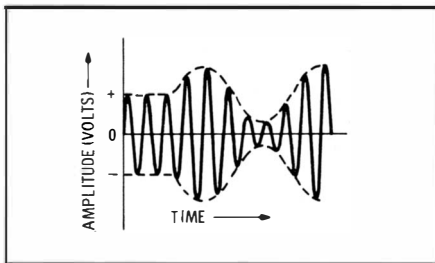

(A) *Voltage detection.*
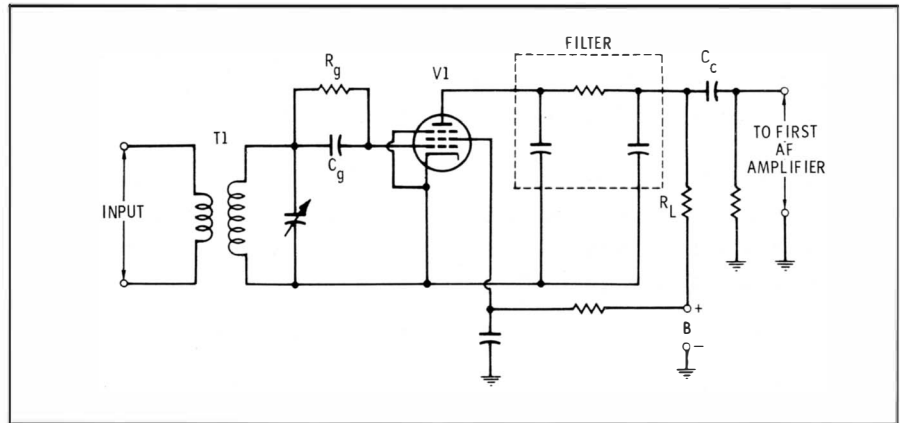
(B) *Current detection.*

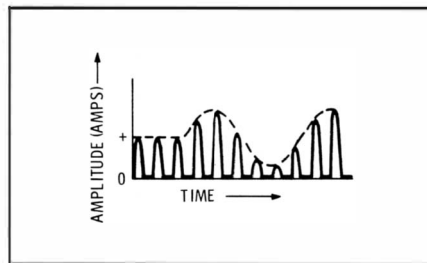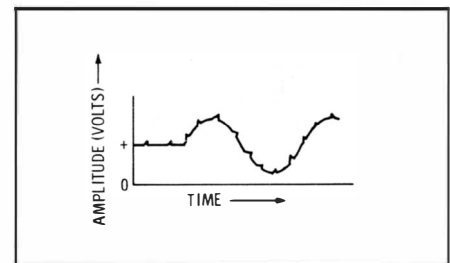**Fig. 4-2. Input and output waveforms of diode detectors.**

(A) *Triode circuit.*

(B) *Pentode circuit.*

(C) *Signal input voltage.*   (D) *Grid current.*   (E) *Voltage across R_g-C_g.*

Fig. 4-4. Grid-leak detector circuit.

disadvantage is a tendency to overload and distort on strong signal inputs. The pentode tube provides greater audio gain than a triode tube.

When regeneration is employed, as exemplified in Fig. 4-5, the efficiency of grid-leak detection is greatly increased. In effect, regeneration provides rf amplification by the detector tube. However, the use of regenerative detectors is limited to receivers operated by technical personnel, such as "ham" radio receivers. The chief disadvantage of regeneration is the critical nature of the feedback control; if the regeneration control is advanced slightly past the point of instability, the detector "takes off" and oscillates, with resulting distortion of the incoming signal. We will occasionally encounter the plate-detector illustrated in Fig. 4-6 and the infinite-impedance detector illustrated in Fig. 4-7. These detectors are found chiefly in specialized equipment.

As shown in Fig. 4-6, a plate-detector tube is normally biased to operate in Class B. Thereby, rectification is obtained in the plate circuit. Although the efficiency of a plate detector is comparatively low, it has the advantage of a high input impedance. This feature normally minimizes the loading on the preceding i-f circuit and provides maximum selectivity. Note that if the peak voltage of the applied signal exceeds the bias voltage provided by R_k, the control grid will draw current, and the selectivity of the preceding i-f circuit will be impaired. The infinite-impedance detector exemplified in Fig. 4-7 is basically a plate detector. However, since the cathode resistor R1 operates as the demodulator load, negative feedback occurs, and the input impedance of the tube is even greater than that of a conventional plate detector. Consequently, there is less loading effect on the preceding i-f circuit.

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Demodulation of an a-m signal by a common-emitter transistor detector is shown in Fig. 4-8. This configuration is analogous to that of a vacuum-tube, grid-leak detector. Rectification takes place in the emitter-base circuit of the transistor. Amplification is obtained in the emitter-collector circuit. R1 acts as the diode-load resistor, and C2 filters out the i-f component. The amplified audio signal drops across R4 and is coupled via C5 to the following stage. C3 is an audio-bypass capacitor; R3 is an emitter-stabilizing resistor. R2 is a base-bias resistor. In normal operation, the transistor is biased almost to cutoff, so that efficient rectification is obtained in the base-emitter circuit. C4 is the final filtering element for eliminating the i-f component in the demodulated signal.

We will also find the common-base transistor detector in some receivers; this configuration is exemplified in Fig. 4-9. Detection takes place in the emitter-base circuit, and amplification is obtained in the collector-base circuit. C3 serves as a filtering capacitor. The designer's choice between the common-emitter and common-base detector configurations is chiefly one of impedance relations. As shown in Fig. 4-10, the common-base circuit normally has the highest voltage gain, but it also has a low value of input resistance. Because of this, the preceding stage is loaded considerably, and its selectivity is less than if the common-emitter configuration were used.

Audio Amplifier Essentials

Most of the audio amplifiers used in radio receivers operate in Class A. This means that operation is on the linear portion of the collector or plate characteristics. The bias is such that there is collector current or plate current over the complete cycle of an audio signal; there is current also when no signal is present. A minority of audio amplifiers in radio receivers are operated in Class B. This means that the bias is such that the collector current or the
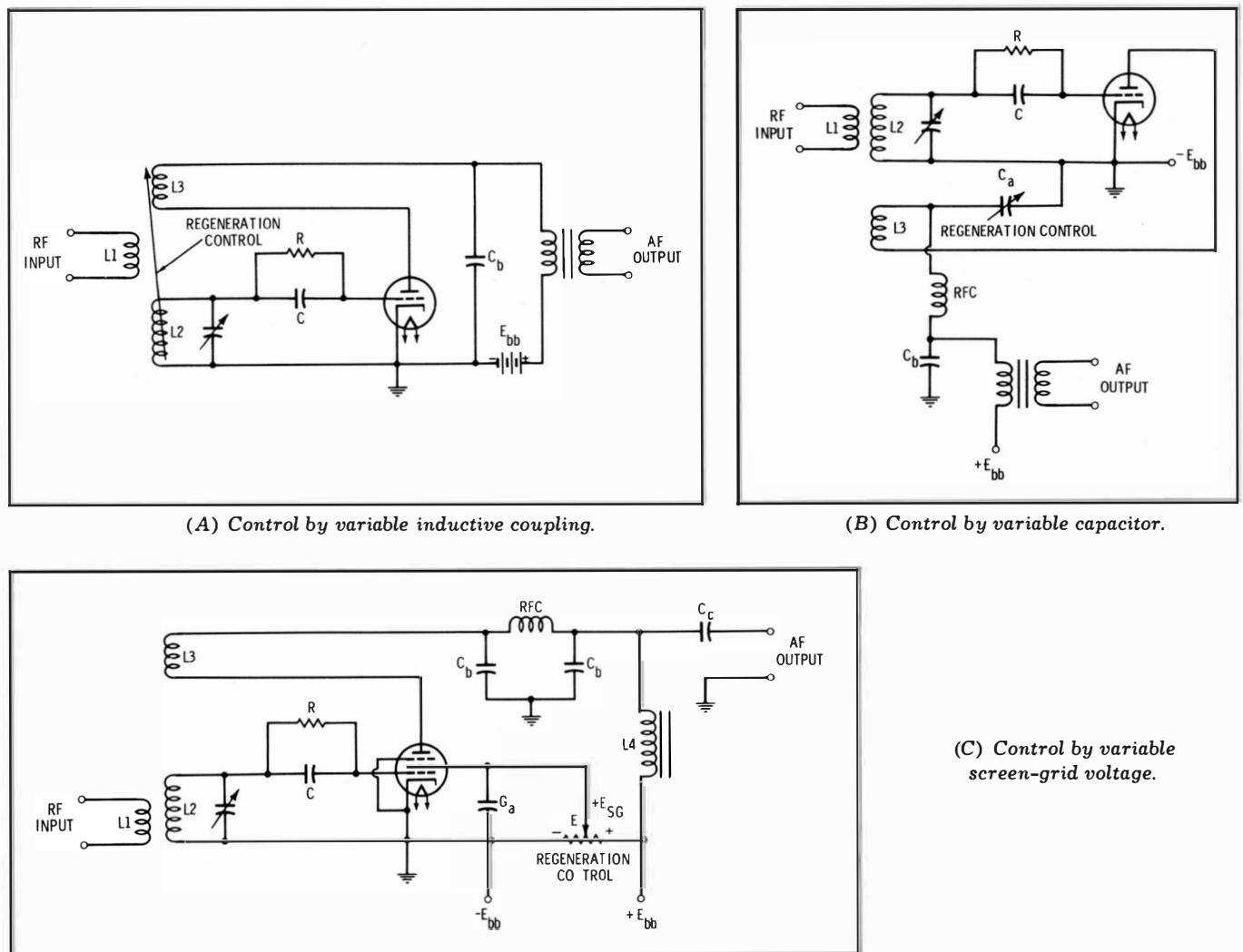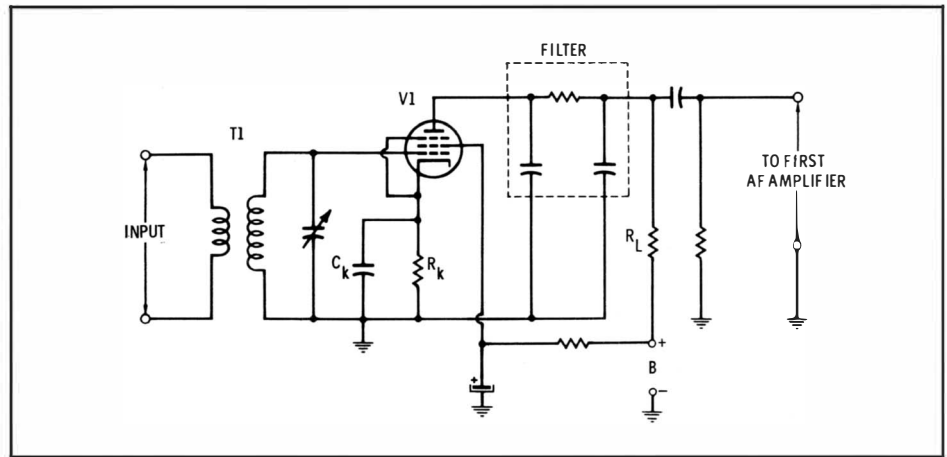

(A) *Control by variable inductive coupling.*

(B) *Control by variable capacitor.*

(C) *Control by variable screen-grid voltage.*

Fig. 4-5. Regenerative detector circuits.
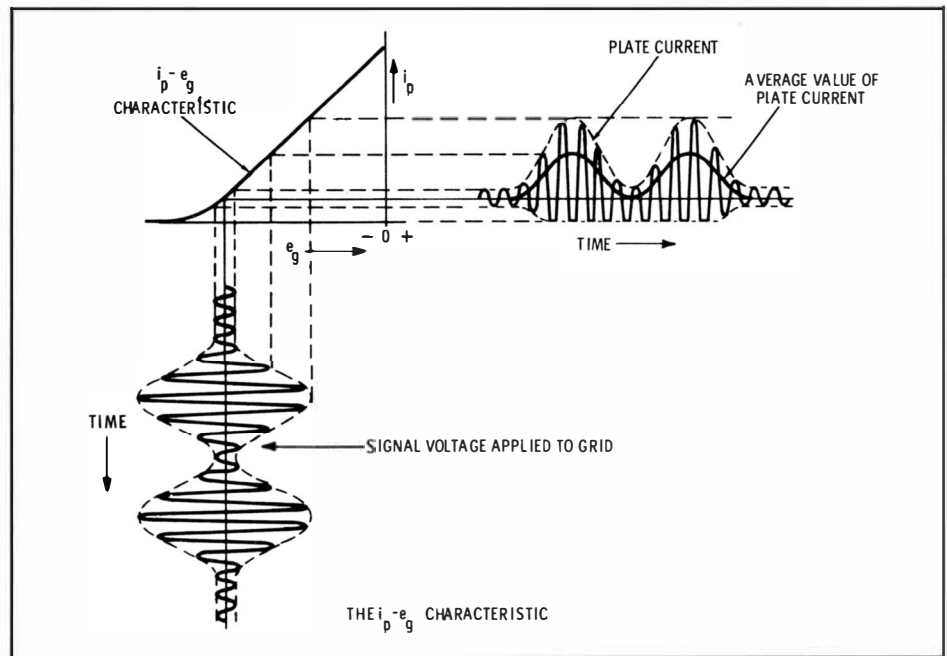
(A) Schematic.

(B) Characteristic curve.

Fig. 4-6. I_p-e_k characteristic for a plate-detector circuit.

plate current is cut off. In turn, a Class-B amplifier produces an output over one-half cycle of the input audio signal. Therefore, Class-B amplifiers are always operated in push-pull, to produce an output over the entire cycle of the audio signal. If one side of a push-pull, Class-B audio stage goes "dead," severe distortion results. Note that a push-pull amplifier may be operated in Class AB. This means that the bias is set so that collector current or plate
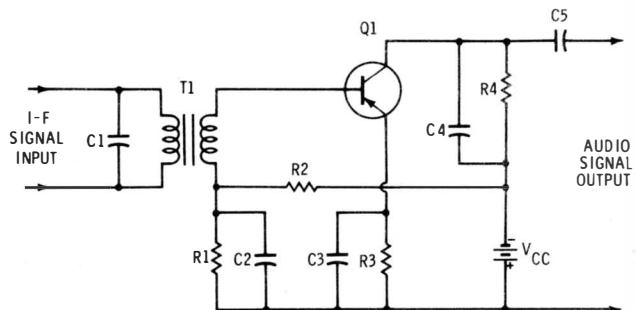

Fig. 4-7. Infinite-impedance detector.
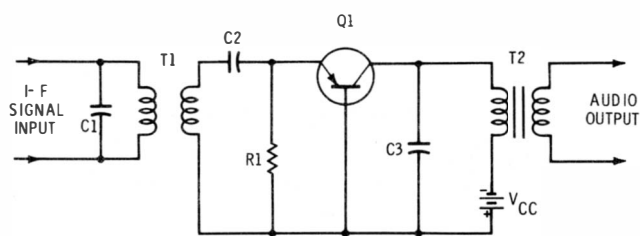

Fig. 4-8. Common-emitter transistor detector.

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Fig. 4-9. Common-base transistor detector.

(A) RC coupling.
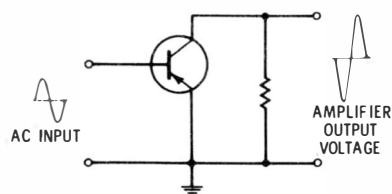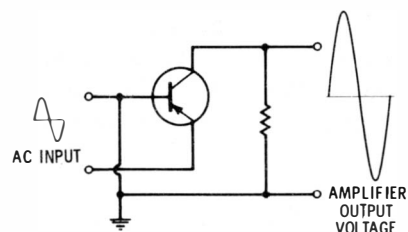

(B) Transformer coupling.

current is zero for less than one-half cycle of the input audio signal. Class-AB operation overcomes a residual form of distortion called crossover distortion.

Signal coupling from one stage to the next may be provided by RC coupling as shown in Fig. 4-11A, by transformers B, by impedances C, or by direct coupling D. An RC coupling network employs economical components; however, its efficiency is comparatively low, because of the power dissipated in the collector load resistor. The most common cause of trouble in this configuration is leakage in C1, which applies excessive forward bias to the following transistor and reduces the gain. Another kind of trouble symptom is caused by loss of capacitance or open-circuiting of C1; this defect always causes low-frequency attenuation and weakens the signal. If the capacitor opens, the signal is stopped. The common-emitter configuration is almost always used, because it provides the least difference of input
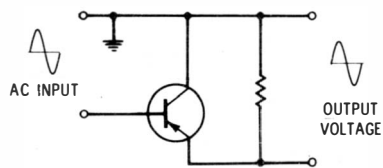

VOLTAGE GAIN: 270 TIMES
CURRENT GAIN: 35 TIMES
POWER GAIN: 40dB
INPUT RESISTANCE: 1.3K
OUTPUT RESISTANCE: 50K
(FOR GENERATOR INTERNAL RESISTANCE OF 1K)

(A) Common emitter.

(C) Impedance coupling.

(D) Direct coupling.

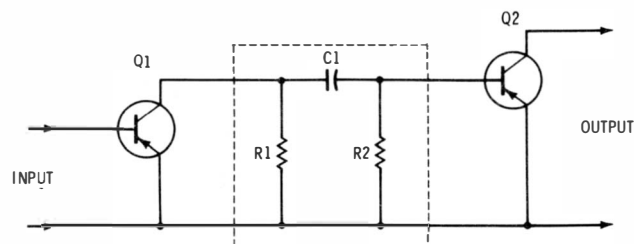**Fig. 4-11. Interstage coupling networks.**

VOLTAGE GAIN: 380 TIMES
CURRENT GAIN: 0.98
POWER GAIN: 26dB
INPUT RESISTANCE: 35 OHMS
OUTPUT RESISTANCE: 1 MEGOHM
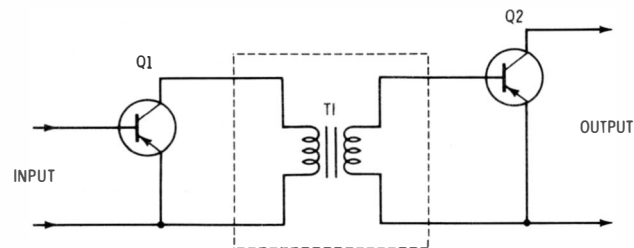(FOR GENERATOR INTERNAL RESISTANCE OF 1K)

(B) Common base.

