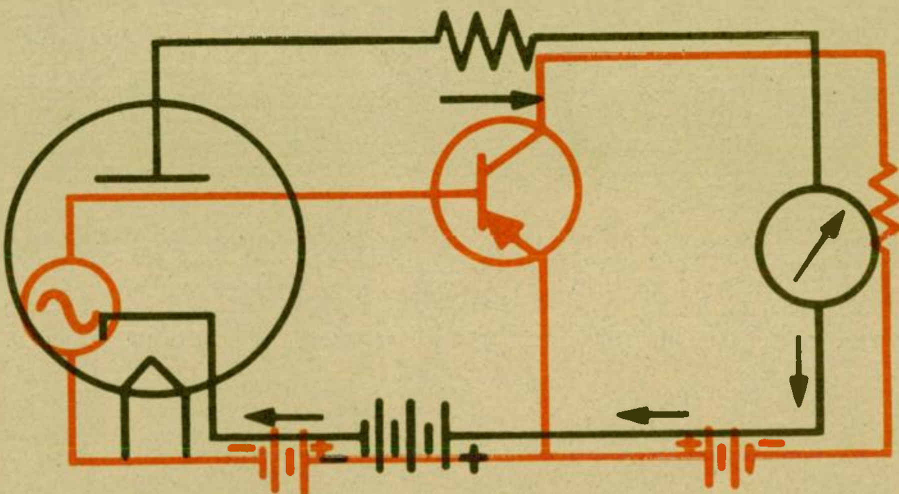
LESSON NO. 49

WORKING WITH TRANSISTORS



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WORKING WITH TRANSISTORS

INTRODUCTION

The greatest single development in electronics since the amplifying vacuum tube (in 1907) was the transistor, announced in 1948. Ironically, semiconductor use predates the vacuum tube by one year. The cat whisker-crystal combination was first used for signal detection in 1906. Because this early combination was somewhat erratic in its operation, it was soon replaced by the more stable vacuum tube. The crystal detector was all but forgotten for several years except by a few experimenters.

The point contact diode was discovered prior to 1940 and was used in military electronics equipment. Its rectifying junction was formed by permitting the point of a stiff wire contact to exert pressure on the surface of a germanium crystal. The pressure of this spring-like contact altered the structure of the crystal around the area of contact in such a way that it permitted current to flow in only one direction between the pressure contact and the stressed area. Another electrical (ohmic) contact was made by securing a conductive plate to one face of the crystal.

The semiconductor diode remained an unexplained phenomena until researchers concentrated their efforts during the middle and late 1940's. Scientists at Bell Labs attached an additional junction and discovered that when current was injected into this contact a small amount of current would control a much larger current through the junction. Thus, the transistor was discovered.

Early point contact transistors were both fragile and costly devices and did not become very popular except for experimentation. Nevertheless, the success of equipment manufactured with their use was encouraging to most other manufacturers of electronic products.

Shortly after the announcement of the transistor, experimenters discovered how PN junctions could be chemically formed in a piece of germanium or silicon, thus eliminating the necessity of an unstable point contact. This led to the development of the junction transistor; a very rugged device that could be produced in quantity at low cost. Soon manufacturers in all phases of electronics were developing and producing solid state gear rather than vacuum tube products.

Working with transistors is considerably different from working with vacuum tubes. The terms applied to transistors are unique as well as the magnitude of their voltages and currents. Vacuum tubes are inserted into sockets permitting easy replacement, whereas in many cases transistors are soldered directly into the circuitry. There is a limit to the amount of heat that can be applied to a transistor's leads without permanently affecting its performance.

A vacuum tube normally deteriorates slowly and has a predictable useful life. Aside from structural failures, its useful life ends when its cathode emission is no longer sufficient to provide an adequate number of electrons to supply normal plate current.

Transistors do not normally deteriorate from age like vacuum tubes. Instead their failures can usually be attributed to:

1. Structural defects at the time of manufacture.
2. Damage due to physical shock or mishandling.
3. Broken seals, due to shock or improper handling, that allow contaminants to enter and alter their chemical and conductive characteristics.
4. Shorted or open junctions due to excessive voltage being applied.

There are many other distinctive characteristics relative to transistors and most of these will be discussed in the following text.

SOLID STATE SYMBOLS

Symbolic representation of components is the shorthand of electronics. It permits a page or two of schematic drawing to represent a complex unit such as a stereo hi-fi or TV set.

The active element (tube, transistor or solid state amplifier) is the core of each circuit. With the active element as the focal point, other components are grouped around it. This combination represents a stage.

Nearly all the activity in a solid state stage centers around the semiconductor element. Therefore, we need to become very familiar with how solid state devices are drawn.

You were introduced to semiconductor diodes in earlier lessons and learned that they were represented by an arrow pointed at a bar (Fig. 1). The unit may or may not be shown enclosed in a circle. They will also appear in drawings with the arrow of the diode pointed in any of several directions as shown in Figure 1. Regardless of which way the arrow points, electron current flow will always be opposite this direction.

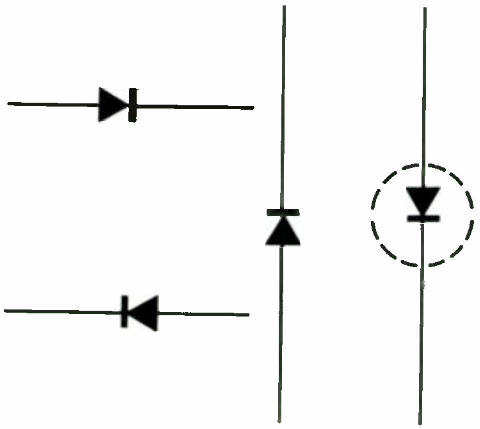


Figure 1 — Diodes orientated in four directions, showing the different ways they are drawn on schematics.

2 Diodes are often identified with letters of the alphabet. Common notations are CR (crystal rectifier) and D (diode). A number often follows the letter designation to identify its position on the schematic.

Zener diodes are frequently used with solid state circuitry to stabilize the bias voltages. Figure 2 shows two common symbols used to designate zener regulating diodes. Unlike current in ordinary diodes zener current flows with the arrow. In the back direction (against the arrow) zener diodes act like ordinary diodes.

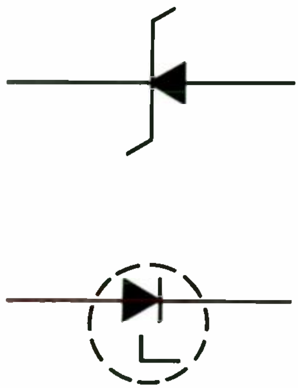


Figure 2 — Symbols for zener regulating diodes.

Transistors may be orientated in a number of different ways on schematic drawings. Figure 3 shows the many different ways that NPN and PNP transistors can be drawn on schematics. Transistors are drawn so as to simplify the tracing of signal paths and bias voltages.

Transistor polarities are often intermixed in solid state circuits. An illustration of intermixed NPN-PNP solid state is shown in Figure 4.

3 Notice that the transistors shown in Figure 4 are designated by the letter "Q" followed by the numbers 1 and 2 respectively to determine their position in the schematic. The letter "Q" is the most often used designation for transistors although other designations are sometimes used. The letters "TR" are the most common alternate to "Q" for identifying a transistor's position.

Identification System (Diodes and Transistors)

Diodes were assigned an alphanumeric system of identification prior to the discovery of the transistor. Because a diode had one junction and one polarity of voltage and current, it was designated as a 1N device. The number following the "1N" (which always designates a diode) was assigned according to the order in which a new diode was registered with a national registration agency. Thus, a 1N34 diode was the 34th diode type registered.

Transistors are assigned 2N designations because they have two junctions and operate with two polarities of voltage and current. The number type assignment for transistors follows the system used for diodes. Thus, a 2N94 transistor was the 94th transistor type registered.

SIZE DESIGNATION

A system for designating the sizes
4 of transistors has been devised and "TO" charts are included in various transistor manuals. Both size and physical forms of transistors are included in TO (Transistor Outline)

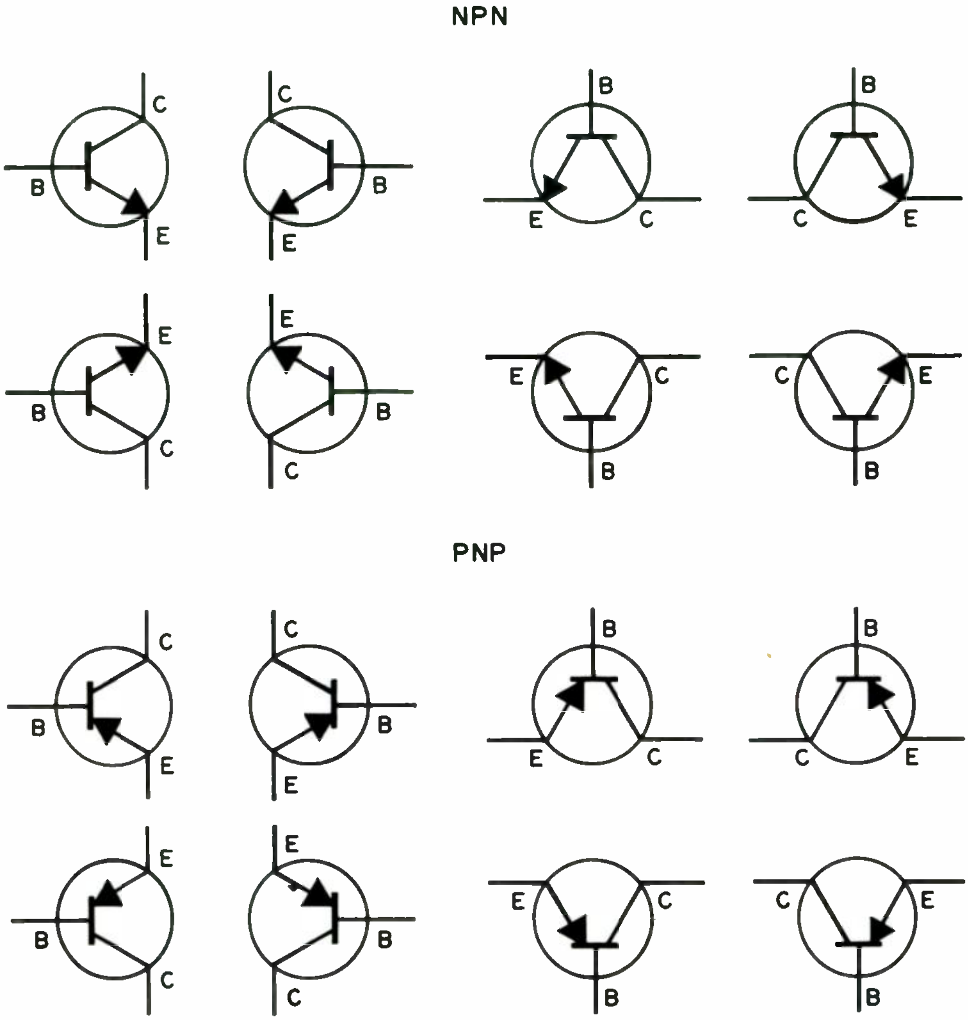


Figure 3 — Orientation of NPN and PNP transistors on schematic drawings.

charts. Diodes use a similar system called DO (Diode Outline) designations.

Figure 5 shows several sizes and shapes of transistors and diodes. The TO 5 style was very popular for early transistors. The device itself was contained in a sealed metal can. Notice the tab protruding from the edge of the can; it marks the approximate location of the emitter lead. Style TO 36 was very popular for high power transistors. Transistors represented by style TO 92 represent a departure from early transistor construction. Manufacturers dispensed with the sealed metal container used for earlier devices and instead enclosed the transistor element (frequently referred to as a chip) in molded epoxy with the shape shown.

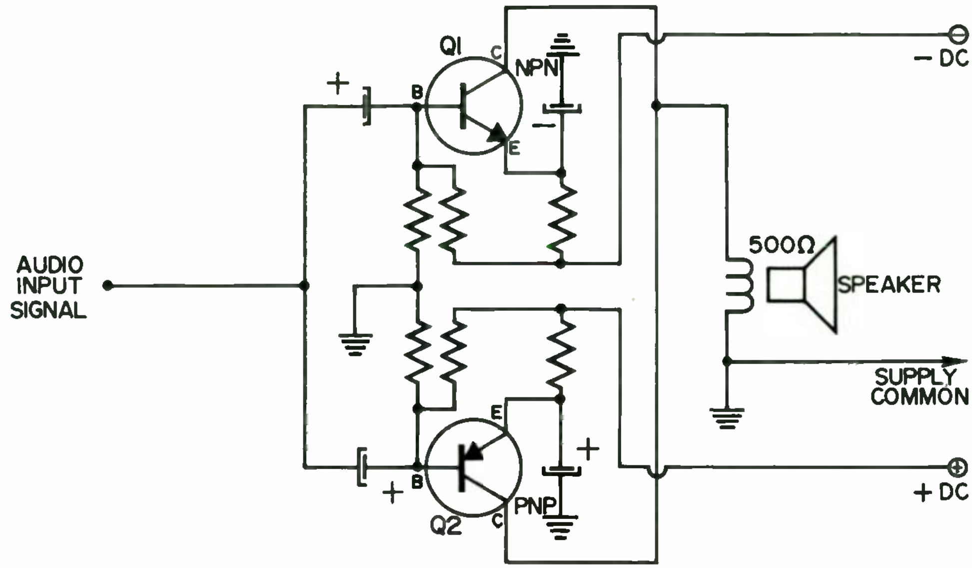


Figure 4—Intermixed PNP and NPN transistors in a complementary-symmetry audio output stage.

Any recent transistor manual will acquaint you with all the various sizes and styles of transistors and diodes.

SPECIFICATION LISTINGS

5 Specification sheets tell what a device does or can do. Some of the common characteristics that are noted in specification sheets are:

- Power dissipation
- Maximum voltage ratings
- Maximum current ratings
- Beta (current gain)
- Junction temperature
- Outline reference
- Applications
- Current leakage (ICBO)
- Maximum frequency capability

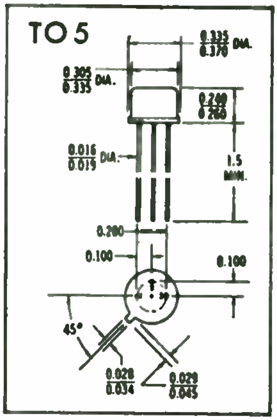
These are some of the most important ratings listed in transistor manuals, although many others appear in manuals devoted to engineering and design.

Power dissipation is generally a maximum value that is especially important when substituting audio power transistors. A derating factor or chart may be included. This chart shows the amount that power dissipation must be reduced as the temperature rises.

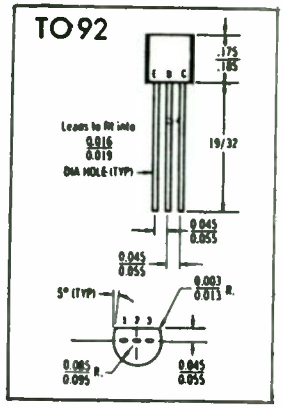
Voltage ratings are very important considerations with transistors. Once a junction has been punched through due to over voltage the device is permanently damaged and must be replaced. There are maximum allowable voltages that can be safely applied between any two elements of a transistor. These are listed in charts and are specified for both directions (forward voltage and reverse voltage).

Maximum current ratings are listed for specific operating (bias) voltages. These naturally must be reduced if the device is operated at a voltage greater than the reference, to keep the device

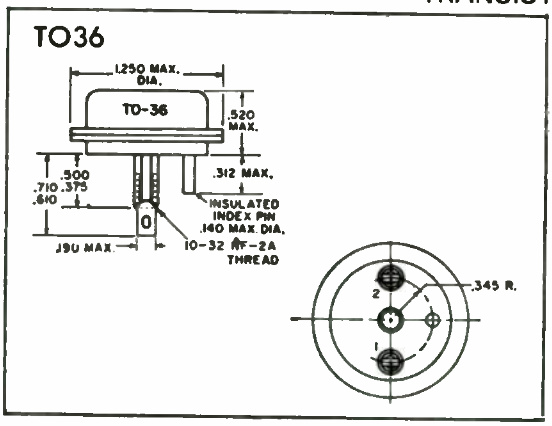
TRANSISTOR OUTLINES



LOW POWER
TRANSISTORS

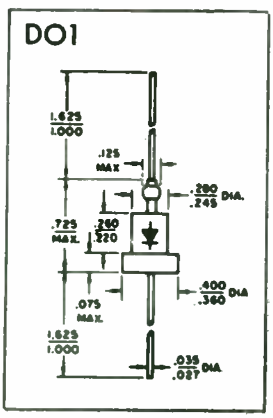


LOW POWER
TRANSISTORS

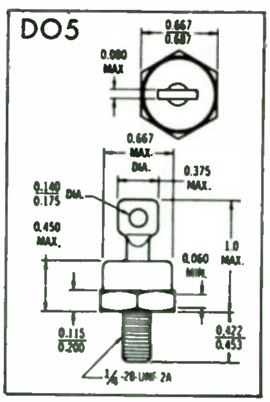


HIGH POWER
TRANSISTORS

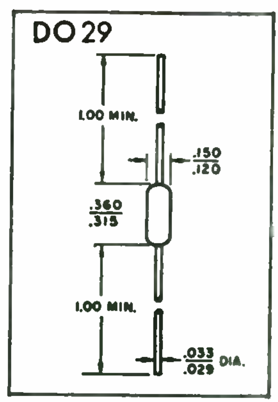
DIODE OUTLINES



EARLY SIGNAL
DIODE



POWER RECTIFIER
DIODE



MOLDED EPOXY
SIGNAL DIODE

Figure 5 — Device outlines for some transistors and diodes.

below its maximum allowable power dissipation.

Beta is the minimum forward current gain that may be expected for any transistor of a given type. Almost all transistors will have gain characteristics superior to those listed in specification sheets in transistor manuals.