VOLTAGE GAIN: 1
CURRENT GAIN: 36 TIMES
POWER GAIN: 15dB
INPUT RESISTANCE: 350K
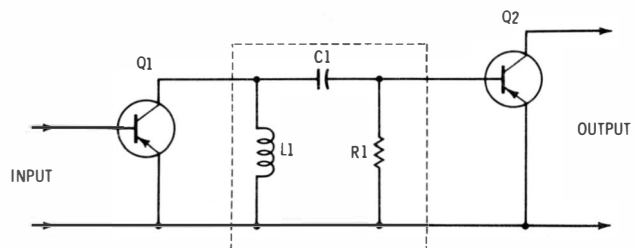OUTPUT RESISTANCE: 500 OHMS
(FOR GENERATOR INTERNAL RESISTANCE OF 1K)

(C) Common collector.

Fig. 4-10. Transistor circuit parameters.

versus output resistance (Fig. 4-10), and develops reasonable power gain with simple circuitry.

Transformer coupling, as illustrated in Fig. 4-11B, provides maximum available gain, inasmuch as the winding ratio can be selected to match the input and output impedances of the transistors. A transformer also provides high operating efficiency, because no collector load resistor is employed. On the other hand, transformers have the disadvantages of comparatively high cost and appreciable bulk and weight. Only the very expensive types of audio transformers have as good a frequency response as an RC-coupling network. The impedance-coupled arrangement, shown in Fig. 4-11C, occupies an intermediate place between the RC amplifier and the transformer-coupled amplifier. It employs an audio

inductor instead of a collector-load resistor. The chief advantage of this configuration, when compared with an RC-coupled stage, is higher efficiency.

Direct coupling, shown in Fig. 4-11D, provides maximum production economy and very good frequency response. Operating efficiency is high. Its gain is somewhat better than that of an RC-coupled or impedance-coupled stage, but is less than that of a transformer-coupled stage. The chief disadvantage of direct coupling is its susceptibility to temperature instability, which requires the use of rather elaborate stabilization means. In turn, a sizeable portion of the potential production economy is often lost, and the number of stages that can be directly coupled in practice is limited. Repair of direct-coupled amplifiers involves the use of replacement components with closer tolerances than those used with ac-coupled amplifiers.

Tube and Transistor Volume Controls

The classification of volume (or gain) controls as *voltage dividers* or as *current dividers* basically depends on the relative magnitudes of the source and load impedances. Let us consider the class of voltage
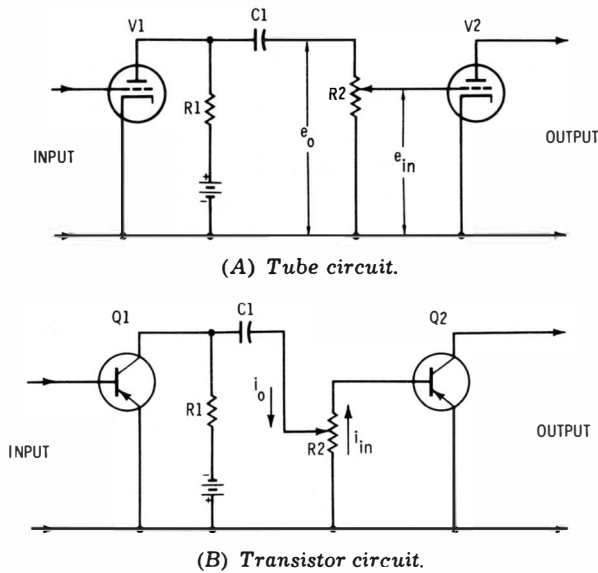

(A) Tube circuit.

(B) Transistor circuit.

Fig. 4-12. Volume controls used as voltage or current dividers.

dividers. If the source impedance is low compared to the load impedance, the volume control is described as a voltage divider. With reference to Fig. 4-12A, the plate impedance of V1 is low compared to the grid impedance of V2. Therefore, R2 is described as a voltage divider. Next, let us consider the class of current dividers. If the source impedance is high in comparison to the load impedance, the volume control is described as a current divider. With reference to Fig. 4-12B, the collector imped-

ance of Q1 is high compared to the base impedance of Q2. Therefore, R2 is described as a current divider.

One of the common trouble symptoms produced by volume controls is noise. Variable resistors tend to become erratic and noisy because of extended wear. When a volume control is replaced, the same resistance value should be used as in the original. A volume control affects audio tone reproduction, as well as volume. For example, R2 in Fig. 4-12A is shunted by stray circuit capacitance (not shown). Therefore, the higher audio frequencies become attenuated as the control is set to lower positions. To minimize this high-frequency loss, the resistance value of R2 must not exceed a certain upper value. On the other hand, if the value of R2 is too small, the lower audio frequencies become unduly attenuated, because they produce a voltage drop across C1. Therefore, the resistance value of R2 must not be less than a certain lower value. This range is called the operating tolerance of the volume control.
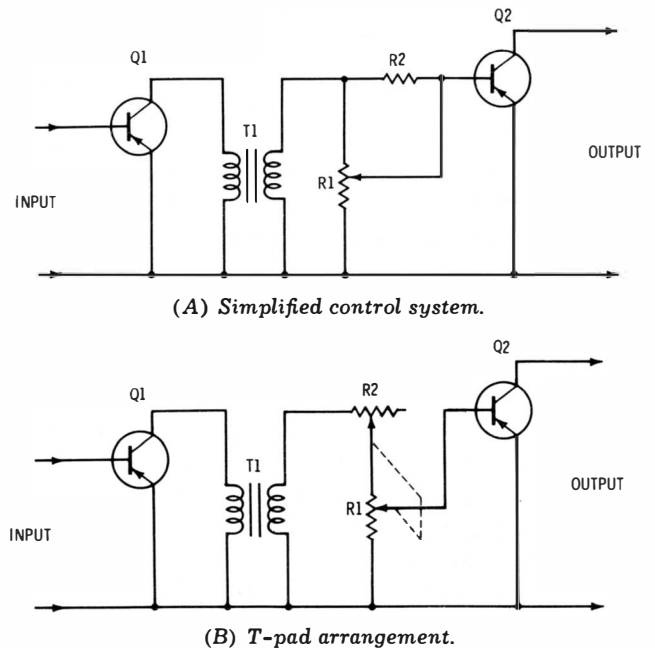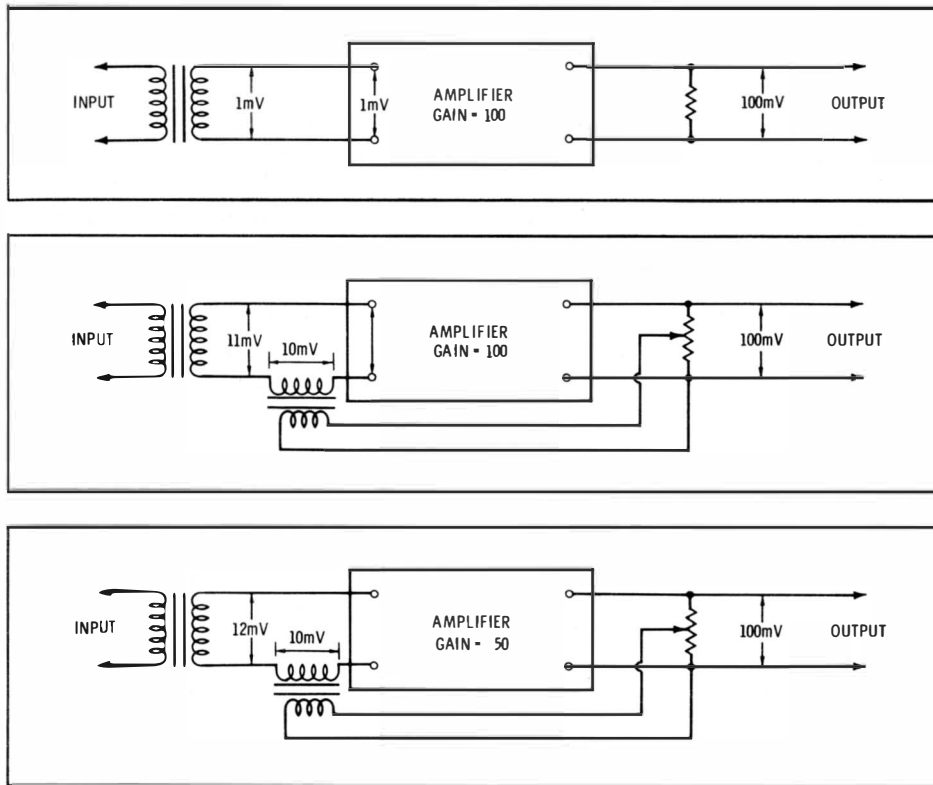

(A) Simplified control system.

(B) T-pad arrangement.

Fig. 4-13. Volume control circuits used in transformer-coupled amplifiers.

Volume controls used in transformer-coupled amplifiers must meet requirements analogous to controls used in RC-coupled amplifiers. To avoid distortion due to changing reflected impedance, a T-type control is ideal. In economy-type receivers, we will often find a compromise arrangement, such as is shown in Fig. 4-13A. Deluxe designs commonly provide a T-pad arrangement, as exemplified in Fig. 4-13B. In replacing these volume controls, it is desirable to use components with the original values.

(A) *Amplifier without feedback.*

(B) *Ten percent feedback, gain 100.*

(C) *Ten percent feedback, gain 50.*

Fig. 4-14. Effects of degenerative feedback.

Volume controls in elaborate receivers may also have specified audio tapers, which designates the manner in which the total resistance varies with the control setting.
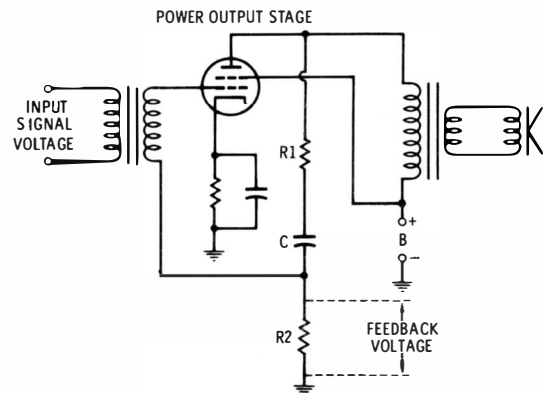
Negative Feedback

When a portion of the audio output voltage is fed back to the input of the same or a preceding stage in opposite phase to the applied signal, negative feedback is present and degeneration takes place. A circuit that provides degeneration is called an inverse or negative-feedback circuit. When degeneration is present, the voltage fed back is opposing the applied input voltage and therefore reduces its amplitude, as exemplified in Fig. 4-14. Since the feedback voltage subtracts from the applied input signal, the stage gain is reduced. However, the reduced gain is offset by reduction of frequency distortion and amplitude distortion. The stability of the circuit is also improved. In repairing a negative-feedback loop, it is necessary to use original component values to avoid disturbing the characteristics of the amplifier.
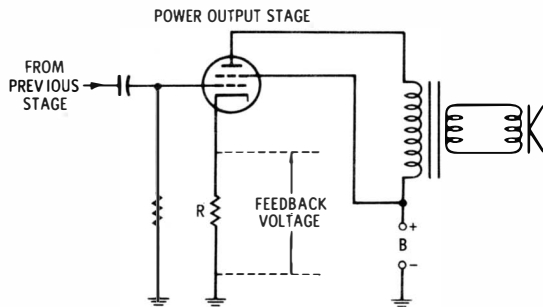
Two commonly used circuits, shown in Fig. 4-15, are examples of the application of negative feedback in audio amplifiers. In A, the voltage divider consisting of R1 and R2 is connected across the plate circuit of an audio-output tube. Capacitor C between the two resistors prevents the dc plate voltage from being applied to the grid of the tube. The voltage divider applies a portion of the audio output voltage back to the grid. This voltage is equal approximately to the fraction $(R2/R1 + R2)$ times the output voltage. This feedback voltage is in series with the input transformer secondary and is in opposite phase to the voltage induced in that winding by the preceding amplifier stage. We call this circuit action *constant-voltage feedback,* since its magnitude depends on the audio output voltage.

Next, in Fig. 4-15B, negative feedback is obtained by omitting the bypass capacitor across the cathode bias resistor. The portion of the output signal voltage dropped across R opposes the signal input voltage between grid and ground. Therefore, degeneration takes place, and the stage gain is reduced. This method of applying negative feedback is called *constant-current feedback,* because the feedback voltage is proportional to the cathode current. We will find that much more elaborate feedback circuits are often used in de luxe receivers. However, the basic principle is always the same. When negative feedback is carried around two or more stages, it becomes increasingly important to maintain exact component values—particularly of capacitors, which affect signal phase shift. For example, a leaky capacitor in an elaborate negative-feedback circuit may cause uncontrollable oscillation.

(A) Voltage divider feedback.

(B) Cathode resistor feedback.

Fig. 4-15. Negative-feedback circuits.

Phase Inverters

In Fig. 4-16, a split-load phase inverter is shown, with Q1 driving a push-pull output stage comprising Q2 and Q3. The path of output current from Q1 is through R3 and also through R2. Note that R2
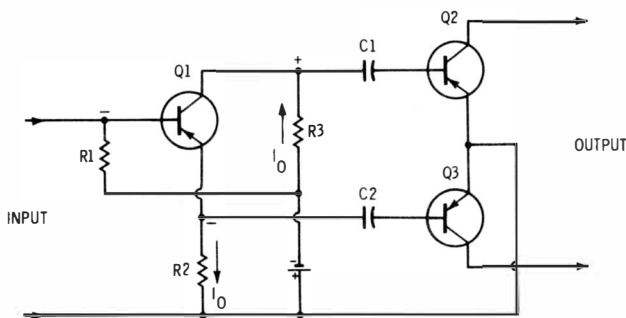

Fig. 4-16. Basic circuit for a one-stage phase inverter.

and R3 normally have equal values, and the base-bias voltage is determined by the value of R1. When the input signal aids the forward bias (driving the base more negative), the output current I_o increases. This increased output current causes the top terminal of R3 to become more positive with respect to ground, and the top terminal of R2 becomes more negative with respect to ground. On the other hand, when the input signal opposes the forward bias, the foregoing changes are reversed. Thus, a pair of out-

put signals are produced that are 180 degrees out of phase. In turn, Q2 and Q3 are driven in push-pull.

Since the arrangement in Fig. 4-16 tends to distort on strong input signals, due to the inequality of emitter and collector internal impedances, elaborate receivers often use the arrangement shown in Fig. 4-17. R4 compensates for the foregoing inequality, and the proportions of R2 and R3 are chosen to provide a balanced drive to Q2 and Q3. The gain of a one-stage phase inverter is quite low, and comparatively high-level drive is required. More elaborately
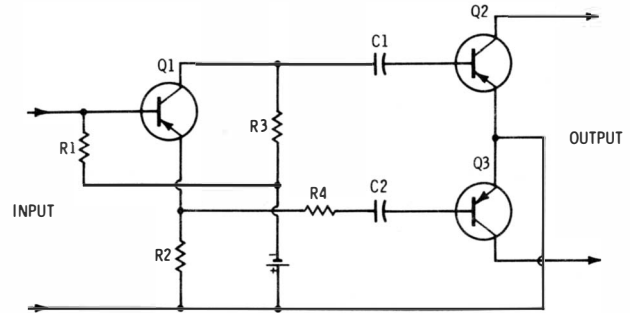

Fig. 4-17. One-stage phase inverter that includes equalized output impedance.

designed receivers often provide additional gain in the inverter section by means of a two-stage phase inverter. We will find two basic configurations in common use, called the common-emitter/common-base and the common-emitter/common-emitter circuits, as exemplified in Figs. 4-18 and 4-19. The chief precaution in servicing this type of inverter is to use replacement parts having values as close to the original values as may be practical.