The term ICBO refers to the amount of current leakage within the device due to minority carriers. Current leakage (ICBO) adds to the base input current to cause more collector-emitter current to flow. ICBO increases with temperature and must be included as a consideration when selecting suitable replacements for a transistor. The ICBO leakage doubles for each 8° of temperature rise above 20°C in silicon devices. In germanium devices current leakage doubles for each 10° temperature rise. It may seem that germanium devices are superior because leakage increases less, percentage-wise than silicon. Actually, silicon is superior at higher temperatures because of two factors:

1. Silicon has far less leakage at 20°C than germanium devices.
2. Silicon devices can operate at temperatures where germanium would either be unstable electrically or their structure would be destroyed by the heat.

Two terms are used to identify the frequency capability of a transistor. These are:

Gain-bandwidth product
Alpha cut off frequency

Gain-bandwidth product is the frequency at which the gain of a transistor becomes unity or 1. This term is used as an expression of the figure of merit of a transistor, relative to its frequency handling capability.

Alpha cut off frequency is the frequency at which the gain of a transistor is 0.707 of its value at a frequency of 1000 Hz. It is a very common figure for expressing the upper frequency limits of a transistor.

TRANSISTOR CONFIGURATIONS

6 Transistors are used in electronic circuits with three basic configurations. These are:

Common emitter (grounded emitter)
Common collector (emitter follower)
Common base (grounded base)

Common emitter configurations are
7 more frequently used than other arrangements. The signal into a common emitter amplifier is applied to the base. Signal current from the base to emitter controls a much larger current from the emitter to the collector. The amplified output signal is available at the collector or across a load in series with the collector.

Common emitter amplifiers offer a compromise between current gain, voltage gain, and input/output impedances that is favorable for most signal handling applications. They provide moderate current and voltage gain with a relatively high output impedance. Their input impedance is lower than common collector amplifiers but high enough for most applications.

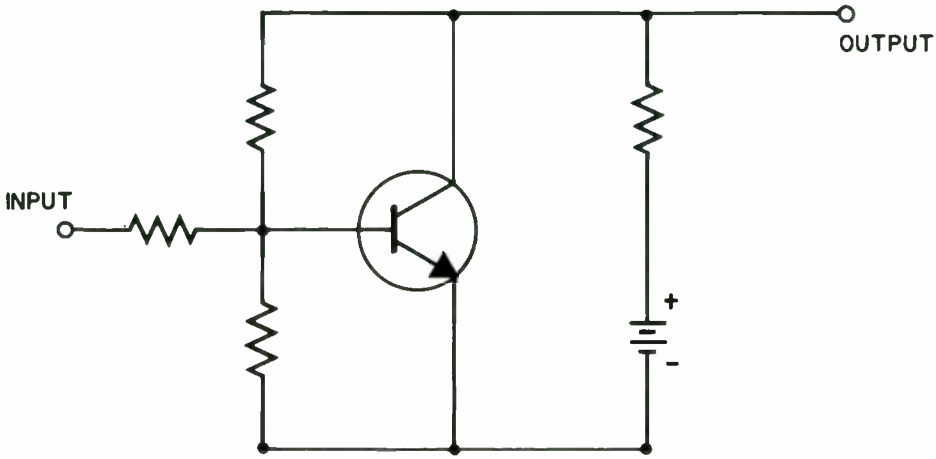


Figure 6 — Basic common emitter amplifier.

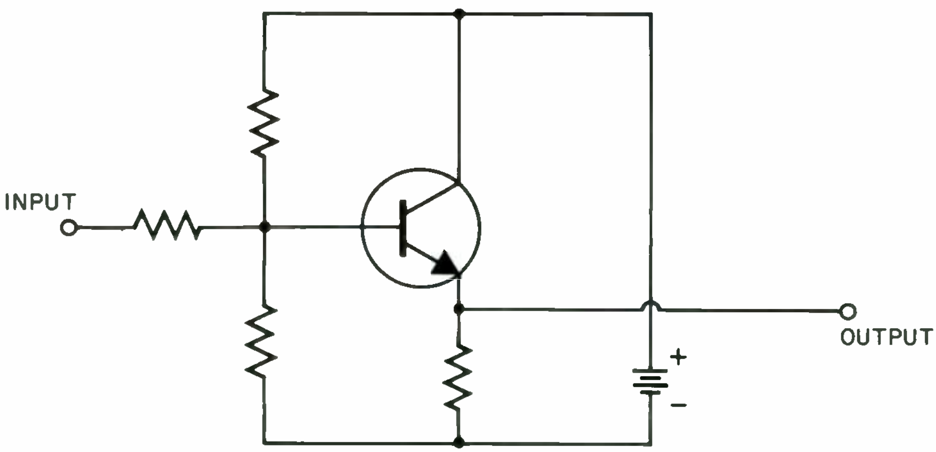


Figure 7 — Basic common collector amplifier.

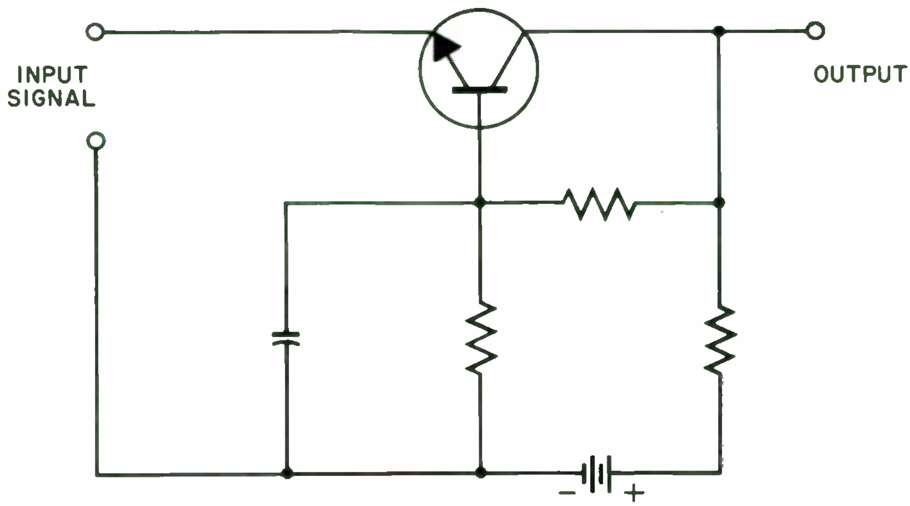


Figure 8 — Basic common base amplifier.

Common collector amplifiers are used when maximum electrical isolation is needed between the signal source and the output of the amplifier. They offer high input impedances requiring very little signal current. Consequently, the current gain of common collector amplifiers is high. Their voltage gain, however, is always less than unity.

A common base amplifier has the highest voltage gain of all configurations. Its current gain and input impedance though are both low. The low input impedance permits the device to work from a low impedance signal source to produce a large amount of output signal voltage.

APPLICATIONS AND REPLACEMENT

Specific types of transistors are designed and sold to perform certain functions. These functions are noted in all good transistor manuals and transistors are referenced according to recommended usage. A sample chart is shown in Figure 9.

The first consideration when substituting transistors is polarity. An NPN device must always be replaced with another appropriate NPN device. A PNP transistor likewise, must be replaced by a similar PNP transistor. Never substitute a PNP for NPN or an NPN for a PNP; they won't work.

There are several characteristics that must be considered with equal importance. These are:

- Style and size
- Recommended purpose
- Voltage, current, and power
- Gain factors
- Frequency capabilities
- Temperature rating
- Silicon versus germanium devices

The style and size of a replacement transistor must be quite similar to the old one. The more alike the two are the easier it is to install the new one.

TRANSISTOR TYPE	SPECIONS	RECOMMENDED USE
2N1086 2N1086A		Mixer/Oscillator AM Broadcast Receivers
2N1414		Audio Amplifier & Audio Driver
2N3855 2N3855A		RF — IF Amplifier FM, FM-AM, TV
2N4398 2N4398A		High Power Audio Output

Figure 9 — Sample list showing recommended use column.

Replacement transistors must be from the same basic family. If the defective one is a TV IF amplifier, then the replacement should be recommended for TV IF amplifier applications. You certainly wouldn't use an audio transistor to replace a high frequency type.

Substitute transistors must have equal or better voltage, current, and power ratings. A transistor rated at 25 volts maximum collector-emitter voltage cannot be used to replace one rated at 40 volts. Neither can a transistor rated at 300-ma maximum collector current be replaced by one with a maximum collector current rating of 120 ma. The reverse of this, however, may be permissable when other characteristics are similar.

Current gain (HFe) or Beta is an important consideration when substituting transistors. Always select a replacement from the same beta range. Thus, if the old transistor has a minimum beta of 80, the replacement should have a gain figure close to this value. Substituting one with a lower beta will result in less gain and possible distortion due to the difference in bias stabilization requirements. A transistor with a high beta figure might give more gain, but again its parameters may be upset because of a difference in required stabilization current. The higher beta units might also produce oscillation, chirps, or squeals.

The frequency specifications for a replacement type must be equal or greater than those of the one being replaced and they must be stated in the same measurement terms. If the upper frequency limit is listed as gain bandwidth product (ω_T or F_T) for one it must be listed likewise for the other. If the frequency is specified as the alpha cut off frequency (F_{HFB}) for one transistor the same units must be compared when selecting a replacement.

The standard method of specifying operating temperature for solid state devices is junction temperature (T_J). This is the maximum temperature permitted at the junctions within the device. A unit with a T_J rating of

85°C must be replaced by one having a similar rating; equal or better.

Improved versions of many early transistor types were developed having better characteristics. One of the important advancements made was improved temperature capability. Rather than assigning new type numbers for these improved versions they were identified by an A, B, or C following the original type number. For example:

2N404 has T_J = 85°C
2N404A has T_J = 100°C

Other improvements may be included besides, or in addition to, better temperature characteristics.

Early transistors were made from germanium which has a relatively low melting point. Their use was limited to lower temperature environments to prevent destruction of the transistors themselves.

Silicon has gradually replaced germanium units in solid state products. Silicon can operate at double the temperatures permitted for germanium devices. The upper limit of T_J for silicon is 200°C whereas germanium devices are limited to 100°C or the boiling point of water. The actual temperature of the air surrounding a transistor must be kept much lower than the maximum permitted at the junction. How much lower depends upon its case design, whether or not it contains or is mounted to a heat sink, and how much power it is handling.

In general, you will not need to compare specifications when substituting transistors. Your electronic supply house will recommend a suitable replacement if the original type is unavailable. We suggest that you purchase a good substitution manual and keep it handy. These can be bought from your electronic supply house or wherever technical publications are sold. The Howard Sams Publishing Co. supplies a complete line of service literature including PHOTOFACT packages for servicing. PHOTOFACT packages supply detailed service information relative to nearly any home electronic product sold, including imported as well as domestic units.

When substituting transistors it is seldom advisable to replace a germanium unit with a silicon unit; or conversely. There are distinct differences between the two kinds of devices that generally prohibit interchanging them. There are exceptions, however, and your supplier can advise you about these exceptions.

HEAT SINKS

The term *heat sinks* refers to any material or tool that conducts heat away from a transistor; or any device that prevents heat from reaching and damaging the junctions of a transistor.

Functional heat sinks identify either a separate heat radiating attachment to a transistor; or a radiating metal surface to which a transistor is attached.

Figure 10A shows a *top hat* heat sink for use on small transistors. It is designed to fit snugly over the transistor's case and contains fins that radiate heat into the surrounding air.

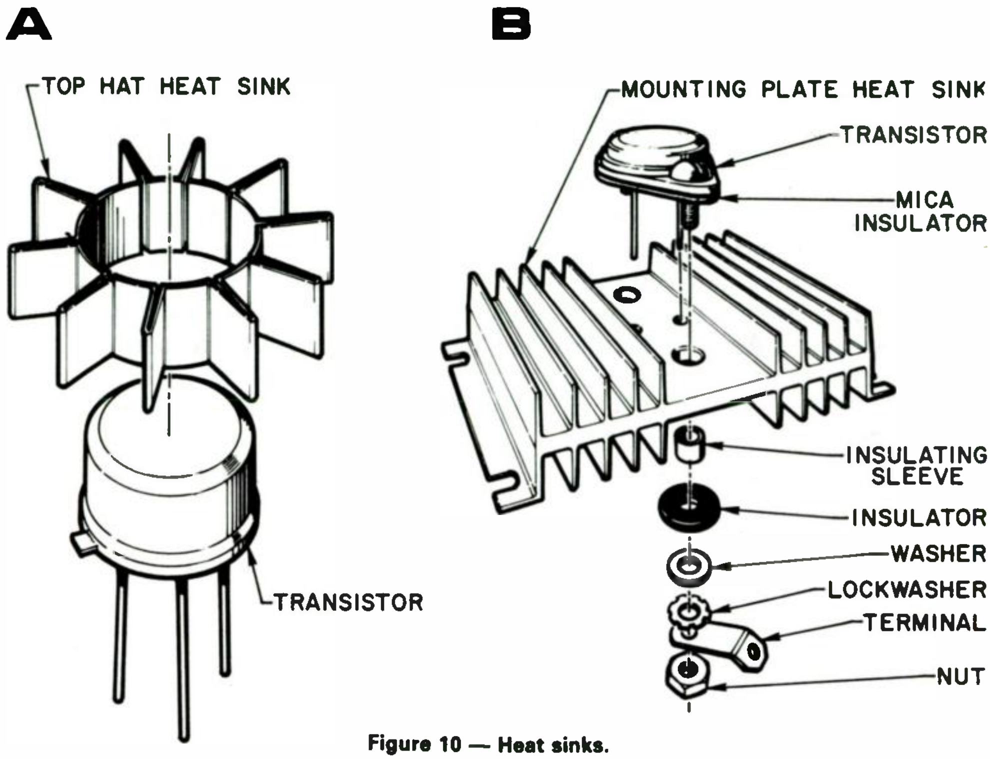


Figure 10 — Heat sinks.

Figure 10B shows a larger style heat sink to which a transistor is attached. It is the kind generally used with large power transistors.

The term heat sink also applies to tools that protect a transistor while it is being soldered into circuitry. Special clip-on units are available, but alligator clips and long nosed pliers can be used effectively. Protective heat sinks are attached temporarily to the leads being soldered, between the transistor and the point to which heat is being applied. The mass of the sink absorbs heat and prevents it from reaching the transistor.

TESTING TRANSISTORS

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

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

When you are checking measured voltages against those on a schematic be sure the battery or the power supply is the same voltage as that indicated on the schematic. If it is different, you will not be able to depend on the other values being correct.

DC power supplies are available for testing units that require a low DC voltage. Be sure that the power supply is connected in the correct polarity. If it is reversed, it is possible to damage components in the receiver.

ALWAYS turn the power supply down before you connect it to the circuit to be checked. After it is connected, slowly turn up the voltage and observe the current meter. If the current is normal, turn the voltage up to the value indicated on the schematic. If the current is excessive, reduce the voltage until less than half of the normal current is indicated and then proceed to check for the trouble.

Checking the Transistor Amplifier

The common-emitter configuration is used for nearly all transistor circuits. The voltage at the base will be just slightly different from the voltage at the emitter, but may be plus or minus in relation to the base. Figure 11 shows two IF stages from a receiver, one PNP and one NPN. The collector of Q2 measures zero volts, and the collector of Q3 measures 5.1 volts. Without a schematic of this receiver, the technician might be misled by this condition, since transistors used as IF amplifiers are usually of similar conduction types.

A check of the base and emitter voltages in this receiver will reveal that the potential is less at the base of Q2 than at the emitter, and the potential is higher at the base of Q3 than at the emitter. Both biases are correct.

Collector current can be measured by checking the voltage drop across a known resistance in the emitter or collector circuit. For example, resistor R3 in the emitter of Q2 in Figure 11 is 150 ohms, and the voltage drop across R3 is 5.1 minus 4.8 or 0.3 volt. The current equals E/R, or .3/150, or 2 milliamperes. The current for transistor Q3 can be calculated by using resistor R6 in the emitter lead or a resistor such as R7 in the collector if the circuit contains one.

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

Improper transistor bias will produce an improper current in the emitter or collector circuit. The bias for transistor Q3 in Figure 11 is determined by R4 and R5. These resistors will seldom be off value

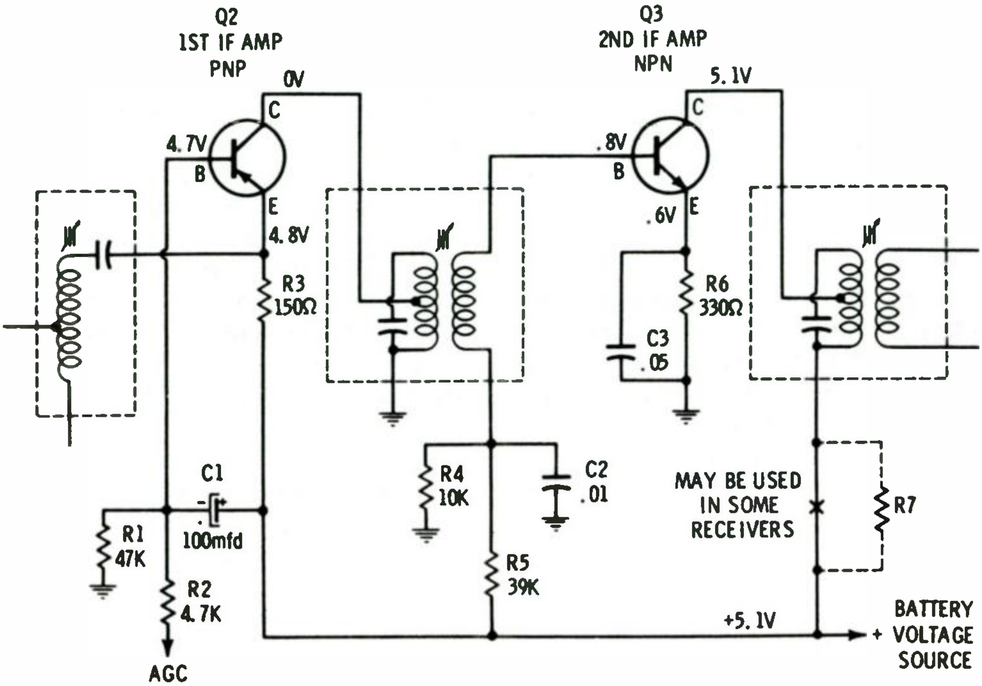


Figure 11—IF amplifiers using both PNP and NPN transistors.

because they carry very small currents; but when the bias is wrong, they should be checked.