Power Amplifiers

Power (or output) audio amplifiers are of the single-ended and push-pull Class-A types in radios where high power output and high efficiency are not basic requirements. When operated within their normal power range, these types of amplifier normally
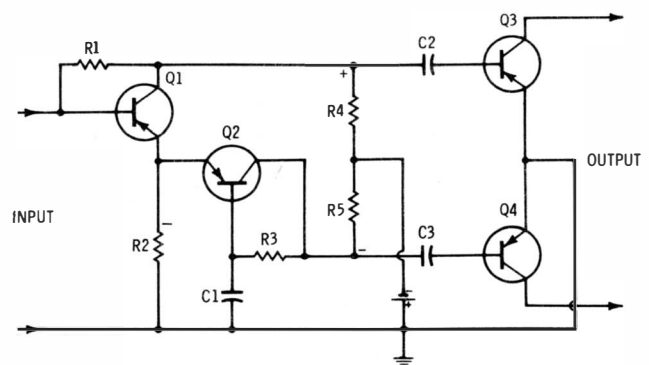

Fig. 4-18. Two-stage phase inverter using two transistors in a common-emitter and common-base configuration.
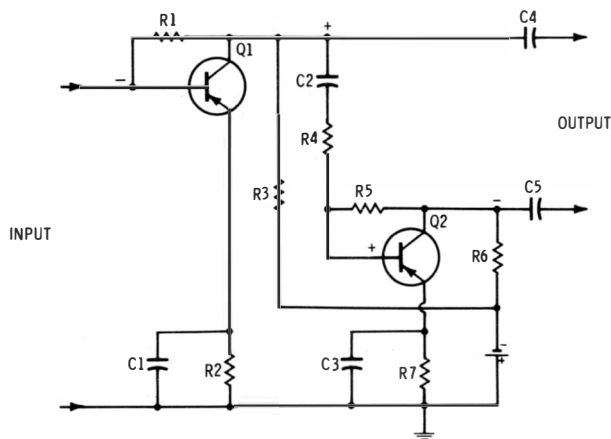
Fig. 4-19. Two-stage phase inverter using two transistors in the common-emitter configuration.

have little distortion. Class-B push-pull audio amplifiers are used in large receivers that are intended for use in entertainment centers, public locations, and similar situations that require considerable acoustic power. Let us consider the operation of a Class-B push-pull, zero-bias amplifier. Fig. 4-20 shows a simplified circuit for a Class-B amplifier. The emitter-base junctions are zero-biased. Each transistor normally conducts on alternate half cycles of the audio signal. In turn, the half cycles are combined in the secondary of the output transformer. High efficiency is obtained, because neither transistor conducts while the amplifier is idling.
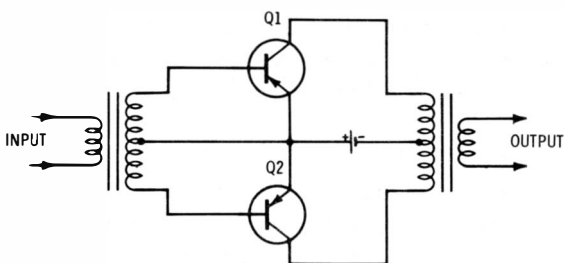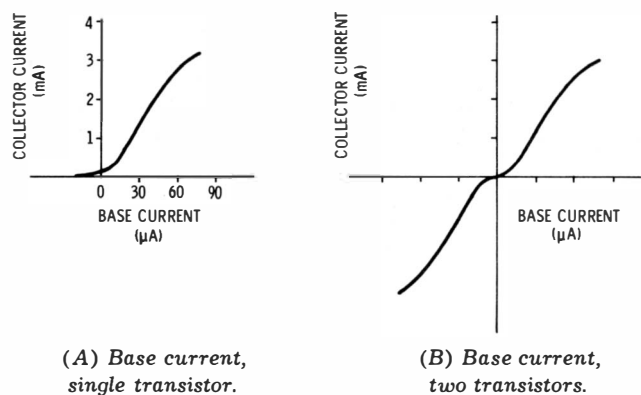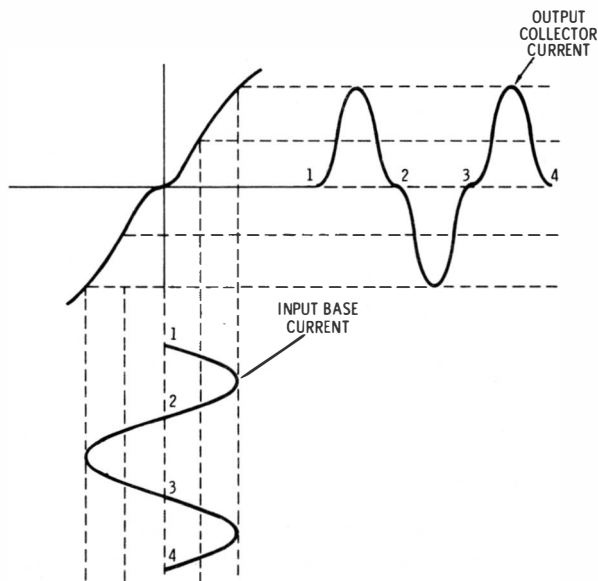

Fig. 4-20. Basic circuit for Class-B, push-pull amplifier with zero base-emitter bias.

Fig. 4-21 shows why the foregoing arrangement is not as linear as is desirable. The base-current versus collector-current curve becomes nonlinear in the vicinity of zero bias. In a push-pull stage, the result is *crossover distortion,* which can be ignored in an economy-type receiver, but is unacceptable in a de luxe receiver. However, if a small forward bias is applied to the base-emitter junctions, crossover distortion is then eliminated, as illustrated in Fig. 4-22. This mode of operation is said to employ biasing to *projected cutoff.* It is not Class-AB operation in the technical sense of the term. A configuration for a Class-B push-pull amplifier, with a small forward

(A) Base current, single transistor.

(B) Base current, two transistors.

(C) Input-output current relation.

Fig. 4-21. Dynamic transfer curves for Class-B, push-pull amplifier with zero bias.

bias applied to the base-emitter junctions, is shown in Fig. 4-23. Note that a bypass capacitor *must not* be connected across R1. Otherwise, the base-bias voltage increases as the input signal amplitude increases, and serious distortion can occur.

Capacitance-Diode Coupling

An emitter-bypass capacitor cannot be used in the circuit of Fig. 4-23, because it would charge to the peak signal voltage and reverse-bias the base-emitter junction. The same general principle applies to RC coupling in a Class-B push-pull amplifier. With reference to Fig. 4-24A, we observe that when Q1 is driven into conduction, it leaves a positive charge on the right-hand plate of C1 after the half cycle has passed. Therefore, C1 is now reverse-biased. The charge on C1 cannot escape through Q1, because the transistor normally operates in Class-B and is now reverse-biased. That is, the charge on C1 can flow only through R3. If R3 has a low resistance, the re-
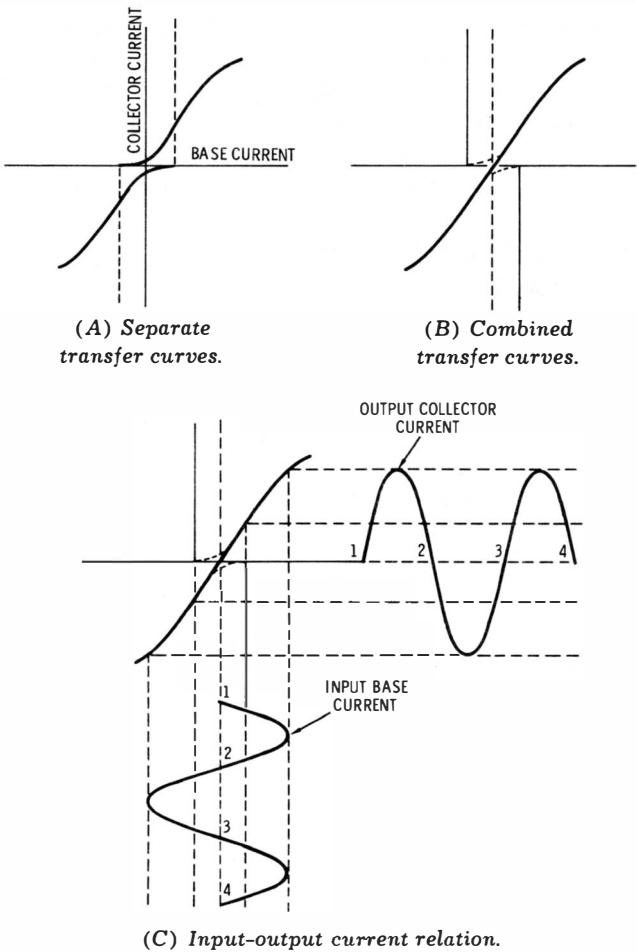
(A) Separate transfer curves.

(B) Combined transfer curves.

(C) Input-output current relation.

Fig. 4-22. Biasing to projected cutoff.

(A) RC coupling.

(B) Capacitance-diode coupling.

Fig. 4-24. Class-B, push-pull configurations.

verse bias can be minimized, but the low-frequency response of the amplifier will be poor, and the gain will be impaired. On the other hand, if R3 has a high value, substantial reverse bias will develop at the bases of the transistors, and serious audio distortion will occur. Therefore, the value of R3 is a compromise, at best, in this simple configuration.

Good frequency response, high gain, and low distortion can be realized by using diodes instead of resistors in the base-return circuit, as shown in Fig. 4-24B. When Q1 is driven into conduction, electrons
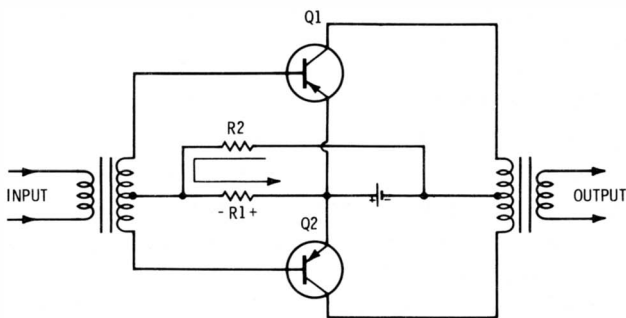

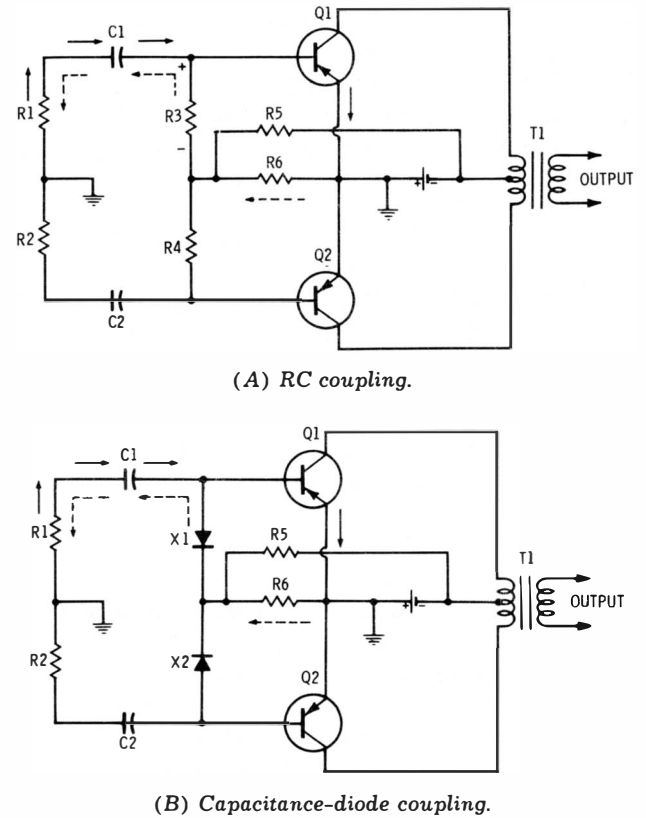**Fig. 4-23. Class-B, push-pull amplifier circuit using a small forward bias.**

flow from the right-hand plate of C1 into the base. However, the positive charge on C1 is not trapped in this situation—as the half cycle of drive decreases in amplitude, electrons flow through X1 in sufficient numbers to prevent build-up of signal-developed bias. Good frequency response is obtained in normal operation, because a diode normally has very high back resistance. Therefore, when Q1 is being driven into conduction, X1 is out of the circuit from a practical point of view. Since audio signal current does not flow through X1, the stage develops high gain. Maintenance of the normal small forward bias at all times ensures that negligible distortion will occur.

Complementary-Symmetry Circuit

We will find complementary-symmetry circuits in some audio amplifiers. Fig. 4-25 shows how a pnp and an npn transistor may be connected in a single stage so that the dc electron current path in the output circuit is completed through the emitter-collector junctions of the transistors. This arrangement is called a complementary-symmetry circuit. It has the advantage of dispensing with a phase-inverter driver stage, and does not require a center-tapped input transformer. Note that this configuration also eliminates the need for discharge diodes with capacitance coupling. The output circuit employs a parallel con-

nection with respect to load R1, and thereby elimi-nates the need for a tapped-primary transformer in the output circuit. As in any push-pull stage, replace-ment transistors should be reasonably well matched to avoid distortion. Note that in normal operation, there is no dc current through the load R1.
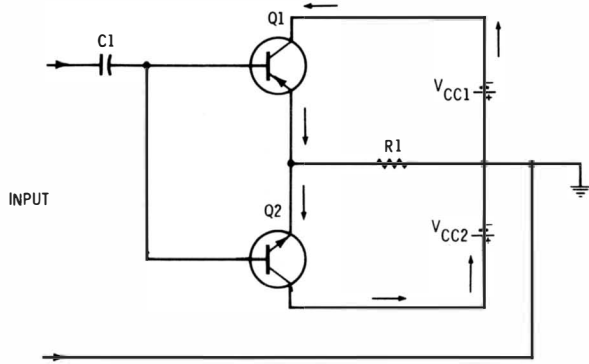

Fig. 4-25. Basic zero-bias complementary-symmetry circuit.

In other complementary-symmetry configurations, a small forward bias is applied to the base-emitter junctions of the transistors, as shown in Fig. 4-26. Bias currents are bled from the collectors to the bases by resistors R2 and R3, which form a voltage divider in combination with R1. Normally, the value of R1 is very small, so that it has a negligible un-balancing action on the audio signal. This arrange-ment has the advantage of minimizing residual cross-over distortion. As in the case of the zero-bias
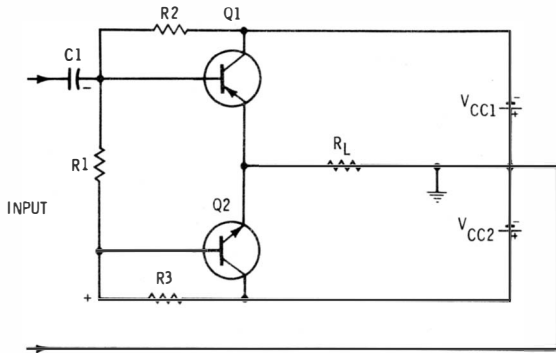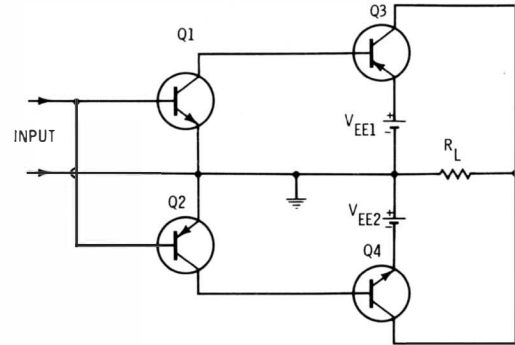

Fig. 4-26. Complementary-symmetry circuit with small forward bias.
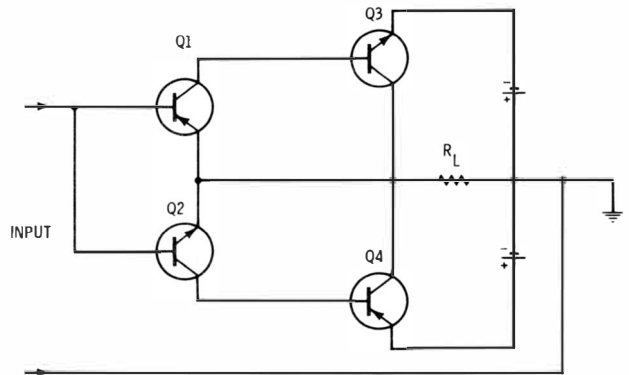
arrangement, there is normally no direct current through R_L; therefore the output from the amplifier can be applied directly to the voice coil of a speaker, and an output transformer is not required.

Elaborate receivers sometimes employ audio-out-put sections with direct-coupled complementary-symmetry stages, as shown in Fig. 4-27. In A, a com-mon-emitter complementary symmetry stage (Q3 and Q4) is directly driven by the preceding comple-mentary-symmetry stage (Q1 and Q2). Single-ended drive is applied to Q1 and Q2. This arrangement pro-vides high gain and, good frequency response, and eliminates the need for a phase inverter and an out-put transformer. In B, the configuration provides high input resistance. The signal voltage dropped across R_L develops negative feedback in the input circuit of Q1 and Q2, thereby presenting a high input resistance. Negative feedback also improves the lin-earity of the amplifier at high output levels.

(A) Normal input resistance.

(B) High input resistance.

Fig. 4-27. Examples of direct-coupled complementary-symmetry stages.

ANALYSIS OF COMMON SYMPTOMS

An analysis of the common trouble symptoms listed earlier in this chapter is presented in this section.

1. Dead Receiver

When a "dead receiver" trouble symptom is caused by a defect in the audio section, no output will be obtained when a signal from a noise or har-monic generator is applied at the output of the de-tector. Pinpointing of a defective component can be accomplished in most cases by signal-tracing or signal-injection techniques. In elaborate push-pull configurations, further dc voltage and resistance

measurements are sometimes required to resolve doubtful possibilities due to circuit interactions.

Possible causes of no output because of defects in the audio section are as follows:

a. Shorted capacitor (see Fig. 4-28).
b. Defective output transistor.
c. Burned or open resistor in output stage (see Fig. 4-29).
d. Detector diode open.
e. Defective driver transistor (less likely than a defective output transistor).
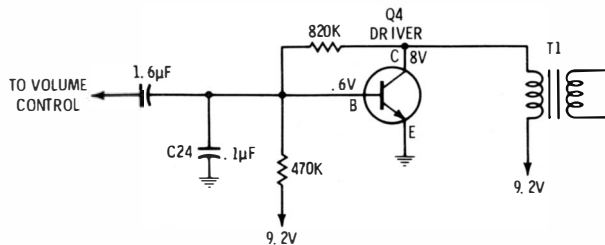f. Open voice coil in speaker.

Fig. 4-28. Shorted C24 will cause completely dead radio.

2. Weak Output

Generally speaking, weak output is caused by marginal defects in the audio section that involve the same components as a dead-receiver symptom. That is, if the component fails completely, it is likely to stop the signal completely. It is often helpful to observe whether weak output is accompanied by distortion, or if the signal is merely attenuated and remains undistorted. For example, if an emitter bypass capacitor opens up, the resulting degeneration will weaken the signal, but will not distort it. On the other hand, a leaky driver transistor usually distorts the signal as it weakens its amplitude. In this section, we will note trouble conditions that produce weak output without introducing distortion.