An example of a circuit that will add confusion to the service problem is shown in Figure 12. This audio driver and output circuit contains both conduction types, PNP and NPN, and both germanium and silicon types of transistor.

The bias at the base-to-emitter junction is indicated for both types. The driver (Q4) is a germanium transistor that is biased at approximately 0.2 volt. The output stage (Q5) is a silicon transistor that is biased at approximately 0.6 volt. The polarity of the bias is marked at the arrows on Figure 12. The bias on a normally-operating Class-A stage will indicate the conduction (PNP or NPN) type by the voltage polarity and the transistor material (silicon or germanium) is indicated by the value of the bias voltage.

Notice in this amplifier that the output transistor is biased from the collector of the driver and the bias for the driver is controlled by the voltage existing at the emitter of the output stage. This is a negative-feedback arrangement in which the bias and transistor conduction tend to stabilize each other.

Testing Transistor Current Gain

The transistor must be able to control the current in the emitter and collector circuits. Current control can be checked without removing the transistor from the circuit. Before any suspected component is removed from

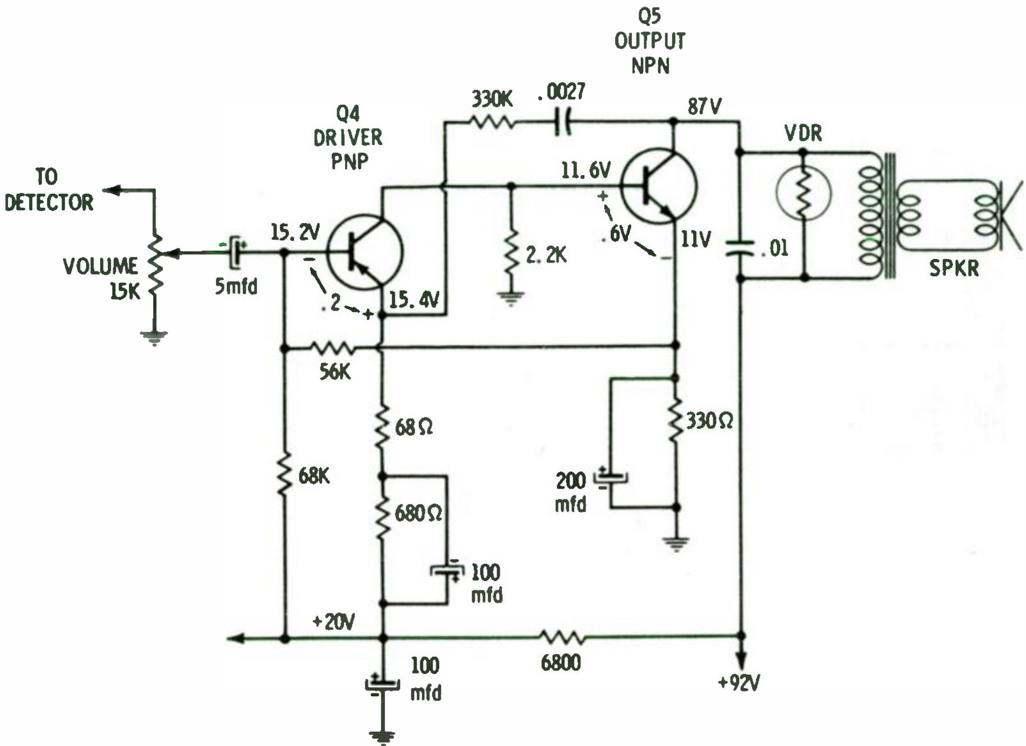


Figure 12 — Audio amplifier that contains both silicon and germanium transistors.

the circuit, the current-gain tests should be performed. These tests are applicable to any transistor amplifier, whether in the oscillator, converter, IF, or audio circuits. The collector current should cut off when the base and emitter are shorted and a transistor should exhibit either increased or decreased conduction depending on the bias change.

Test I Locate a resistor in the emitter or collector circuit. In Figure 11, resistor R6 can be used. The reading of 0.6 volt is due to the current in transistor Q3. Short the base to the emitter. This will cut off the transistor and reduce the voltage across R6 to practically zero. A transistor that cannot be cut off is defective and should be replaced. A small voltage across the emitter resistor will be produced by the bias current. In the event a collector resistor such as R7 in Figure 11 is used, the small voltage will usually be due to leakage currents. If the leakage current is excessive, the transistor should be removed and checked outside the circuit.

Test II An additional test is to parallel one of the bias resistors with one of equal or nearly equal value. An example would be placing a 39K resistor in parallel with resistor R5 in Figure 11. This would about double the emitter current, and the voltage

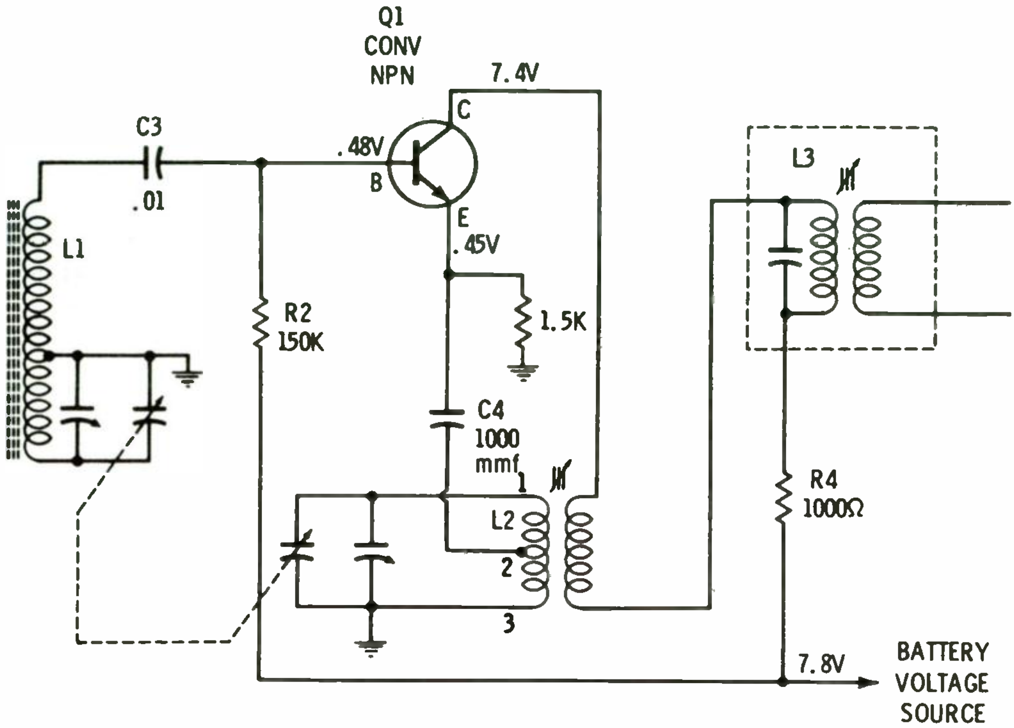


Figure 13 — A typical oscillator circuit in a broadcast receiver.

across R6 should increase to approximately 1 volt.

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

Checking Oscillators

The oscillator section of a receiver is shown in Figure 13. The collector current in transistor Q1 is approximately 0.3 ma. This is calculated by dividing the 0.45-volt drop across resistor R4 by 1,500.

When an oscillator is not operating, collector current will increase to about twice the operating value. In the circuit in Figure 13, the collector current will rise to nearly 0.8 ma, and this will cause the voltage at the emitter to rise to about 1 volt.

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

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

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

Checking Class-A Audio Amplifiers

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

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

The most accurate test for Class-A operation is made with use of an oscilloscope and an audio-signal generator. The scope will show clipping of the positive or negative swings before the normal output is reached. Knowing the polarity that is clipped also indicates whether the bias is too high or too low.

Checking Push-Pull Output

The push-pull output stage usually is biased near cutoff, and current drain increases when a signal is applied. A milliammeter in series with the supply will indicate how the stage is operating. Excessive current in either or both transistors will be indicated by a high meter reading.

The individual currents can be checked by measuring the voltage across each emitter resistor. When the emitter resistor is common to both units and one transistor is suspected of being defective, one emitter lead can be opened and another resistor of the same value placed in that lead (Fig. 14). The original emitter resistor R1 is not touched. The emitter lead of transistor Q1 is opened, and resistor R2 is temporarily clipped or tack soldered between the emitter terminal and ground. The current balance between the two transistors can now be checked both with and without a signal being applied to the arrangement.