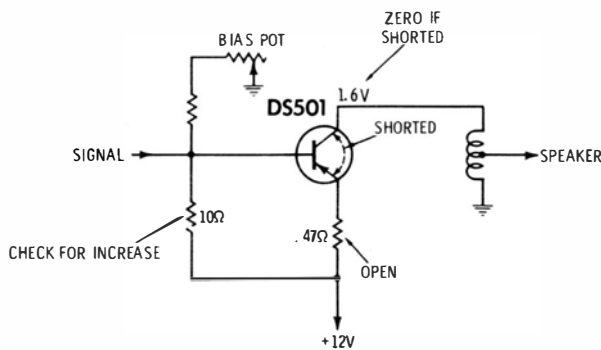Possible causes of weak output due to defects in the audio section are:

Fig. 4-29. Some common faults in power stage.

a. Open emitter bypass capacitor.
b. Open bypass capacitor in bias-stabilization circuit.
c. Incorrect type of replacement transformer.
d. Erratic or worn volume control.
e. Shorted capacitor in tone-control circuit.

3. Distorted Sound

Most complaints concerning distorted sound are caused by defects in the audio section. However, to avoid possible waste of time, it is good practice to drive the receiver with an a-m generator, and to check the waveforms for distortion in the various receiver sections. The defective stage can thereby be localized, and the faulty component can usually be pinpointed by means of dc voltage and resistance measurements. The chief exception occurs when a capacitor is open, and this situation can usually be pinned down by scope waveform analysis.

Possible causes of distorted sound due to defects in the audio section are:

a. Output transformer fault; check for a short, an open circuit, or a resistance change.
b. Leaky driver transistor.
c. Push-pull transistors biased past cutoff; look for open diode.
d. Defective speaker; make substitution test.
e. Incorrect type of replacement transistor.
f. Leaky capacitor in negative-feedback circuit.

4. Noise and/or Hum in the Audio Signal

Many kinds of noise occur in various defective receivers. For example, one type of defect will cause rattles and clicks, whereas another type of defect will cause squeals. Other faults can cause hissing or frying sounds. Hum is encountered only in ac-operated receivers, and is usually due to failing capacitors in the power-supply section. Sometimes an erratic thumping is heard, accompanied by the audio signal cutting in and out. Each type of noise has distinctive causes, and an experienced technician can often make a shrewd guess concerning the defect to look for.

Posisble causes of noise and/or hum due to defects in the audio section are:

a. Leakage between conductors on the printed-circuit board in the audio section produces a hissing or frying sound. Check for creeping battery chemicals or electrolytic capacitor chemicals.
b. Badly worn volume control; the noise condition will be aggravated if a leaky coupling capacitor

lets direct current through the resistive element.

c. Cold-soldered or unsoldered connection; usually produces clicks or rattles when the receiver is moved.

d. Defective voice coil in speaker; make a substitution test.

e. Unstable transistor (less likely, but possible).

f. Unstable detector diode (less likely than other component defects).

5. Intermittent Operation

Intermittents in the audio section involve the same general defects that were previously noted. Localization often requires monitoring of individual stages with voltmeters, signal tracers, or scopes. Speeding up an intermittent symptom may be a problem; however, jarring, tapping of components, switching the power supply off and on, heating, and spray cooling will often be helpful. Transistors may be judiciously heated, but the tip of a soldering iron should not be permitted to touch the case or leads of the semiconductor.

Possible causes of intermittent operation due to defects in the audio section are:

a. Microscopic break in the printed-circuit board.

b. Intermittent transistor (plastic-cased types are more likely to become defective).

c. Cold-soldered or unsoldered connection.

d. Unstable capacitor.

e. Deteriorated resistor.

f. Corroded winding in audio transformer.

6. External Interference

The audio section is less susceptible to external interference than the other sections of the receiver. However, under some conditions, external interference can be picked up by the audio section. Sometimes the interference is not due to an actual defect in the audio section, but to operation of the receiver under improper conditions.

Possible causes of external interference are as follows:

a. Battery charger may not have been turned off.

b. Audio transformers may pick up hum if the receiver is operated near a large motor or other electrical power equipment.

c. Exposed wires run to a remote speaker will pick up any strong stray fields, particularly if the output transformer is mounted on the speaker.

d. Switching transients can enter the audio amplifier via the power supply, particularly in ac-dc type receivers.

e. In combination receivers, a defective function switch can permit external interference to gain entry to the audio amplifier.

f. A microphonic audio component will pick up sounds, as from the speaker, and will cause various forms of interference in the reproduced signal. In a typical case history, a capacitor became microphonic and caused this trouble symptom.

Chapter 5

Automatic Volume Control Troubles

Although manual volume control permits adjustment of the receiver gain to a desired level, it is also necessary to have additional, automatic control of receiver volume, or gain. Avc prevents extreme variations in output power, and thereby avoids blasting when the receiver is tuned from a weak station to a strong station. Avc also makes it unnecessary to readjust the manual volume control, unless a very weak station is tuned in. Distant stations tend to fluctuate in field strength, and avc helps to maintain a constant output level under these conditions. An avc system regulates the gain of the rf and i-f stages. Various trouble symptoms resulting from defects in the avc system are as follows:
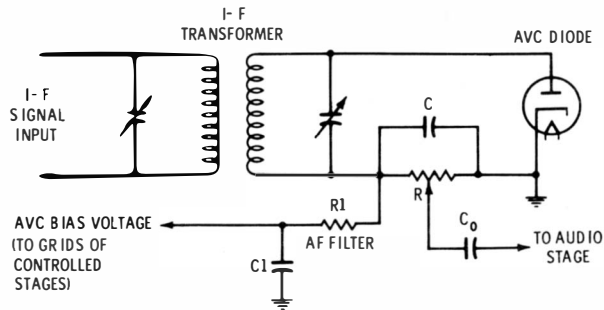
1. Poor avc action and distortion on strong stations.
2. No avc action; receiver operates at high gain.
3. No avc action; receiver operates on low gain.
4. Avc level jumps up or down at intervals.
5. Receiver motorboats on weak signals.
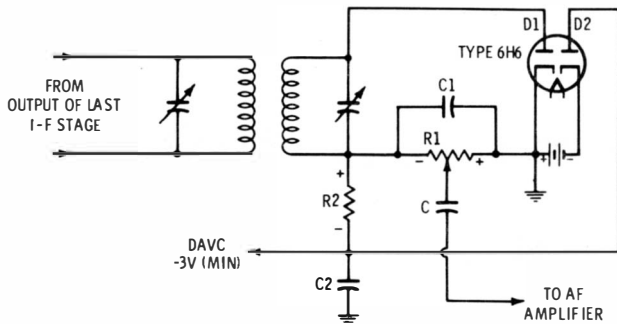6. Avc action retarded.

GENERAL DISCUSSION

In a tube-type receiver, the rf, i-f and mixer stages utilize remote-cutoff tubes, whose gain can be controlled by varying the grid-bias values. A more negative bias reduces the gain of a tube. If several stages are avc-controlled, ample variation or receiver sensitivity can be obtained when tuning from weak signals to strong signals. Of course, the use of avc cannot increase the sensitivity of a receiver beyond its maximum value in the absence of avc. Fig. 5-1 shows how an avc circuit is connected into a diode detector circuit. The diode current in the load resistance R produces a voltage drop that makes the left end of R negative with respect to ground. This negative voltage is applied through filter circuit R1C1 to bias the grids of the preceding stages that are avc-controlled. As a signal increases in strength, the gain of the controlled stages is thereby reduced by the increasing value of bias.

Note that the filter circuit R1C1 in Fig. 5-1A prevents the avc level from varying at an audio-frequency rate. In turn, the avc output voltage is a dc voltage that changes level slowly in response to variations in field strength. On the other hand, the time constant of R and C is sufficiently short that only the intermediate frequency is filtered out, and the audio-frequency envelope is passed along to the audio stage. In case C1 should open up, the avc bias voltage would follow the rise and fall of the audio envelope, thereby producing distortion in the rf and i-f signals. The opposite situation, in which C1 has much too large a value, causes the changes in avc level to lag excessively behind variations in field strength. The result is that when we tune in a strong station, the sound output tends to blast momentarily until the avc voltage has sufficient time to respond.

(A) Basic avc circuit.

(B) Delayed avc circuit.

Fig. 5-1. Automatic volume control circuits.

Delayed AVC

Next, consider the delayed avc configuration illustrated in Fig. 5-1B. In many applications, it is desirable to have maximum rf and i-f gain available for weak signals. Note that some communication receivers have a manual avc cut-out switch, which is thrown when maximum receiver sensitivity is needed. However, this can be done automatically by means of delayed avc. This control method prevents the application of avc bias until the signal strength is a certain predetermined value. The diode section, D1, of the twin diode operates as a detector and avc diode. R1 and C1 are the diode load resistance and filter capacitance for the audio signal, while R2 and C2 operate as an avc filter so that the output is essentially a dc bias voltage.

The delayed avc action takes place as follows. Note that the cathode of diode section D2 is returned through a fixed supply voltage of −3 volts to the cathode of D1, and to ground. This fixed voltage can be supplied by a small bias cell, or by connecting the cathode of D2 to a tap on a voltage divider across the B+ line. This fixed voltage causes dc current in R1 and R2 in series with diode D2. Thus, a voltage drop is produced that places the avc tap at the lower end of R2 at approximately −3 volts, since the voltage drop across D2 is very small. This 3-volt fixed bias is about the value required for maximum sensitivity of the remote-cutoff tubes.

Any incoming signals that are not sufficiently strong to develop a rectified voltage across R1 in excess of 3 volts are processed by the controlled tubes at a bias of −3 volts. On strong signals, however, the rectified signal voltage across R1 exceeds 3 volts, which cancels out the fixed 3-volt bias. In turn, the plate voltage of D2 becomes negative and current stops in the diode. Thereafter, the avc voltage is controlled entirely by the rectified signal voltage developed across R1.

Squelch Operation

A squelch circuit is the opposite of a delayed avc circuit, in that it "kills" the receiver sensitivity until the signal strength exceeds a predetermined level. If a sensitive receiver employing avc is tuned between stations or tuned to a very weak station, the noise level is often objectionable. This can be overcome when weak stations are not of interest, by using a squelch (or quiet automatic volume control) circuit. Communications receivers with qavc generally provide a manually adjustable level control, so that the point at which qavc "kills" reception is under the operator's control. Fig. 5-2 shows the biased diode detector qavc configuration. Note that the diode load is returned to a tap on the cathode resistor. This voltage is negative with respect to the cathode, so that the detector is inoperative unless the incoming signal is in excess of the qavc voltage.

Noise Discrimination

Highly sensitive receivers develop considerable noise when tuned to weak signals, and this noise can be minimized by means of audio noise limiting circuits. Two general methods are employed for this purpose. One method renders the receiver inoperative during the occurrence of a noise pulse that ex-
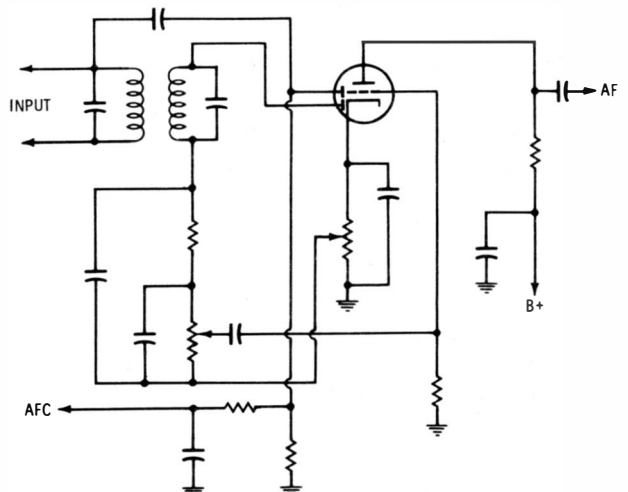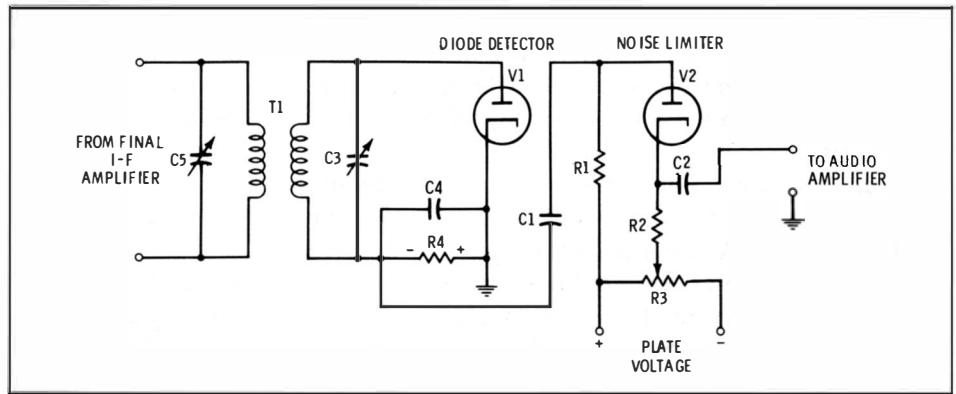

Fig. 5-2. Biased diode detector quiet avc configuration.

Fig. 5-3. Typical audio noise-limiter circuit.

ceeds the signal amplitude appreciably. These are often called *silencer* circuits. This category of circuits has a basic similarity to qavc, but differs in that the qavc action automatically takes place when needed (when a noise pulse arrives). The other method is a limiting or clipping technique that slices off any incoming signal in excess of a predetermined level. Fig. 5-3 shows a typical audio noise-limiter circuit.
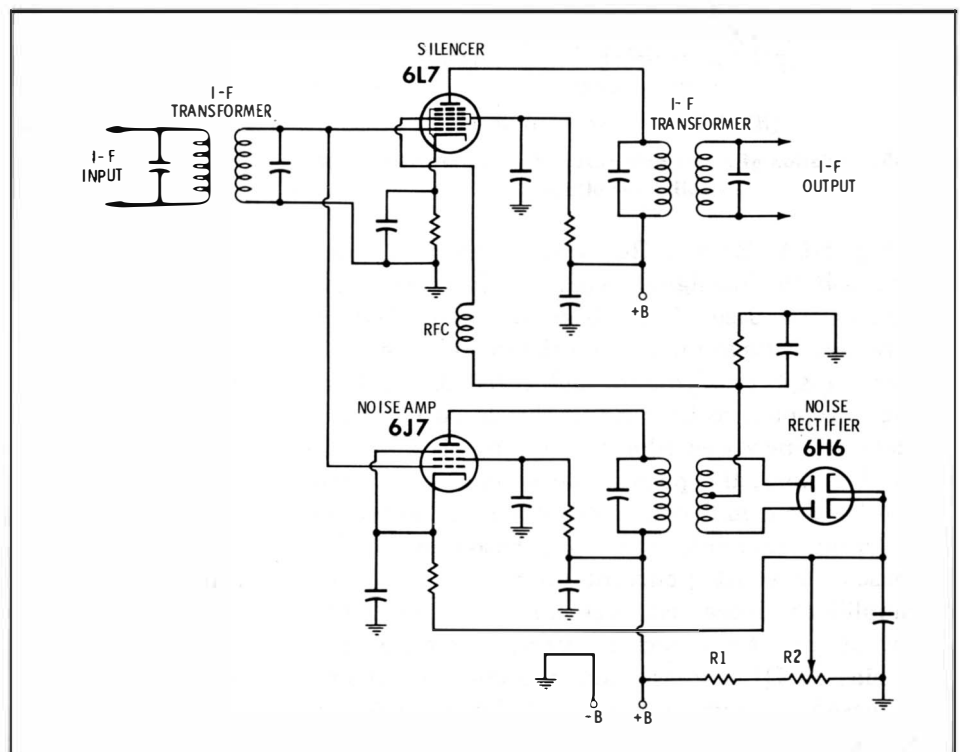
A noise-silencing circuit is shown in Fig. 5-4. When a noise pulse is applied to the circuit, the gain of the i-f stage is momentarily decreased. Any noise pulse with an amplitude in excess of the predetermined level is sampled at the grid of the i-f amplifier, amplified by the noise-amplifier stage, and rectified by the full-wave diode noise rectifier. Note that the noise circuits are tuned to the intermediate frequency. A rectified noise voltage is applied in the

form of a negative-bias pulse to the No. 3 grid of the i-f amplifier tube. As a result, passage of the noise disturbance through the i-f tube is prevented. Severe distortion is always present on marginal signals. The threshold control, R2, determines the level at which the silencer becomes operative.

Solid-State AVC Arrangements

One method of varying the gain of a transistor amplifier is by variation of the dc emitter current. The resulting variation in power gain versus dc emitter current in the common-base and common-emitter configurations is shown in Fig. 5-5A. The curves shown are those for 455-kHz amplifiers operated with a fixed collector voltage of 4 volts. Another method of varying the gain of a transistor amplifier is by variation of the dc collector voltage.
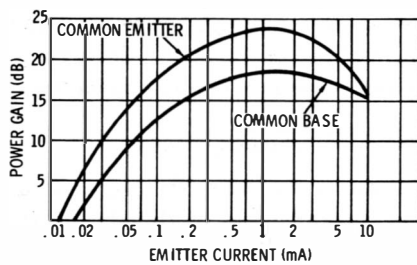

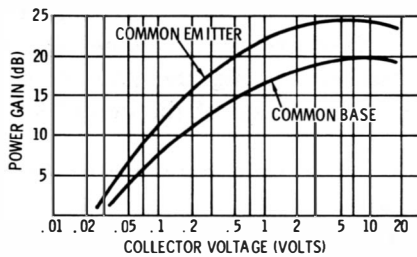Fig. 5-4. An i-f noise-silencing circuit.

The resulting variation in power gain versus dc collector voltage in the common-base and common-emitter configurations is shown in Fig. 5-5B. These curves are for 455-kHz amplifiers operated with a fixed emitter current of 1 mA.

Let us consider *dc emitter-current control* action. The power gain of the common-emitter amplifier shown in Fig. 5-6A is controlled by feeding the avc voltage to the base of the amplifier, thereby varying the dc emitter current. In this example, the tuned amplifier is also operating as a dc amplifier to increase the dc current output of the detector. Note that if the dc current output from the detector happens to be adequate, then the dc emitter current of the tuned amplifier can be varied directly.
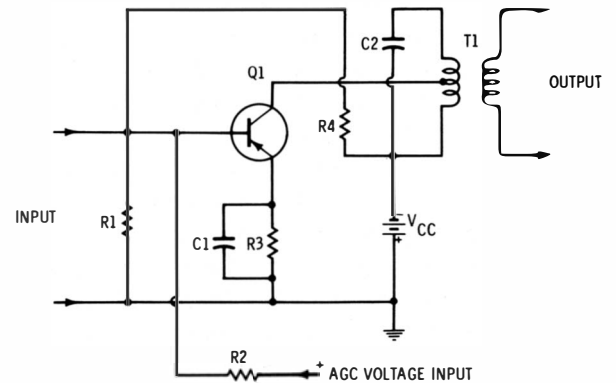

(A) *Emitter current curve.*

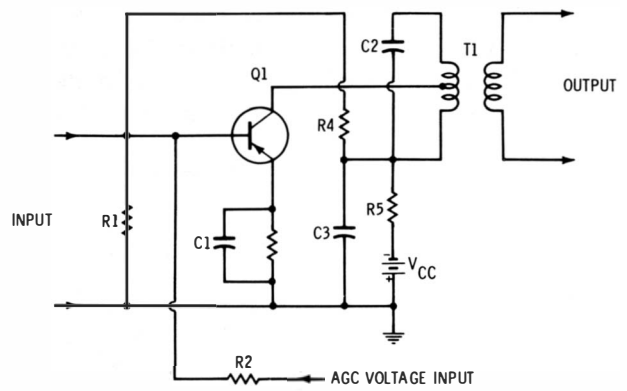(B) *Collector voltage curve.*

Fig. 5-5. Variation of power gain versus dc emitter current and dc collector voltage.

In Fig. 5-6A, R1 and R4 form a voltage divider to establish the no-signal negative (forward) bias applied to the base of the transistor. We observe that the agc voltage input from the detector is positive with respect to ground, and is fed to the base through dropping resistor R2. If the dc output from the detector increases (due to a strong signal input to the detector), the positive dc voltage fed to the base of Q1 through dropping resistor R2 reduces the net negative (forward) bias on the base and thereby decreases the emitter current. In turn, the gain of the amplifier is decreased, as seen in Fig. 5-5A. If the dc output from the detector decreases, the net forward bias on Q1 increases and the emitter current is increased. In turn, the gain of the amplifier is increased.

Next, let us consider dc collector voltage control, as illustrated in Fig. 5-6B. The power gain of the common-emitter amplifier is controlled by feeding the avc voltage to the base of the transistor. This varies the dc emitter current, which in turn varies the dc collector voltage. This variation in dc collector voltage results from passing the dc collector current through R5, which has a value of at least 10 k ohms. In this example, the tuned amplifier is also operating as a dc amplifier to increase the dc voltage output from the detector. Direct variation of the dc collector voltage is possible, provided that the dc voltage output from the detector is sufficiently great.

(A) *Avc by emitter-current variation.*

(B) *Avc by collector-voltage variation.*

Fig. 5-6. Common-emitter amplifier with avc.

In Fig. 5-6B, R1 and R2 form a voltage divider that establishes the no-signal negative (forward) bias on the base of the transistor. The avc voltage from the detector is negative with respect to ground, and is fed to the base through dropping resistor R2. If the dc output from the detector increases (due to a high-level signal applied to the detector), the negative dc voltage fed to the base of Q1 through dropping resistor R2 increases the net negative (forward) bias on the base and increases the emitter current and the collector current. Increased collector-current in R5 reduces the collector voltage, and thereby reduces the gain of the amplifier.

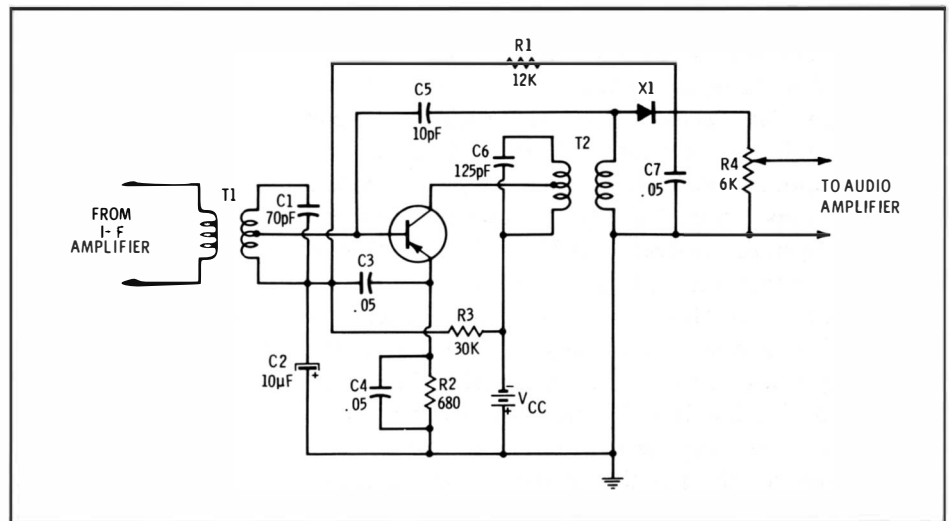**Fig. 5-7. An i-f amplifier and detector with avc network.**

Fig. 5-7 shows a typical configuration for a 455-kHz amplifier and detector. The rectified output from diode X1 is filtered by C7 and R4. That is, the i-f carrier is filtered out so that the voltage across C7 consists of an audio signal mixed with a dc voltage that is positive with respect to ground. This dc component is directly proportional to the magnitude of the i-f carrier. The dc voltage is fed to the base of Q1 through dropping resistor R1, thereby providing avc action. R1 and C2 form an audio decoupling network to prevent audio feedback to the base of Q1. In this example, avc action entails control of the dc emitter current value.

Half-Wave and Full-Wave Doubler AVC Arrangements

Transistor avc circuits are commonly classified into the half-wave system and the full-wave doubler system. The half-wave system employs one diode; it controls the gain of the r-f and i-f stages, or only the rf stage may be gain-controlled. However, the full-wave system employs two diodes; both the rf and i-f sections are gain-controlled. An advantage

of the full-wave configuration is its greater output voltage, which provides improved control of the audio level. That is, the volume control does not need readjustment as often as when the half-wave system is employed. Another difference between these arrangements and the simple configuration shown in Fig. 5-7 is the use of separate diodes for detection and for avc rectification.

Fig. 5-8 shows the basic half-wave avc system. The bleeder-current path produces a voltage drop (about 9.6 volts) across the 470-k resistor, which biases the base of Q1 for normal gain during weak-signal operation. Note that the i-f–stage bias divider, consisting of the 47-k and 18-k resistors in Fig. 5-9, provides a similar bias condition for Q2. When a strong incoming signal is present, the collector of Q2 develops an i-f output. During the instant that the collector is positive, additional electrons will flow from ground to the bottom plate of the 150-pF capacitor. This current adds to the bleeder current and increases the voltage across the 470-k resistor. The net effect is a small increase in the bias voltage of Q1, which reduces the gain of the stage.
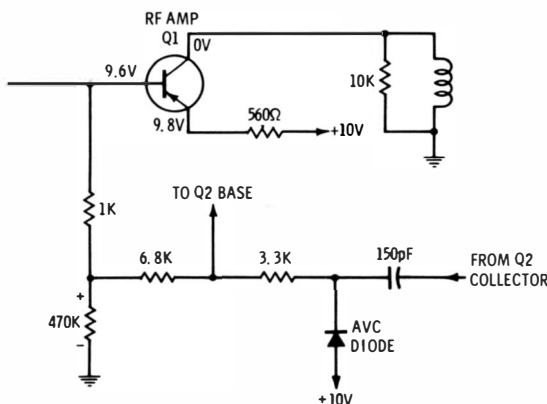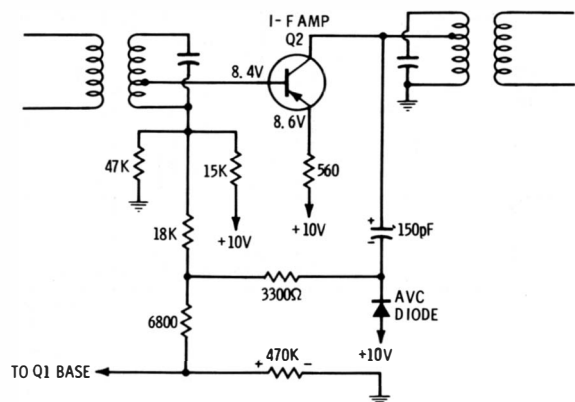

Fig. 5-8. Basic half-wave avc system.

Fig. 5-9. Avc branch circuit for Q2.

On the following half cycle, during the instant that the collector is negative, the 150-pF capacitor in Fig. 5-9 discharges through the diode to the 10-volt source. This "seesaw" action, which draws current through one circuit and then discharges it through another circuit, is necessary for normal avc system operation. Next, let us consider the full-wave avc system illustrated in Fig. 5-10. We observe that the control method is similar to that of the half-wave system. However, more control current is developed as a result of employing two avc diodes. Following a positive-to-negative signal swing at the collector of Q2, the 180-pF capacitor is left with the charge, as shown. As the next positive swing occurs at the collector, the positive voltage of the signal is added to the charge on the capacitor to produce a larger positive voltage at the junction of the two diodes. In turn, more avc current is produced than in a half-wave circuit.

A common avc trouble symptom is distortion on strong stations. Check out the avc system by measuring voltages across emitter resistors (see Fig. 5-11). Using the lowest dc-voltage range, tune the receiver to a strong station; the 0.2-volt reading normally drops to practically zero. However, if the circuit does not respond correctly, check for a defective avc diode. Note that if the reading in Fig. 5-11 is two or three times the normal value of 0.2 volt, one of the following defects may be present:

1. The transistor may have collector-junction leakage. Measure the base-to-emitter voltage. Tune the receiver between stations. If the drop across the emitter resistor is two or three times its normal value, an emitter-to-base reading of 0.2 volt indicates a leaky transistor. However, if the emitter-to-base bias has changed for increased conduction, the transistor is probably all right.

2. There may be an open circuit in the avc bleeder-current path. A high emitter-resistor voltage drop, along with a high emitter-base reading, indicates an open in the bleeder-current circuit. The avc diode is suspected first.
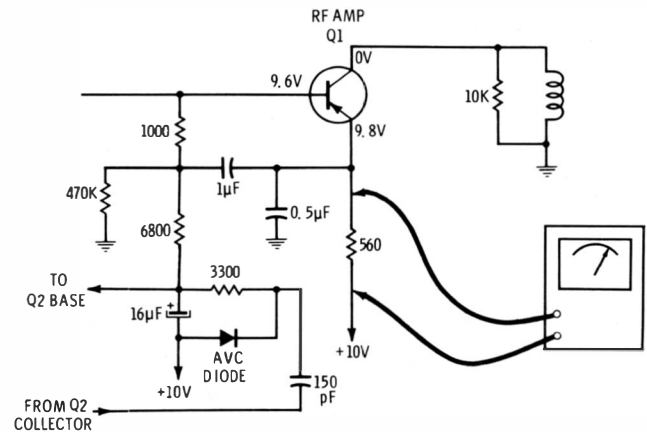

Fig. 5-11. Check avc action by measuring emitter-resistor voltage drop.

3. One problem that should be kept in mind is that a replacement diode may have been connected in reverse polarity into the circuit. The symptoms are the same as for an open-circuit defect. The receiver output is weak, and a tough-dog situation can result if the possibility of reverse polarity is overlooked.

4. A capacitor might have opened up. Open capacitors can result in oscillation; if this condition is suspected, quick-check by bridging the suspect with a good capacitor. Leaky or shorted capacitors can throw the rf and i-f transistors into heavy conduction. A high emitter-resistor
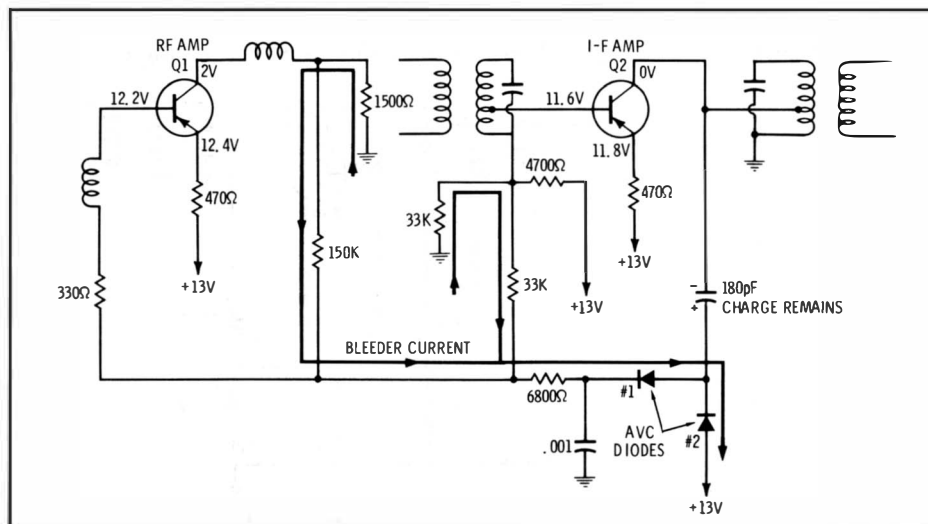

Fig. 5-10. A full-wave avc system.

voltage drop, along with a high emitter-to-base voltage, prompts suspicion of leakage or a short-circuit in an associated capacitor.

Amplified AVC

Elaborate receivers may employ amplified avc to obtain the most effective control of output level over a wide range of signal field strength. One method of obtaining amplified avc is shown in Fig. 5-12. The avc diode operates from a separate i-f amplifier stage, whereby a higher signal level is applied to the avc diode than to the detector diode. Another method employs a dc amplifier, as shown in Fig.
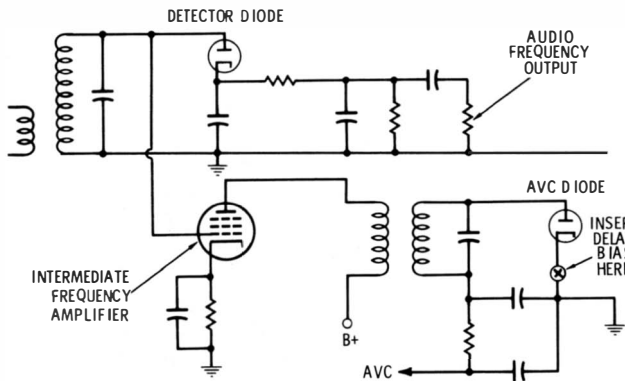

Fig. 5-12. Avc amplification at the intermediate frequency.

5-13. The rectified output from diode X1 is applied to the grid of tube V1. This tube has its cathode connected to a high resistance that is returned to a negative voltage source. In normal operation, the initial condition is with the cathode of V1 at a slightly positive voltage, to provide a certain delay action. The rectified voltage produced by an incoming signal will bias the grid of V1 negative, reduc-

ing the plate current and decreasing the cathode voltage. In turn, the rise in avc voltage is greater than the rise in output from the avc diode.

When maximum uniformity of detector output is required over a wide range of input signal field strengths, a compensated avc system is employed. The basic arrangement is shown in Fig. 5-14. The avc section operates from a separate branch of the i-f amplifier. It differs from the foregoing methods, however, in that avc voltage is applied to one i-f

Fig. 5-13. Avc amplification by a dc amplifier.

stage after the avc takeoff point. This method compensates for the incomplete level correction inherent in other sytems, so that the detector output is practically constant over the entire dynamic range of the avc system. That is, any avc system other than a compensated system will have a rising characteristic, whereas a normally operating compensated system has a flat characteristic.

Fig. 5-14. Compensated avc.

ANALYSIS OF
COMMON TROUBLE SYMPTOMS

An analysis of common trouble symptoms listed earlier in this chapter is presented in this section:

1. Poor AVC Action and Distortion on Strong Stations

Distortion on strong stations can be caused by defects in the audio section, as explained in the preceding chapter. When distortion is due to a defect in the avc section, there is an accompanying symptom of little or no variation of avc voltage when a strong signal is tuned in. Typical defects in this situation are as follows:

a. Open capacitor in avc circuit (may also cause motorboating or oscillation).
b. Open avc diode.
c. Leaky transistor in the avc system.
d. Avc diode polarity reversed.
e. Open resistor (less likely than other defects, but possible).

2. No AVC Action; Receiver Operates at High Gain

In communications receivers that have a manual avc switch, check to see that the switch is set to its avc position. Failure of the avc circuit to respond to a strong incoming signal can be caused either by a short-circuit or by an open-circuit fault. The possible failure points can be evaluated by reference to the circuit diagram, taking into account the high-gain condition. In other words, the defect in this situation provides a bias near the normal operating point of the controlled transistor or tube. For example, with reference to Fig. 5-1B, we would suspect that R2 might have increased greatly in value, or might have a poor connection. On the other hand, we would not suspect that C1 might be short-circuited, because the resulting loss of signal would "kill" the audio output.

Possible causes of no avc action, with the receiver operating at high gain can be due to defects such as the following:

a. Defective resistor.
b. Cold-soldered or unsoldered connection.
c. Diode connected in reverse polarity (in receivers that employ avc by emitter-current control).
d. Break in printed-circuit board wiring.
e. Defective capacitor (not in all avc systems; check schematic).