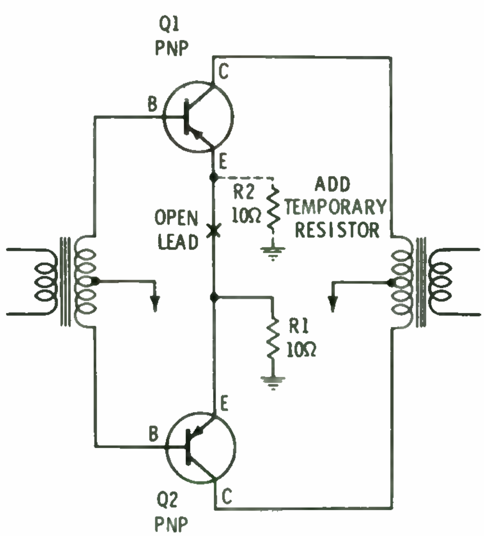


Figure 14 — An arrangement for checking the current balance in a push-pull output circuit.

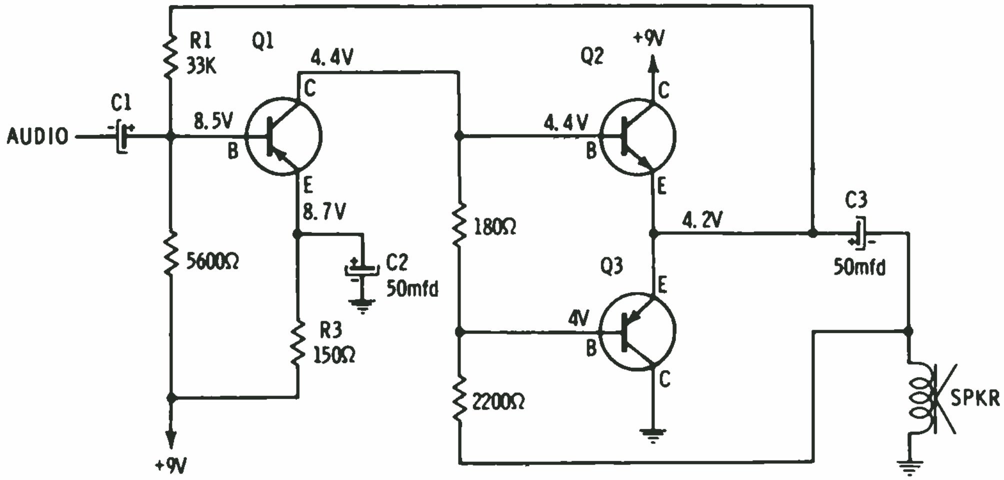


Figure 15 — A complementary push-pull amplifier.

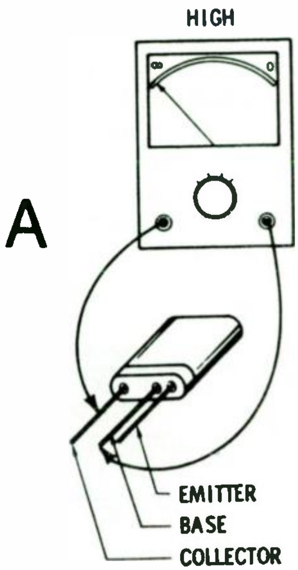
A transformerless output circuit (Fig. 15) can be checked by using a voltmeter. As a general rule, this type of circuit is quite stable due to the feedback through R1 to the base of transistor Q1. The conduction of transistor Q1 determines the bias of the output transistors. The voltage at the emitters of Q2 and Q3 should be approximately one-half of the nine volt supply. A defective component will cause this voltage to change and result in distortion at increased volume levels.

Out-Of-Circuit Tests

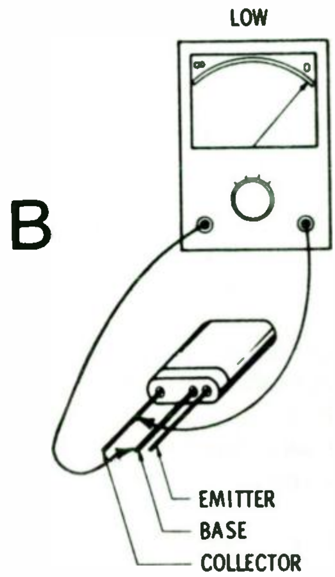
A rapid check of a transistor can be made with an ohmmeter. Such a procedure is shown in Figure 16. Be sure the battery voltage in the meter does not exceed the voltage rating of the transistor. Also be sure not to use the low meter scales for the low-power transistor. On the high meter scales, the current between the probes is limited by high internal resistances; but on the low scales, the current can become quite high and overheat the transistor junction. If you are unsure about your ohmmeter, connect the probes to a milliammeter and check the current on each ohms scale. Also check the voltage at the probe tips for each of the ohms scale.

Start each test by setting the ohmmeter on the highest scale, then reduce it to the scale that produces an appropriate reading. The X10,000 and X100,000 scales on most meters are usually safe for checking low-power transistors. The X10 and X100 scales are usually correct for the high-power transistors.

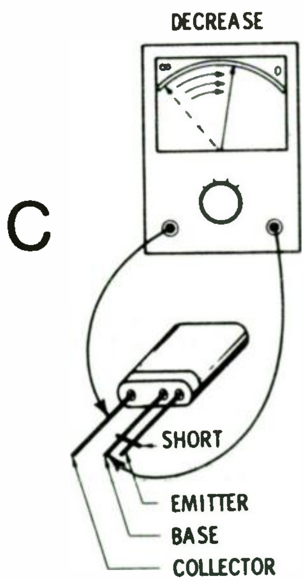
Set the ohmmeter to the highest range, and connect the leads to the base and the collector terminals (Fig. 16A). Reverse the connections and note the direction that provides the highest reading (Fig. 16B). This is the reverse-bias direction. Connect the leads in this direction, observe the meter reading, and short the emitter and base terminals together as shown



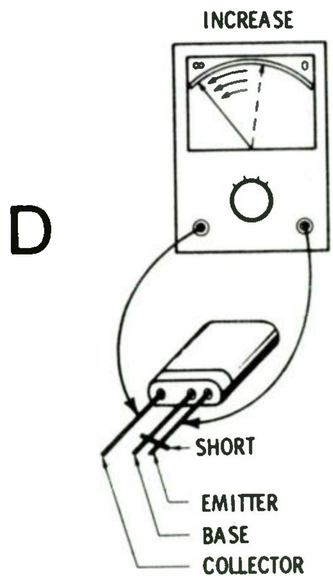
A - Resistance measured between collector and base.



B - Same resistance measurement as in (A), but with ohmmeter leads reversed.



C - Resistance measured between collector and base, with a short placed between base and emitter.



D - Resistance measured between collector and emitter, with a short placed between base and emitter.

Figure 16 — Procedure for checking a transistor with an ohmmeter.

in Figure 16C. The resistance reading should decrease.

Remove the ohmmeter lead from the base terminal and connect it to the emitter terminal. Observe the resistance reading, then short the base to the emitter (Fig. 16D). The resistance should increase.

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

> Caution — There are a number of transistors that have emitter-to-base breakdown voltages (V_{EB}) that range as low as 0.5 volts. These are usually high frequency units used in applications such as television tuners and RF stages in FM and communications equipment. These types can be easily damaged by the voltage from an ohmmeter.

A number of transistor testers are available on the market. Some of these give a value reading; others give only a good-bad indication. Transistor testers are available either as separate units or combined with other test instruments, such as tube testers. For most receiver repairs, a good-bad indication is all that is required. The most positive test, however, is direct substitution of the questionable transistor.

Substitution

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

Don't be hasty, however, when
10 using the substitution technique. Be sure that there is not another fault, elsewhere in the circuitry, that has caused the transistor to fail. If something blew the old one it will also blow the new one.

Once you have located and corrected the original fault, or determined that another fault does not exist, then you can safely substitute a new transistor. If this appears to solve the problem, allow the unit to operate for a period of time to be sure the set is fixed. After any repair, this is a wise practice to follow.

SUMMARY

Before installing replacement transistors observe that:

1. the replacement is of correct polarity (NPN or PNP).
2. the replacement transistor is of the same basic style and size (TO number).
3. the leads are inserted correctly. Reversing the leads can cause permanent damage to the new transistor.
4. the characteristics of the new transistor are compatible with the old transistor. Direct, same type replacements are preferred when available.

5. the proper low heat range soldering iron is used for soldered-in transistors.

Use care when removing transistors that are soldered into circuitry. If you make a mess of the wiring or printed circuitry the repair will be much more difficult and time consuming. The accepted way to remove a transistor is to apply the soldering iron momentarily to each joint and quickly draw off the molten solder with a solder sucker. Once the solder is removed from all the leads the transistor can be simply lifted out.

When soldering in a new transistor always use a suitable heat sink on each lead on the transistor side of the joint. The most simple method is to grasp this lead with a pair of long nosed pliers. Hold the lead with the pliers until the joint has cooled. An alligator clip can be snapped onto the lead as an alternate method prior to soldering; or you may wish to use commercially available solder sinks.

Install the new transistor in the precise location and with the same hardware as the old one. If the metal case of a transistor is attached to one of the leads the case must be isolated from other components. Also, if a heat sink was used it must be reinstalled.

Transistors are not difficult to work with if care is exercised. If not, repairs can become very complicated.

TEST

Lesson Number 49

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-049-1.

1. Most transistor failures are due to:

2 A. structural defects from manufacturing.
B. damage of contaminants entering through broken seals due to shock or mishandling.
C. shorted or open junctions due to excessive voltage.
D. all of the above.

2. Diodes are generally identified on a schematic as either

A. D or CR.
3 B. D or TR.
C. Q or TR.
D. Q or D.

3. Transistors are most often identified on a schematic as either

A. D or CR.
B. D or TR.
3 C. Q or TR.
D. Q or D.

4. The size and physical shape of transistors is shown in______charts.

A. DO
3 B. DQ
C. TO
D. CR

5. The characteristics stated in specification listings tell

A. what a device looks like.
5 B. what a device does or can do.
C. a device's minimum voltage, current, and power ratings.
D. what a device's case is made from.

6. Transistors are used in three basic circuit configurations:

A. common base, common collector, common plate
B. common base, common anode, common emitter
7 C. common base, common collector, common emitter
D. common grid, common collector, common emitter

7. The most often used transistor configuration is a

A. common base.
B. common collector.
7 C. grounded base.
D. common emitter.

8. An NPN transistor _________ be substituted for a PNP.

A. can always
9 B. must not
C. can sometimes
D. can seldom

9. The purpose of a heat sink is to keep a transistor

A. hot.
11 B. cool.
C. soldered.
D. dry.

10. When using the substitution method of checking a suspected transistor, the substitute transistor should be installed

20 A. as soon as you suspect a problem.
B. only after the rest of the circuitry has been thoroughly checked.
C. with the power to the unit turned on.
D. with a large, hot, soldering iron.

Notes

Notes

Portions of this lesson from
ABC's of Transistors
by George B. Mann.
Courtesy of Howard W. Sams, Inc.

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

EAGERNESS

Starting in a new field always arouses one's interest and enthusiasm. While the subject is new, the field has appeal and interest which creates enthusiasm.

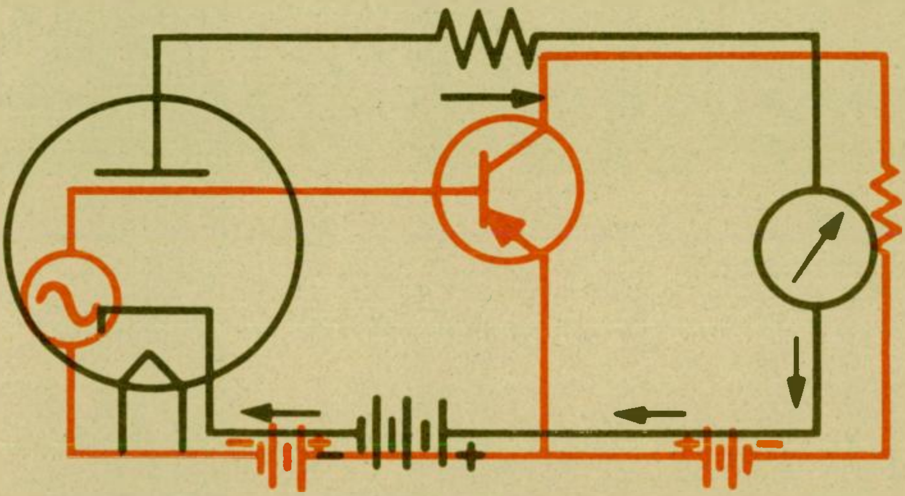
While beginnings are important, it is the "long haul" that determines whether or not the end will be successful. It takes follow-through to accomplish anything worthwhile.

The first few lessons and the last few lessons are easy to study. Enthusiasm alone can carry you through. But how you study the lessons in between is what really counts. Enthusiasm must be backed up by determination and perserverance. All must be studied carefully, thoroughly, and continually. Tackle them one at a time—master each lesson—and then go on to the next. This is the time when STEADY progress toward your goal will give you beneficial results.

S. T. Christensen

LESSON NO. 50

CONNECTING THE COMPONENTS



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-050

407

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

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CONTENTS

CONNECTING THE COMPONENTS

INTRODUCTION

Troubleshooting electronic equipment is a fascinating job for most technicians. To become proficient at troubleshooting, you must know something about the unit's operation, its components, its power supply and its circuit voltages. You must also understand your test equipment and know how to use service literature and drawings. The more you know about all of these, the faster you can locate the trouble and the less time you will waste on wrong hunches. Troubleshooting procedures should be organized so that you can eliminate all the components and wiring that cannot be the cause of the trouble. You can then proceed with the probable causes. In addition, you should check the probable causes in logical order, beginning with the most likely causes, leaving the least likely until last.

For example, suppose that a pilot light is out. In proceeding to find out why it is out, mentally outline the steps that you will follow. Of course, you should first check the bulb to see if it is burned out. If it is not burned out, think of the next most logical reason for its not burning. If another pilot light in the set is burning, you must then assume that there is some trouble in the circuit leading to this light. This trouble can be found in one of several ways: You can use a voltmeter and check for voltage back along the circuit; you could also use an ohmmeter to check for continuity. In either case, you would eventually need to replace a component or make a physical correction in the circuitry.

The next step after locating a defective component is selecting or obtaining a suitable replacement. This should be done prior to removing the old component. By having the new component ready to install as soon as the defective one is removed, there is less chance of miswiring the new part.

In this lesson we will discuss removal of old components as well as installation of new ones. Certain precautions and safeguards will be pointed out which will prevent damage to circuitry, wiring and parts. The object of this lesson is to alert you to the importance of practicing professional repair techniques.

IDENTIFYING AND LOCATING COMPONENTS

An important step in isolating problems to stages or parts is being able to identify and locate components. The identification of components can be a problem until you gain experience. Certain capacitors, resistors, and diodes may have similarities in their basic appearance. It is often difficult to tell them apart (Fig. 1). One certain way to distinguish one from another is by noting their location in a circuit.

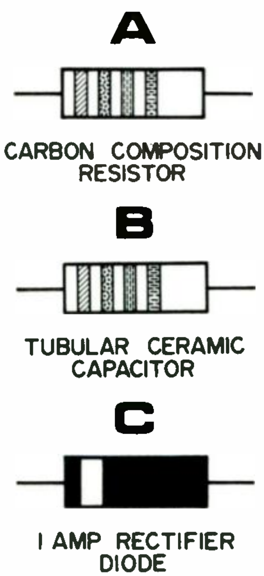


Figure 1 - Similarities exist between certain resistors, capacitors, and diodes.

If you have professional service literature for the specific unit being serviced, component location and identification become less of a chore. The Howard W. Sams Co. publishes excellent service literature under the title PHOTOFACT publications. These are available in convenient packages at nearly all electronic parts houses. Binders and file drawers are also available for storage of this material.

Each package contains complete service literature on several radios, phonos, tape recorders, and TVs. The information for each specific unit is detailed and contains schematics, parts lists, component layout pictorials, service adjustment locations, alignment instructions and any additional information necessary for troubleshooting. Practically all TV-Radio service shops rely on PHOTOFACT publications for information.

After determining the symptoms, another early step in troubleshooting is studying a schematic drawing with the pictorial (component location) guide. Once you have determined that the defect is in a specific stage, you must next determine which component is at fault. To do so often requires testing several components within the stage. Each component to be tested should be located on the schematic drawing and then evaluated for its possible fault. If it appears that a specific component can cause the defect, it is first located on the pictorial drawing and then in the circuit. (Figures 2A and 2B are samples of a pictorial and schematic drawing.) Once a component is located, simple testing will usually determine if it is good or bad.

Electronic products are built from sections called stages. Each stage consists of selected components (resistors, capacitors, inductors, and/or diodes) grouped around one or more active devices