3. No AVC Action; Receiver Operates at Low Gain

When there is no response of the avc system to a strong incoming signal, and the receiver operates at low gain, the defect is such that the transistor or tube is biased steadily to a low-gain point on its transfer characteristic. Fig. 5-5 shows the relations that are involved in a solid-state receiver, and the relation between grid bias and plate-current variation for a typical avc-controlled tube is shown in Fig. 5-15. The logical possibilities in a given situation can be evaluated by a review of the schematic.
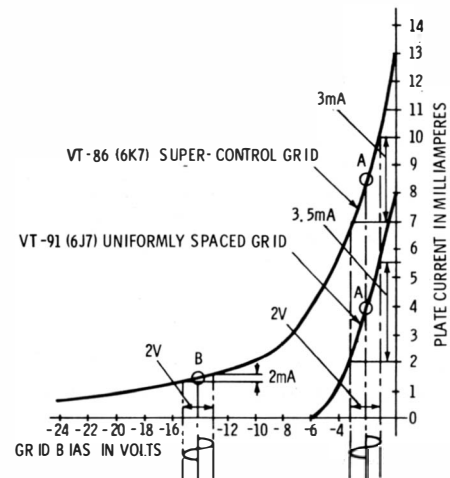

Fig. 5-15. Characteristic curve of 6K7 tube showing high gain at point A and low gain at point B.

Possible causes of no avc action, with the receiver operating at low gain are:

a. Shorted avc filter capacitor in a configuration such as is shown in Fig. 5-7.
b. Open avc filter capacitor (can cause marginal i-f oscillation).
c. Reversed polarity of avc diode in receivers employing gain control by means of collector-voltage variation.
d. Incorrect type of replacement transistor.
e. Short-circuit between printed-circuit conductors due to solder splash.

4. AVC Level Jumps Up or Down at Intervals

This is a rather common trouble symptom in old-model receivers that have seen long service. It is basically due to marginal defects in components of the avc system, and is a form of intermittent condition. Capacitors are ready suspects, and poor connections are frequent offenders. In tube-type receivers, corroded socket springs may be responsible. A

systematic approach is usually necessary, in order to pinpoint the defective component.

Possible causes of avc level jumps are as follows:

a. Marginal leakage and instability in an avc filter capacitor.
b. Cold-soldered connection.
c. Corroded socket spring.
d. Unstable transistor.
e. Deteriorated resistor (less likely, but possible).

5. Receiver Motorboats on Weak Signals

This trouble symptom is almost always caused by an open avc filter capacitor. However, it can occasionally be caused by a shorted capacitor in an elaborate system, such as a compensated avc system. Beginners may have difficulty in distinguishing between motorboating caused by open power-supply decoupling capacitors and motorboating caused by open avc capacitors. The practical approach in case of doubt is to clamp the avc line with a fixed battery source. Then, if the motorboating stops, we know that the trouble is in the avc system. On the other hand, if the motorboating continues, we know that the trouble will be found in the power-supply system.

6. AVC Action Retarded

This is a trouble symptom that produces a brief, sharp blast when the receiver is tuned to a strong station. That is, the avc system responds too slowly and does not reduce the receiver gain as rapidly as is desirable. The basic trouble is an excessively long time constant in the avc filter circuit. For example, with reference to Fig. 5-10, the 6800-ohm resistor might have increased greatly in value. Or, an incorrect capacitor replacement might have been made previously. For example, if the 0.001-μF capacitor is erroneously replaced with a 0.1-μF capacitor, the avc action will be seriously retarded.

Chapter 6

Troubleshooting Power Supplies

Various types of power supplies are used in different types of radio receivers. The general service bench is chiefly concerned with battery systems, transformer-type arrangements, ac/dc power supplies, and vibrator designs. A defective power supply usually has subnormal output voltage. However, it is quite possible for a defective regulated power supply to produce an output voltage that is above normal. A power supply is rated for a particular current demand; if a receiver defect causes this current rating to be exceeded, the output voltage from the power supply will decrease, and some of its components may be damaged.

Common trouble symptoms caused by power-supply defects are:

1. Dead receiver.
2. Weak reception.
3. Hum in sound output.
4. Noise in sound output.
5. Drift in tuning.
6. Motorboating.

GENERAL DISCUSSION

Battery power supplies are used principally in portable receivers and auto receivers. The terminal voltage of a battery should always be tested under load, because the open-circuit voltage of a battery will always be about the same, regardless of its age and condition. Fig. 6-1 shows a convenient way to measure the current drain of a transistor radio. The current reading of the VOM should be noted both before and after the radio is turned on. There is normally zero current drain when the radio is turned off; otherwise, a circuit defect that shortens the battery life is present. When the radio is turned on, the current value should measure approximately the same as the manufacturer's rated value. If the current drain is excessive, there is either a circuit defect or a faulty transistor in the receiver.

Battery power supplies can produce trouble symptoms from imperfect connections. For example, Fig. 6-2 shows how series-arranged cells can be taped together if crackling sounds result from poor contact between cells. Most battery-powered receivers utilize primary cells. However, some receivers employ rechargeable batteries with a built-in or auxiliary charger (see Fig. 6-3). It is poor practice to operate this type of radio while the battery is being charged. Not only is excessive hum likely to be audible, but the overvoltage that is produced by the charger will damage the transistors in some receivers.

When batteries are replaced in any receiver, it is essential to observe polarity. Incorrect polarity always results in a "dead receiver" symptom, and may cause transistor damage in some receivers. This can be a tricky point for the beginner, because some mercury cells have a similar appearance to ordinary flashlight cells, but have opposite terminal polarity. Therefore, in case of doubt, it is advisable to check the polarity of a replacement cell with a dc voltmeter. The terminal voltage of a fresh zinc-carbon cell will measure approximately 1.5 volts on open circuit; a mercury cell will measure about 1.34 volts, and a nickel-cadmium cell will measure approxi-
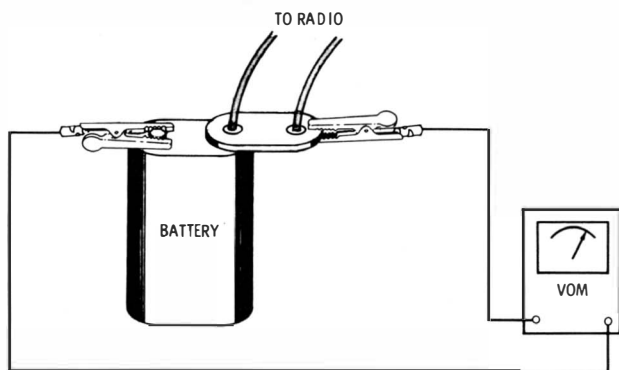
Fig. 6-1. Checking the current drain of a transistor radio.

mately 1.2 volts. In other words, a zinc-carbon cell normally has a somewhat higher terminal voltage than other types of cells.

Auto radios are powered by lead-acid storage batteries that have a very low internal resistance. Therefore, the terminal voltage of a cell (nominally 2 volts) increases but slightly during the charging process. In turn, an auto radio operates satisfactorily from the car battery while it is being charged. The chief problem that we encounter in this regard is electrical noise. Let us consider the various sources of noise that must be contended with, and the ways in which electrical noise can be reduced or eliminated.

The most common sources of noise in an auto installation are spark radiation from the high-tension ignition circuit, spark radiation from the generator brushes and commutator, arc and spark radiation from the voltage-regulator circuit, and static discharges from wheels and tires. In older cars, noise sources also arise from poorly connected metal parts, and it is often necessary to bridge the poor contact joint or area with copper braid. Ignition noise will be picked up from passing vehicles that do not have noise suppressors; however, this is a comparatively minor source of annoyance. When traveling in rural areas, interference is sometimes caused by leaky insulators on power lines adjacent to the highway. This is also a comparatively minor source of disturbance.

Fig. 6-4 shows the basic method of reducing or eliminating ignition interference. Each spark plug
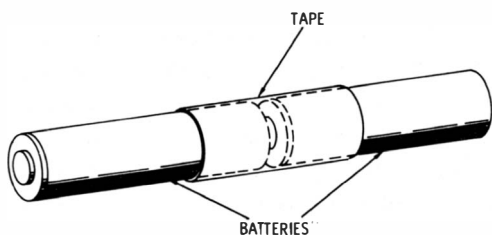

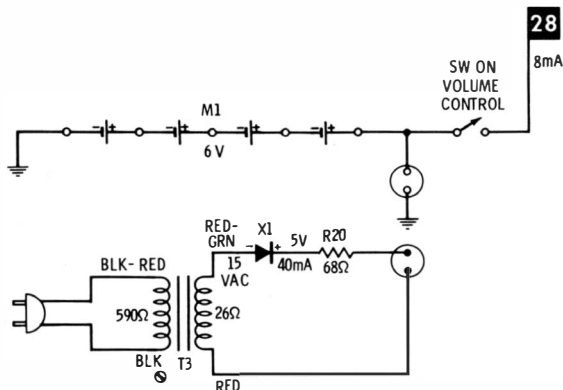**Fig. 6-2. Tape on batteries stops crackling sounds in radio.**

Fig. 6-3. Battery-charging circuit in a small receiver.

is provided with a resistive suppressor at the top of the plug. In most cases, it is necessary to install a suppressor also at the opposite end of each spark-plug cable (at the distributor). A suppressor may be needed at the center connector of the distributor as well. A typical suppressor is illustrated in Fig. 6-5. Bypass capacitors are generally required at the
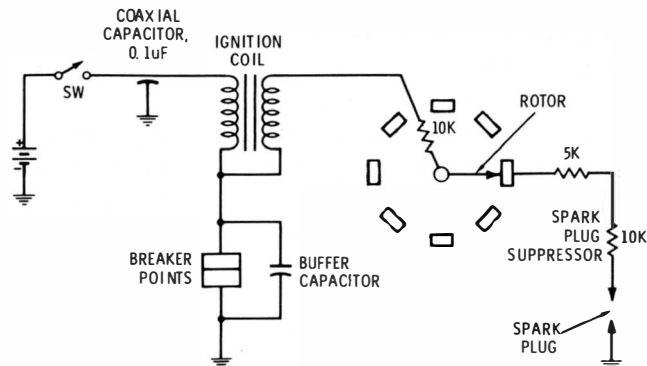

Fig. 6-4. Connection of suppressor resistors and bypass capacitors.

primary terminal of the ignition coil and at the generator terminal. A coaxial-type capacitor, such as is illustrated in Fig. 6-6, has improved bypassing action at high frequencies, such as in the Citizens Band range. Shielded resistive wire can also be used for improved suppressor action at high frequencies, instead of conventional suppressor resistors. The chief disadvantage of shielded resistive wire is its comparatively high cost.

Fig. 6-5. Noise suppressor resistor for a distributor.

Fig. 6-6. Coaxial bypass capacitor.

To reduce or eliminate clicking noises from a voltage regulator, bypass capacitors should be used at each terminal; the coaxial type is most effective at the higher frequencies. Note that a bypass capacitor should not be shunted directly from the field terminal of the voltage regulator and ground, because it will cause increased contact pitting and erosion. That is, this terminal should be bypassed with a $0.002\text{-}\mu\text{F}$ capacitor connected in series with a 5-ohm resistor. The resistor slows down surge currents into the capacitor and provides a time constant that minimizes sparking at the contacts. In severe situations,
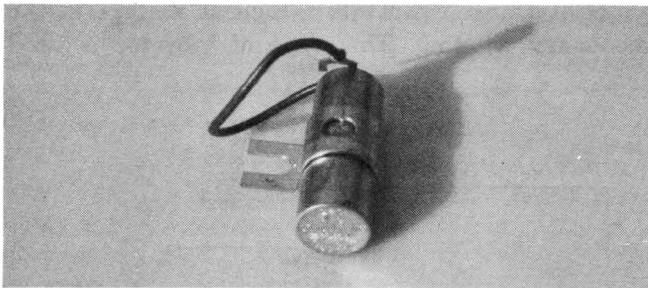

Fig. 6-7. Metal-cased capacitor used in ordinary suppression situations.

shielded wiring can be employed. As in any shielded arrangement, the braid must be well grounded to be effective. When interference is to be suppressed on the broadcast band only, the requirements are less stringent, and a conventional metal-cased capacitor, such as is illustrated in Fig. 6-7, is usually adequate.

AC Power Supplies

The basic half-wave rectifier arrangement is illustrated in Fig. 6-8. This is the configuration that is also used in battery-charging units (Fig. 6-3). When the half-wave rectifier is used as the voltage source in a power supply, the fundamental ripple frequency is 60 Hz. However, when the full-wave arrangement illustrated in Fig. 6-9 is employed, the fundamental ripple frequency is 120 Hz. Electrolytic capacitors are commonly used for smoothing
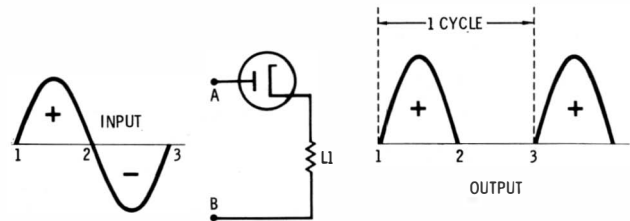

Fig. 6-8. Basic half-wave rectifier operation.

(filtering) the ripple. With other things being equal, twice as much filter capacitance is required in a half-wave power supply to reduce the ripple voltage to a given amplitude. The chief precaution to observe in replacing electrolytic filter capacitors is to observe proper polarity. If wired into the circuit in reverse polarity, the capacitor will soon be damaged, and may explode.

In certain applications, such as in supplying voltage for the high-frequency oscillator in a superheterodyne receiver, it is desirable and often essential to maintain a constant supply voltage. One method of doing this is to use a gaseous voltage-regulator
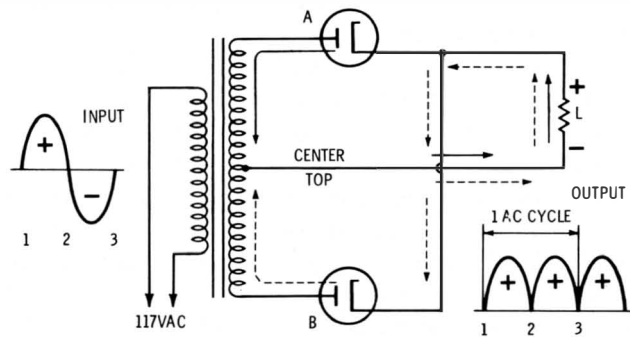

Fig. 6-9. Basic full-wave rectifier operation.

tube, as shown in Fig. 6-10. These tubes are available at a number of rated output voltages, and are designed to maintain a constant voltage drop across their terminals over a considerable range of input voltage and current demand. In solid-state receivers, we will find zener diodes used instead of voltage-regulator tubes; a zener diode serves the same function as a regulator tube. When the current demand of a receiver exceeds the capability of a zener diode, a regulator circuit employing one or more tran-
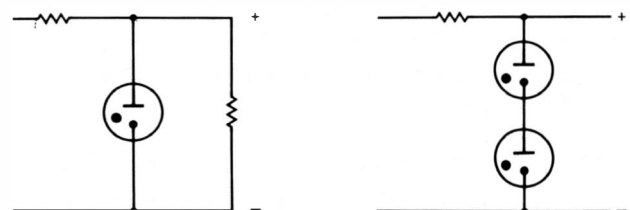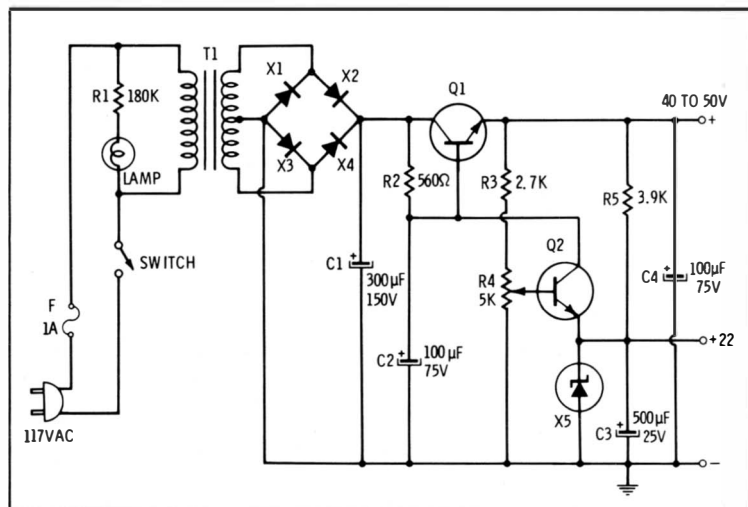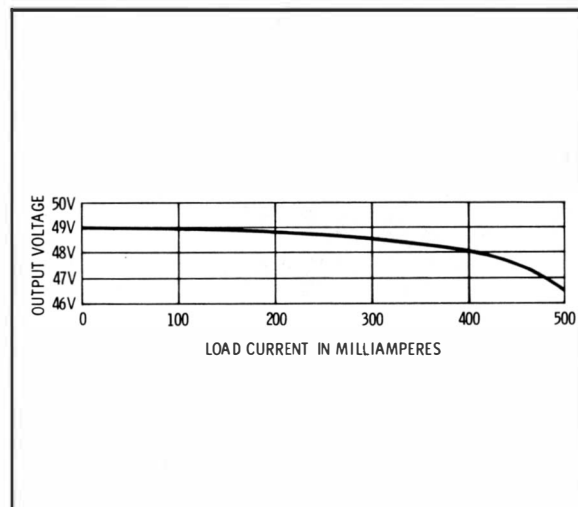

Fig. 6-10. Voltage-regulator circuits.

(A) Schematic.

(B) Regulation characteristic.

Courtesy General Electric Co.

Fig. 6-11. Voltage regulation using transistors and a zener diode.

sistors is utilized. A simple example is shown in Fig. 6-11.

The operation of the regulator circuit shown in Fig. 6-11 is as follows: Transistor Q1 functions as a controlled variable resistor between the source and the load. If the output voltage tends to vary, this change in voltage is applied to the base of Q1 as dc negative feedback, which increases or decreases the effective resistance of Q1. Let us suppose that the voltage at the base of Q2 tends to decrease, thereby causing an increase in the collector voltage, and, in turn, an increase of the base voltage on Q1. This increase in base voltage on Q1 reduces its internal resistance, which increases the output voltage across the load. On the other hand, if the output voltage tends to increase, the circuit action will increase the internal resistance of Q1, and thereby decrease the output voltage across the load.

Note that the function of the zener diode in Fig. 6-11A is to provide a fixed dc voltage reference; the temperature coefficient of the zener diode also helps to compensate for output voltage changes due to the temperature coefficient of transistor Q1. Transistor Q2 functions as a dc amplifier, which provides closer regulation than if a resistor were used in its place. The amount of amplification is adjusted by means of R4. We adjust the potentiometer to obtain the minimum decrease in output voltage as the current demand is increased. The graph in Fig. 6-11B shows the regulation characteristic of this configuration in normal operation.

Vibrator Power Supplies

Older models of tube-type auto radios employ vibrator power supplies that provide B+ voltage from a 6-volt or a 12-volt source. A simple vibrator power supply is shown in Fig. 6-12. It employs a vibrating reed to make and break the direct current circuit in the primary of a step-up transformer. This gives pulsating direct current in the primary winding, which is transformed into a high ac voltage in the secondary winding. This type of vibrator is used
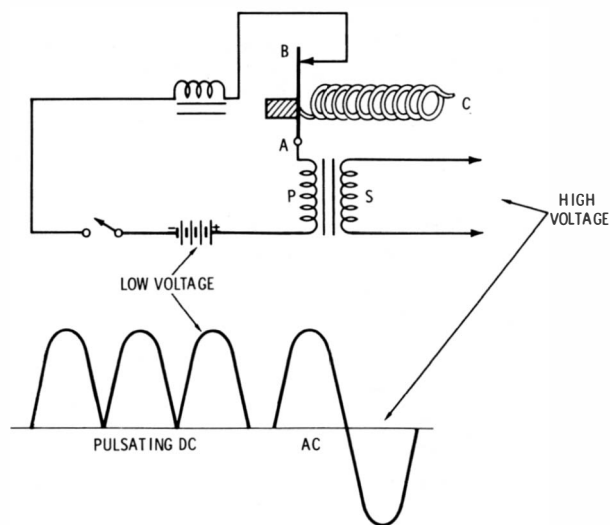

Fig. 6-12. Basic vibrator power-supply system.

with a following half-wave or full-wave rectifier tube. The two chief service problems in this type of power supply are eroded contacts and fatigued vibrator reeds which develop cracks and break in two. Repairs are seldom practical, and the entire vibrator unit is replaced. This is a simple job, inasmuch as vibrators are designed as plug-in devices.

Fig. 6-13 shows the circuit arrangement for a typical vibrator power supply. To obtain a good ac

Fig. 6-13. Typical vibrator supply and filter system.

waveform, a tapped primary is used. Before the battery is switched on, the reed rests against contact C. When the battery is switched on, current in electromagnet A attracts the reed away from C and closes contact B. In turn, there is current through the lower half of the primary winding.. However, this current is brief, because electromagnet A is now shorted out. Therefore, the reed springs back away from B and closes contact C. This produces current in the upper half of the primary winding. Again, this flow is brief, because there is current once more through electromagnet A. Thus, the cycle of operation repeats rapidly, and a high ac voltage is induced in the secondary winding.

Choke L1 and capacitor C1 in Fig. 6-13 function to minimize sparking at the vibrator contacts, and also to bypass rf interference voltages to ground. Capacitor C2 is shunted across the secondary to bypass high-frequency surges, and to develop a comparatively good sine waveform at the power-supply frequency. A full-wave rectifier tube provides pulsating dc, which is smoothed into practically pure dc by a pi-type LC filter. The entire power supply is enclosed by a metal case, to provide shielding and to minimize radiation of interference. Various other types of vibrator power supplies will be found in some of the older receivers; however, they are chiefly variations of the basic arrangement that is shown in Fig. 6-13.

Checking Electrolytic Capacitors

Practically all filters in power supplies use electrolytic capacitors. An electrolytic capacitor can become defective in three ways: (1) It may lose capacitance or even become open-circuited; (2) it may develop excessive leakage; (3) it may develop a poor power factor. Capacitor checkers will usually measure these three characteristics. It is obvious that poor filtering action will result if a filter capacitor loses a substantial amount of its rated capacitance. When an electrolytic capacitor becomes leaky, it tends to run hot and deteriorate rapidly. Leakage increases the current demand on the power

supply, reduces the B+ voltage, and causes increased ripple amplitude (hum). When an electrolytic capacitor develops a poor power factor, its internal resistance is excessive—this can be caused by various defects such as a high-resistance contact, deteriorated electrolyte, or deteriorated foil. In effect, the capacitor acts as if it were connected in series with a resistor. This condition causes increased ripple amplitude.

Troubleshooting Branched B+ Systems

Fig. 6-14 shows a typical branched B+ system. Common trouble symptoms are weak or no reception, with subnormal B+ voltages, and failure of the circuit breaker to remain closed. These conditions are caused by excessive current drain, and can be due either to a defective component in the power supply, or to an abnormal current demand by one of the branch circuits. Electrolytic capacitors are most likely to become defective; for example, excessive leakage in C1, C2, C3, C19, C20, or C21 can cause excessive current drain. However, if the filter capacitors are not defective, the most likely cause of the trouble symptom is abnormal current demand by one of the B+ load circuits. Localization of the faulty circuit often requires a systematic analysis.

Note in Fig. 6-14 that when Branch 1 draws excessive current, the output voltages of the other branches will be decreased, as well as the output voltage from Branch 1. The reason for this situation is that the windings of the transformer have resistance—this is called the internal resistance of the transformer. Any current demand from the secondary will produce a proportional voltage drop across this internal resistance. In turn, if an abnormal current demand is placed on rectifiers X1 and X2, decreased voltage is supplied to rectifiers X3 and X4. By the same token, an abnormal current demand by Branch 2 will cause reduced output voltages from the other branches.

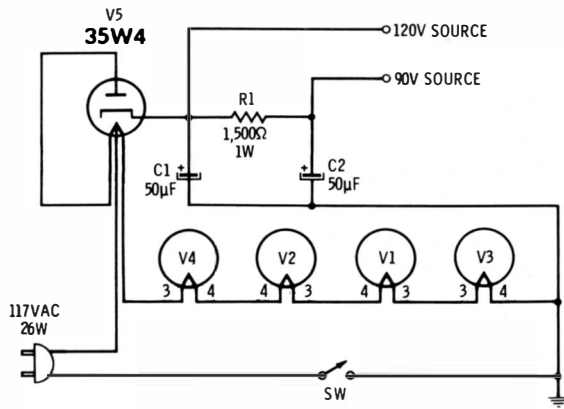Because of the interaction present in branched B+ systems, it is often difficult to localize the branch

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Fig. 6-14. A branched B+ system.

that has an excessive current drain, unless disconnection tests are made. That is, with reference to Fig. 6-14, we may monitor the voltage across X18, while progressively disconnecting and then reconnecting the leads to the various branch loads. When we come to the branch that has excessive current demand, the voltage across X18 will suddenly shoot up to normal value when the lead to that branch is disconnected. After the faulty branch circuit has been localized, it becomes a comparatively simple job to close in on the defective component.

Trouble Conditions in Tube-Type Power Supply

A simple full-wave power supply employing vacuum-diode rectifiers is shown in Fig. 6-15. Troubleshooting is done almost entirely by voltage and resistance measurements. An open circuit in the primary or secondary of transformer T1 will result in no dc output. Also, if the windings are intact, an open circuit in choke L1 or L2 will open the B+ circuit. If filter capacitor C1 short-circuits, the current through tubes V1 and V2 will be very high and will cause the secondary winding to smoke, or will burn out the tubes. If output capacitor C2 short-circuits, there will be no dc output, but be-

Fig. 6-15. Full-wave rectifier power supply.

cause of the resistance of the two chokes, the amount of current will be less than if C1 short-circuits.

As explained previously, the filter capacitors reduce or remove the ripple from the rectifier output. Therefore, if either of the filter capacitors in Fig. 6-15 should open, the B+ voltage will contain objectionable hum. Note that there will also be a substantial drop in the dc output voltage in case C1 opens. Bleeder R discharges the filter capacitors when the power is turned off. This is a safety measure. The bleeder also provides a steady current drain that helps to stabilize the B+ voltage when the unit is switched from a-m broadcast reception to phonograph operation, for example. That is, when part of the receiver is switched out, the B+ voltage tends to

Fig. 6-16. An ac/dc power supply.

rise, but rises less if a bleeder is provided. In case the bleeder opens up, the B+ voltage will be abnormally high.

Before making any resistance measurements in a power supply, it is good practice to short-circuit the filter capacitors with a screwdriver or test lead. The reason for this precaution is that a filter capacitor in good condition and in the absence of a bleeder, can hold enough charge to ruin an ohmmeter. Fig. 6-16 shows a configuration for an ac/dc power supply, many of which are still in use. When power-supply trouble is suspected, many technicians measure the resistance across C1 or C2 at the outset. As a rough rule of thumb, a reading of less than 10,000 ohms indicates trouble—most likely a leaky filter capacitor.

ANALYSIS OF COMMON TROUBLE SYMPTOMS

An analysis of the trouble symptoms listed earlier is presented in this section.

1. Dead Receiver

A "dead receiver" symptom can be caused by defects in various sections. It is easy to localize trouble to the power-supply section by measuring the supply voltage. If the power-supply voltage is abnormally high in a solid-state receiver, it is necessary first to repair the defect and bring the voltage value to normal. In most cases, it then becomes necessary to replace various defective transistors. On the other hand, if the trouble symptom is caused by undervoltage or by no-voltage output, it will suffice to repair the power-supply defect, and the receiver will resume normal operation.

Possible causes of a dead-receiver trouble symptom, due to defects in the power-supply section, are as follows:

a. Battery with one or more cells installed with incorrect polarity.
b. Battery polarity nominally correct, but with battery polarity reversed by charging in wrong direction.
c. Open zener diode, permitting development of excessive output voltage.
d. Shorted zener diode, causing zero voltage output.
e. Very leaky or shorted filter capacitor.
f. Defective rectifier diode.
g. Power-transformer winding burned out, due to previous short-circuit.
h. Open bleeder resistor, causing excessive supply voltage to one branch, but zero supply voltage to another branch.

2. Weak Reception

When weak reception is due to a power-supply defect, localization can be easily made on the basis of voltage measurements. Since it is necessary to know what the normal output voltage values are, the receiver service data must be consulted, or comparative measurements must be made on another receiver of the same type that is in normal working condition. Defects that cause weak reception are generally the same as those that cause a "dead-receiver" symptom, except that the failure differs in degree. For example, a weak battery will first cause weak reception. Then, as its terminal voltage decreases further, the local oscillator will drop out, and the trouble symptom will change into a "dead receiver."

Possible causes of a weak-reception trouble symptom, due to defects in the power-supply section are as follows:

a. Battery with a cell installed with incorrect polarity.
b. Junction leakage in zener diode.
c. Poor front-to-back ratio in a rectifier diode.
d. Filter resistor overheated and increased in value.
e. Shorted turns or layers in the power transformer.

When there are shorted turns or a shorted layer in a power-transformer winding, the core becomes hot and the output voltage is reduced. A short circuit that imposes a very heavy current demand causes the transformer to vibrate and produce a loud hum. If the receiver is not turned off, the transformer will start to smoke, and will usually burn out at the point of defect.

3. Hum in Sound Output

Hum in the sound output due to a power-supply defect may or may not be accompanied by other trouble symptoms. For example, an open input filter capacitor will raise the hum level substantially, but will not reduce the output voltage greatly in configurations such as are shown in Fig. 6-15. On the other hand, an open output filter capacitor will raise the hum level appreciably, and will also cause the B+ voltage to drop considerably. In the case of a simple RC filter, such as is shown in Fig. 6-16, the output voltage will drop substantially if the input filter capacitor is open; the hum level is increased greatly, also. However, if the output filter capacitor opens up, the chief symptom is a large increase in hum level—the output voltage does not drop by a large percentage. Therefore, the experienced technician evaluates a hum condition on the basis of associated symptoms (if any), and with respect to the power-supply circuitry used in the particular receiver.

Possible causes of hum in the sound output, due to power-supply defects, are as follows:

  a. Faulty filter capacitor.
  b. Defective rectifier diode in a full-wave configuration.
  c. Shorted turns or layers in a filter choke.
  d. Abnormal current drain due to voltage-regulator defect.
  e. Incorrect value of previous replacement component.
  f. Cold-soldered or unsoldered connection.

4. Noise in Sound Output

Noise in the sound output can be caused by defects in various sections of a receiver, and the localization of the trouble is not always straightforward. However, when the trouble symptom is being caused by a power-supply defect, localization is easy. We disconnect the filter-output lead in the receiver, and power the circuits from a bench power supply. Then, if the noise disappears from the sound output, we know that the trouble will be found in the power-supply section. A systematic check of possible poor contacts and poor connections will usually turn up the defect. However, there are occasional deceptive situations, caused by marginal breakdowns in electrolytic capacitors, rectifier diodes, or coil windings. Scope waveform analysis is helpful in such cases, to find out where the noise "spikes" are entering. As in most malfunctioning circuits, capacitors are the prime suspects.

Possible causes of noise in the sound output, due to defects in the power-supply section, are as follows:

  a. Poor contact between cells in a battery.
  b. Marginal breakdown in a filter capacitor.
  c. Deteriorated rectifier diode.
  d. Noisy filter resistor.
  e. Marginal short circuit in transformer or filter-choke winding.
  f. Poor connection in power-supply circuit.

5. Drift in Tuning

Drift in tuning is always due in the first analysis to instability in local-oscillator operation. However, the instability can be caused either by a defect in the oscillator circuit or by a defect in the power supply. When the trouble is caused by the power supply, this fact is shown by lack of constancy in the supply-voltage value. That is, if we monitor the supply voltage to the oscillator section and find that the voltage value does not hold constant as the tuning drift progresses, we conclude that the trouble is in the power-supply section.

Possible causes of drift in tuning, due to defects in the power-supply section are as follows:

  a. Deteriorated zener diode or transistor in regulated section of the power supply.
  b. Unstable resistor (increasing or decreasing resistance) in voltage-regulator circuit.
  c. Worn and erratic bias control in regulator circuit.
  d. Leaky and unstable filter capacitor in unregulated power supply.
  e. Thermally unstable resistor.

6. Motorboating

Motorboating, when caused by power-supply defects, is always localized to a defective filter capacitor or decoupling capacitor. The capacitor may be open, or it may have lost sufficient capacitance that its reactance is excessive. A high reactance provides a coupling path from one receiver section to another, and the resulting feedback often produces a motorboating trouble symptom. It is so-called because the sound output has a putt-putt characteristic. The frequency of motorboating can vary over a wide range, and depends both on the extent of the power-supply defect and on the design of the receiver. Experienced technicians know that a seemingly defective component may actually be all right, and that the actual trouble can be caused by a poor connection, defective lead, or broken printed-circuit conductor.

Possible causes of a motorboating trouble symptom due to power-supply defects are as follows:

a. Open filter capacitor or loss of capacitance.
b. Open decoupling capacitor at the far end of a branch B+ lead.

c. Poor ground connection to filter or decoupling capacitor.
d. Broken printed-circuit conductor in capacitor circuit.
e. Incorrect value of replacement capacitor (less likely, but possible).

Chapter 7

Restoring Antique Radio Receivers

There are many collectors who specialize in antique radio receivers, or who combine this activity with telegraph, telephone, or electrical collections. The Antique Wireless Association, with membership limited to 500 collectors at any time, is the chief fraternal headquarters for antique radio buffs. The AWA publishes the *Old Timers Bulletin,* which features news and photographs of various collections, articles on restoring old equipment, historical items, and advertisements of equipment wanted or for sale or trade. The market value of a radio receiver depends chiefly on its antiquity. For example, an IP-500 crystal set (used by the Navy and commercial ships prior to World War I) is worth approximately $250 at the present time. On the other hand, a Federal Jr. crystal set manufactured in the early 1920s is worth approximately $30. Values tend to increase with each passing year.

GENERAL DISCUSSION

Only a small number of antique radios, which have been stored in their original packing cases, will be found in "mint" condition. Even these exceptions usually have minor defects such as deteriorated paper capacitors. Most of the radios acquired by collectors have cabinets that are scratched, peeled, cracked, and so on. These defects are comparatively easy to repair. When damage is extensive, a collector may prefer to build a replica of the original cabinet. For example, Fig. 7-1 shows an example of a Crosley battery radio with a cabinet that is in very poor condition. In this situation, the lid can be retained, but it is necessary to build a replica of the remainder of the cabinet.

Audio Transformers

The collector soon discovers that a good audio transformer is the exception rather than the rule in an old battery radio. Fig. 7-2 illustrates a typical audio transformer in an Erla reflex set. It is very difficult to repair an open winding in an audio transformer, because the wire is very fine and the coils are impregnated with wax. If a replacement transformer cannot be obtained from an antique radio dealer, or from another collector, it is usually possible to put the receiver into operation by changing the amplifier circuit from transformer coupling to

Fig. 7-1. Example of a cabinet in very poor condition.

Fig. 7-2. Arrow points to audio transformer.

(A) *Original circuit.*

(B) *Modified circuit.*

Fig. 7-4. Transformer coupling changed to resistance coupling.

impedance coupling, as shown in Fig. 7-3. In this example, the primary winding is used because the secondary winding is open. A coupling capacitor and a grid-leak resistor are added to the circuit to provide impedance coupling between the tubes. In case the primary winding happens to be open, the secondary winding of the transformer can be used in the impedance-coupled circuit.

(A) *Original circuit.*

(B) *Modified circuit.*

Fig. 7-3. Audio transformer used for impedance coupling.

We will often find situations in which both the primary and secondary windings of an audio transformer are open. In such a case, the receiver can be put into operation by changing the amplifier circuit from transformer coupling to resistance coupling, as shown in Fig. 7-4. Both impedance coupling and resistance coupling provide less gain than tranformer coupling; on the other hand, fidelity is usually improved considerably. It is often possible to mount the added capacitor and resistor behind the audio transformer, where they are not readily visible. Thus, the original appearance of the chassis arrangement is not greatly altered. Some collectors

will replace an original audio transformer with another type of audio transformer that is in working condition. Fig. 7-5 illustrates some various brands of audio transformers used in battery sets.

Fig. 7-5. Various audio transformers used in battery sets.

Tubes

Tubes may present a problem when an attempt is made to put an antique battery set into working condition. The chief tubes originally used were the Types 200, 201, 201A, 199, and WD-11. These are illustrated in Fig. 7-6. Types 200 and 201 are scarce;

Fig. 7-6. Old vacuum tubes. (Rear, left to right) types 200, 201, 201A; (foreground, left to right) WD-11, 199.

the 200 is a gas-content (soft) detector tube, while the 201 is a high-vacuum (hard) amplifier tube. However, either the 200 or the 201 can be replaced with the 201A, which is available from various antique dealers. The 200 and the 201 have tungsten filaments that are operated at incandescence, whereas the 201A has a thoriated filament that is operated at dull red heat. Each of these types is rated at five volts; however, the 200 and 201 filaments draw an ampere, whereas the 201A filament draws ¼ ampere.

Fig. 7-7. Miniature tubes can be substituted for type 199 or WD-11.

The 199 and WD-11 types are comparatively scarce, and most collectors have to use substitutes to put battery sets into operation. A practical method is to connect a 3.15-volt or 1.4-volt miniature tube as a triode, and mount it in a suitable tube base. Fig. 7-7 shows a 3V4 in a 7-pin miniature socket, and also with the miniature socket inserted into a 199-type tube base. A 1DN5 can be similarly mounted in a WD-11 tube base. To remove the base from an old tube, hold the brass pins in a gas flame until the solder melts. This will also loosen the cement that holds the tube, and the glass envelope can be withdrawn from the base, along with its leads. Before inserting the miniature socket into the old base, run leads through the hollow brass pins. Insert the miniature socket, solder the leads, and cut off the excess length. If desired, sealing wax or transformer wax can be melted and carefully poured around the miniature base to hold it firmly in place.

Both the 201A and the 199 tube types can occasionally be rejuvenated, after the filament emission has slumped off. This is done in much the same way that a picture tube is rejuvenated in a TV receiver. Fig. 7-8 illustrates a combined tube tester and rejuvenator for Type 199 and 201A tubes. A switch is provided for reading filament emission, and for applying overvoltage for rejuvenation. The tester

Fig. 7-8. A combination tube tester and rejuvenator.

shown in Fig. 7-8 accommodates only the two types of tubes. A WD-11 tube has a different variety of filament, and cannot be rejuvenated. Occasionally, a collector solves the tube problem by replacing the original sockets in the receiver with a modern type of socket, installing ac tubes, and operating the receiver from an auxiliary power supply. However, an antique receiver loses quite a bit of its value when original parts are replaced by modern parts.

Coils

Damaged coil forms can sometimes be repaired by filling in the broken portion with plastic wood, smoothing the surface, and refinishing with a coat of dark varnish. For example, the coil form shown in Fig. 7-9 had a section broken out, and the winding was damaged when the set was acquired. The coil form was removed from the panel, the damaged winding was taken off, and plastic strips were
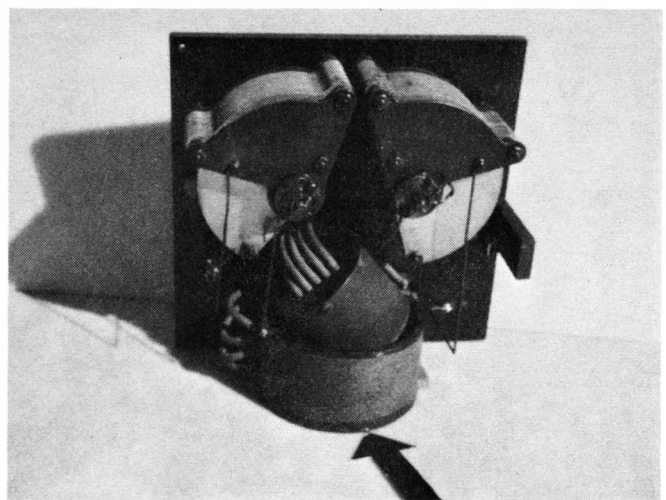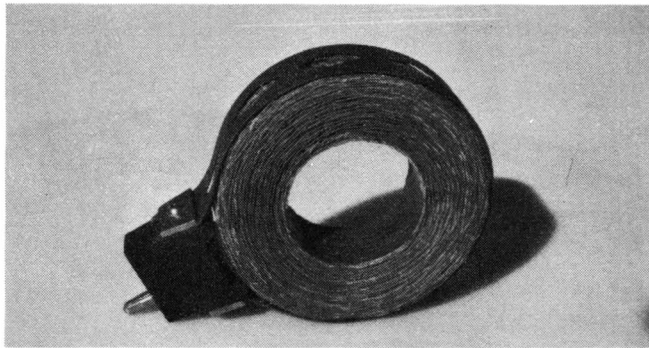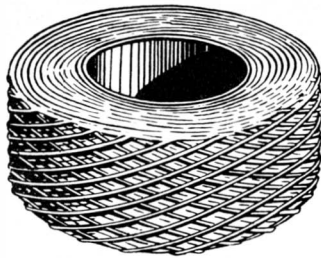

Fig. 7-9. Arrow indicates repaired coil form in DeForest SCR-54 set.

(A) General appearance.

(B) Winding detail.

Fig. 7-10. Honeycomb coil.

clamped on either side of the broken-out section. Next, plastic wood was placed in the section to fill in the missing portion. After drying, the plastic wood was sanded to a smooth surface, and the entire coil form was coated with dark varnish. The coil was then rewound, and the finished job looked practically the same as the original.

Honeycomb coils, such as are illustrated in Fig. 7-10, often become damaged over the years. If a coil is dropped on the floor, the outer layers of the winding become crushed at the edges. In most cases,

Fig. 7-11. Receiver using a coherer detector.

the most practical "repair" is to unwind several of the outer layers and thereby remove the damaged edge. This results in a somewhat smaller coil, but restores its normal appearance. If a good lathe is available, it can be set up to rewind honeycomb coils. It is usually necessary to use the wire from the damaged coil, since cotton-covered wire is very scarce. After the winding is completed, it is standard practice to impregnate the coil with shellac. This ensures that the coil will not unwind, or that the turns will not become loose during the mounting procedure.

Coherers

Marconi-type receivers, such as the one illustrated in Fig. 7-11, employed coherers instead of crystal or tube detectors. A coherer consists of a glass tube with metal filings contained between a pair of metal plugs, as shown in Fig. 7-12. The glass tube may be broken, and the filings may be lost. Repair is comparatively simple; a replacement section of glass tubing can be obtained from a chemical supply house, or even from a drug store. To cut the tubing to correct length, score a groove around the circumference with the corner of a file. Then, the tubing can be separated cleanly at the groove by applying pressure. The filings that are employed may be iron or a mixture of silver and nickel. Earlier coherers used iron filings; however, these filings tend to rust with the passage of time.

Fig. 7-12. A type of coherer as used by Marconi to detect wireless signals.

The filings are normally slightly loose in a properly adjusted coherer. In the example of Fig. 7-11, an adjustment is provided to obtain optimum operation. The resistance of a coherer will be 0.5 megohm, or more, in its resting condition. When a high-frequency signal is applied, the resistance will suddenly drop to several hundred ohms, or less, depending on the strength of the signal. After the filings have cohered, they will retain their low resistance after the signal impulse has stopped. Therefore, a tapper is provided that strikes the glass tube lightly and jars the filings apart; this is called a *decohering* action. The tapper is a form of electric bell that is suitably mounted with respect to the coherer. When

code signals are being reproduced, the bell will ring for the duration of a dot or of a dash.

Carbon Detectors

Carbon detectors, such as the one illustrated in Fig. 7-13, were used after the coherer became obsolete, but before the invention of the catwhisker detector. A carbon detector employs a microphonic contact between carbon and steel. In the example of Fig. 7-13, a steel needle is held by adjustable spring pressure on the edges of a pair of carbon blocks. This type of detector is generally biased by 1.5 volts; the polarity of the bias voltage is not important, but the optimum pressure is somewhat critical. In many cases, the steel rod becomes lost over the years. However, it can be replaced with a section of a darning needle.

Fig. 7-14. Carbon amplifier unit.

Fig. 7-13. Carbon detector.

Another type of carbon detector that was widely used in the early days of wireless communication consisted of a pair of steel blades with a small carbon rod resting on the edges of the blades. The operation of this type of detector is basically the same as just explained. It is likely that the carbon element must be replaced, because of breakage, or because it has been lost. A satisfactory replacement is a length of refill lead for a mechanical pencil. A carbon detector is in correct adjustment when a slight hissing sound is audible in the earphones. The hissing results from a microscopic arc formed at the microphonic contact between the carbon and steel. The chief disadvantage of this type of detector is its tendency to "boom" or "ring" if the receiver is jarred even slightly.

Carbon Amplifiers

Carbon amplifiers were used before the invention of amplifier tubes. A carbon amplifier, such as illustrated in Fig. 7-14, operates on the principle of the microphone. That is, a sensitive carbon microphone

produces considerably more electrical power than the input sound power. Accordingly, amplification is obtained in the configuration shown in Fig. 7-15. The usual restoration problem concerns microphone damage. If more than 3 volts are applied, the carbon granules become overheated and "pack." The granules can be loosened by tapping the microphone, but considerable sensitivity is generally lost, because the surfaces of the granules have been burned. To restore the unit to normal operation, the microphone must be replaced. Try to locate an old-time hearing aid with a carbon microphone—this makes a highly efficient replacement.

A carbon amplifier has considerably more distortion than a vacuum-tube amplifier, because a carbon microphone has a nonlinear characteristic. The amount of amplification, and also the distortion, varies as the microphone is tilted at different angles. When the amplification is greatest, the distortion is most noticeable. Therefore, the orientation of the microphone is somewhat of a compromise. The vertical position shown in Fig. 7-14 provides a reasonable amount of amplification without objectionable distortion. Amplification is greatest when the micro-
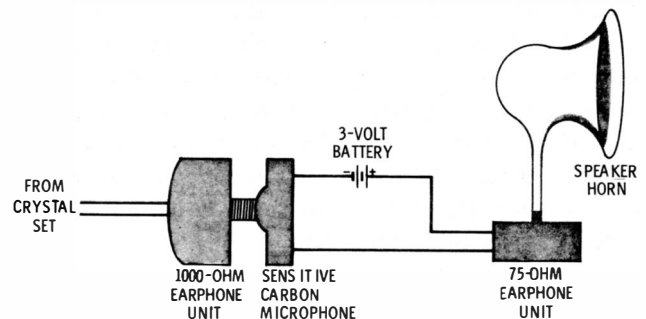

Fig. 7-15. Circuit for carbon amplifier.

phone is mounted at an angle of about 45 degrees; however, the distortion is also very evident.

Panels

Antique radios were manufactured with Bakelite, Formica, or hard-rubber panels. In some cases, panels are in poor condition. Most panels are engraved, as exemplified in Fig. 7-16. If the markings are not clearly visible, first clean the panel with a moist cloth. In case additional attention is needed, the engraved lines can be filled in with white lead or with chalk. White lead is retained better, but is not as easy to work with as chalk. After the filling-in is completed, it is necessary to go over the panel lightly with a dry cloth to remove white smears from the surface. The chief panel defects are scratches and cracks. Hard rubber also tends to warp badly over the years. In general, scratches cannot be repaired, although a light coat of furniture oil polish on the panel will make scratches less visible. Cracks can be repaired to some extent by cementing the broken edges together with plastic cement. Be careful to wipe any excess cement from the surface of the panel before it dries.

Fig. 7-16. Antique receiver showing engraved bakelite panels.

Although panels can be replaced, this is usually a "last resort" measure, because the engraving is then discarded. It is impractical for the usual collector to reproduce the engraving, because it involves highly precise machine operations. If a panel is replaced, it may not be possible to duplicate the original material. For example, hard-rubber sheet is almost impossible to find. Bakelite is sometimes available from large plastics manufacturers, but must usually be purchased in wholesale lots. Formica is quite similar to Bakelite, and is more generally available. Most of the Formica used in the building trades is $\frac{1}{8}$ inch

thick, whereas most antique radios have $\frac{3}{16}$ inch or $\frac{1}{4}$ inch panels. In a pinch, a pair of $\frac{1}{8}$ inch Formica panels can be cemented together under pressure to make up a $\frac{1}{4}$ inch panel.

Formica is occasionally available at surplus stores in $\frac{1}{4}$ inch sheets. This stock provides an identical replacement for the Formica panels used in antique radios. Nearly all radios used black panels, although a few manufacturers chose brown Formica or Bakelite. When a substitute material must be used to replace a defective panel, it is advisable to look around for black Acrylite. This is a generally available plastic material that has a high surface polish similar to Formica or Bakelite. However, Acrylite lacks the tough and hard texture of the laminated thermoplastics. Thus, it is easier to cut and drill, but is also easier to scratch. Its appearance is very similar to Bakelite, and it is a satisfactory replica.

Mineral Detectors

Catwhisker sets employed galena, silicon, or iron pyrites crystals. These minerals can sometimes be purchased from antique dealers who specialize in old-time radio equipment. Otherwise, they are readily available from "rock hound" stores. Since naturally occuring minerals vary considerably in their impurity content, it cannot be assumed that a commercial mineral will provide good detection until it has been tested. If a satisfactory detector crystal cannot be obtained, an expedient is possible which will restore a catwhisker set to working condition. Simply connect a 1N34 crystal diode across the terminals in back of the detector. This will provide normal reception until such time as a replacement chunk of detector mineral can be located.

Two types of fixed crystal detectors were used in antique radios. Carborundum detectors employed a steel point making firm contact with a carborundum crystal. The detector was enclosed in a tubular case with a terminal at each end. No adjustment was provided. The carborundum detector works best when used with a forward bias of approximately 1 volt. The other type of fixed detector was actually a semi-fixed device, in which a short, stout catwhisker with a pointed end was mounted with a silicon crystal. The detector assembly was covered by a removable cap. When a sensitive spot was located by bending and pushing the catwhisker, this type of detector would hold its adjustment for some time in most cases. However, because of thermal cycling, it eventually becomes necessary to readjust this type of "fixed" detector.

Fixed detectors are occasionally available from antique dealers. It is impractical for most collectors

to restore a badly damaged detector, because specially machined parts are required. As in the case of catwhisker detectors, a set can be placed in working condition by connecting a 1N34 crystal across the detector terminals. However, when a carborundum detector is being bridged in this way, set the bias control to zero. In other words, a 1N34 crystal will operate at poor efficiency when biased.

Batteries

All radio receivers classified as true antiques used battery power, or required no power supply, as in the case of catwhisker sets. Bias for carbon detectors and carborundum detectors was customarily obtained from flashlight cells. Coherer receivers were operated from No. 6 dry cells. Nearly all tube-type receivers used 6-volt storage batteries for heating the filaments, and employed B batteries for plate supply. B batteries are still available from large electronic supply houses; they consist of packaged flashlight

cells and generally supply either 45 volts or 90 volts. Some receivers also used C batteries to bias the grids of the amplifier tubes. C batteries are also available from large supply houses. They consist of packaged flashlight cells, with terminals for provision of 1.5, 3, or 4.5 volts.

A portable receiver utilizing WD-11 tubes operates from a No. 6 dry cell for filament heating, and a 22½ or 45-volt B battery for plate supply. Portable receivers with Type 199 tubes utilize two No. 6 dry cells for filament heating. A single-tube set with a Type 199 tube can be operated with a standard flashlight cell for filament heating. Collectors prefer to use batteries similar to those used in the original equipment. However, it is also practical to operate a battery-type set from a bench power supply. The chief requirement is a low hum level, because antique sets will develop considerable hum in the sound output unless the ripple level is quite low in the A, B, and C supply voltages.

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RADIO RECEIVER
SERVICING GUIDE

By Robert G. Middleton

In this book, Mr. Middleton covers troubleshooting and servicing a-m radio receivers, both solid-state and tube-type. Methods of localizing trouble are explained in detail throughout the book, with many notes on the use of appropriate test instruments.

The first chapter takes up general requirements and stresses the need for logical thinking and the use of service data. Under basic troubleshooting procedures, the following topics are covered: checking series heaters, testing components, signal tracing and signal substitution, and transistor testing.

Other chapters are devoted to the functional sections of a superheterodyne receiver, including rf and mixer stages, intermediate-frequency amplifiers, the audio section, avc circuits, and power supplies.

The final chapter on restoring antique radio receivers will bring nostalgic memories to many who witnessed the beginnings of radio broadcasting and receiving.

ABOUT THE AUTHOR

Bob Middleton is one of the few full-time professional free-lance technical writers in the electronics field. His many books and magazine articles have proved invaluable to students, technicians, and engineers because they are based on his own practical experience. His home workshop is filled with a wide variety of test instruments, receivers, and other equipment which he uses to prepare his many books.

Other Sams books by Mr. Middleton include nine volumes of his famous *101 Ways to Use Test Equipment* series, *Solving TV Tough Dogs*, *Bench Servicing Made Easy*, *Troubleshooting With the Oscilloscope*, *Troubleshooting With the VOM & VTVM*, *Electrical & Electronic Signs & Symbols*, *Know Your Square-Wave & Pulse Generators*, *Know Your Color-TV Test Equipment*, *Know Your Signal Generators*, *Know Your Sweep Generators*, *Transistor TV Training Course*, *Transistor-TV Servicing Guide*, *Transistor Color-TV Servicing Guide*, *Color-TV Servicing Guide*, *Record Changer Servicing Guide*, *Hi-Fi Stereo Servicing Guide*, and many others.