Schematic Diagram—Model NT600

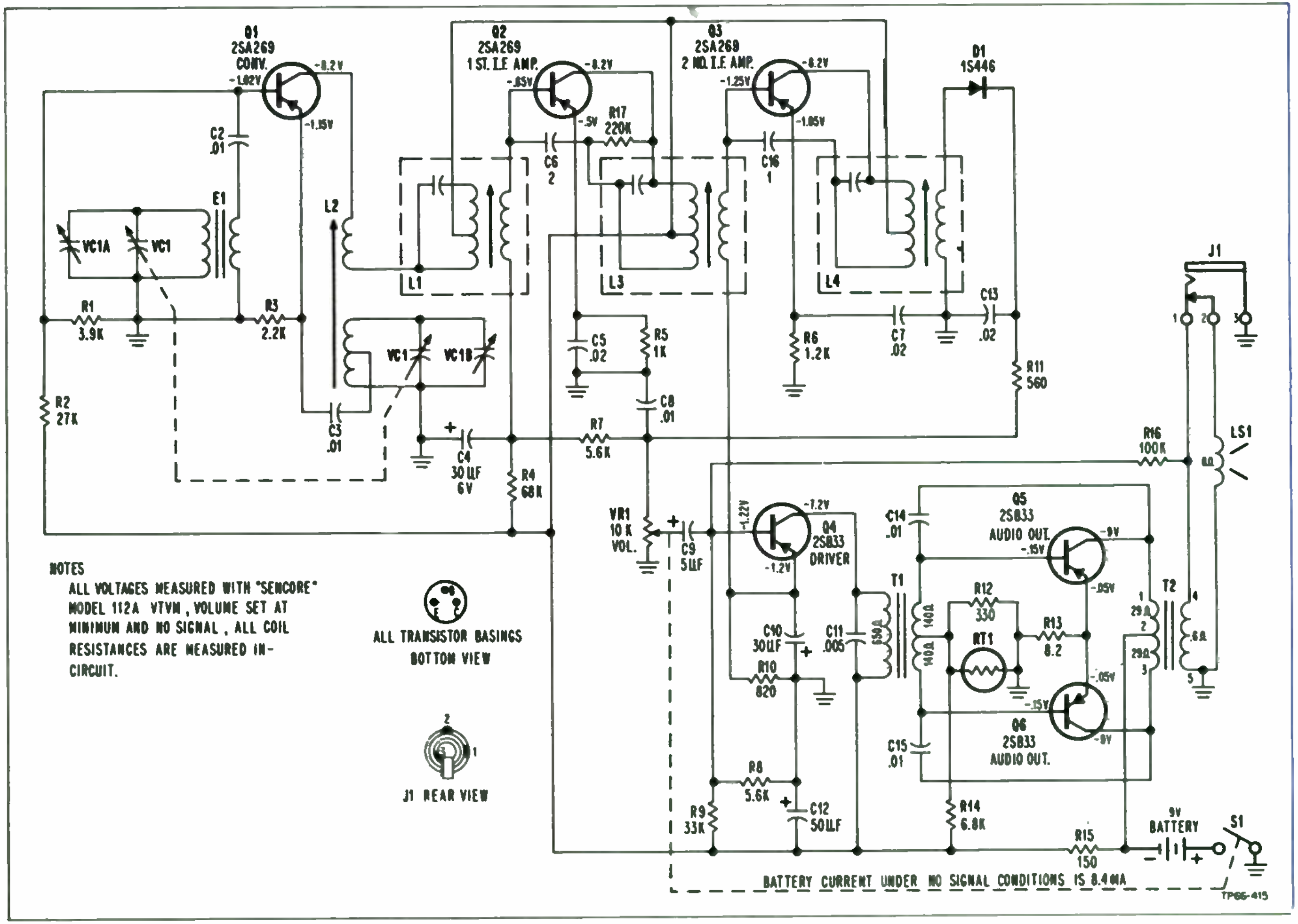
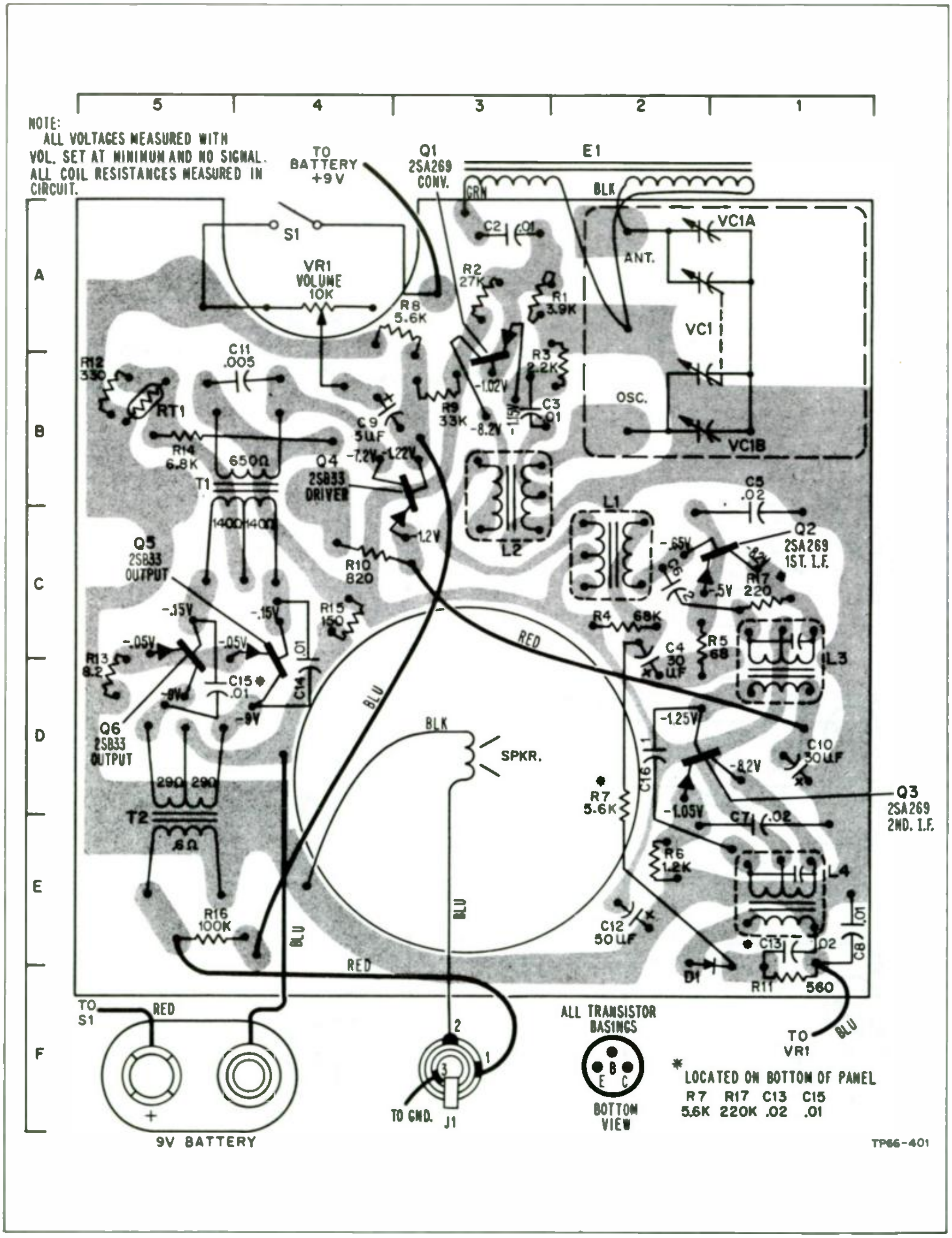


Figure 2A - Schematic service diagram. Courtesy of Philco-Ford.



Courtesy of Philco-Ford

Bottom View - Perma-Circuit Panel Component Layout - Model NT600

Figure 2B - Pictorial diagram.

8 (vacuum tubes, transistors, or other solid state amplifying devices). All the components in a stage work together to act upon the signals received at the input. After the signals are processed, they are passed on to succeeding stages.

In general, the nonactive (passive) components only support the actions of the active device. Thus, resistors may supply bias currents to a transistor and establish its operating point, while a capacitor may be used to couple AC signals into or out of the stage. Capacitors may also be used in a bypassing function rather than a coupling function. Bypass capacitors shunt unwanted AC variations to ground or into the power supply's filter section and prevent them from entering and adversely affecting the operation of a stage.

Most passive components have at least one lead connected to a pin or lead of a tube or transistor in the stage. In cases where a component does not tie directly to the tube or transistor, it nearly always connects to a component that has a common junction with an element of the tube or transistor.

Therefore, it is a simple matter to locate a component in a stage even if you are using only a schematic drawing. First, you must locate on the schematic a pin or lead of the active device with which the component is associated. Next, find this lead or pin on the actual device in the circuit, and simply trace along the circuit leads or printed wiring until you identify the part. With a little practice you can become quite proficient in locating any desired component within a stage.

The illustrations in Figure 3 (A through L) show the schematic drawing of an amplifier and a drawing of the stage showing the actual components. Figure 3A references the bias voltage points and the location of input and output signal leads. The *emitter* (E), *base* (B), and *collector* (C) of the transistor are identified both on the schematic and in the actual circuitry. Succeeding illustrations of Figure 3 pinpoint the location of each component.

In Figure 3B, you see the location of transistor Q_1. It is very important that this component be identified first, since it is the focal point for all other components in the circuitry. After identifying Q_1 and locating its elements (C, B and E), you will be able to find any other part by referencing from the transistor element with which it is associated.

A shielded cable is used to route audio signals into the stage. (See Figure 3C.) The point at which it enters the circuitry can be located by referencing it indirectly to the base of Q_1. From the base of Q_1 we simply trace through capacitor C_1 to the capacitor's other lead where we see the attached shielded cable.

Capacitor C_1 (Fig. 3D) is relatively easy to identify in the circuitry. It is attached directly to the base of Q_1 or between the termination of the shielded cable at the input and the transistor. The inset (upper left Fig. 3D) shows the polarity mark of this electrolytic capacitor.

Resistors R_1, R_2, R_3, R_4 and potentiometer R_5 are easy to locate by referencing to their associated element or elements from the transistor as is capacitor C_4 (Fig. 3L). Thus:

> In Figure 3E, resistor R_1 can be found from its common junction with the base of Q_1.
>
> In Figure 3F, R_2 junctions with the emitter as does capacitor C_2 (Fig. 3G).
>
> Resistor R_3 (Fig. 3H) may be located relative to its junction with either the base or collector and verified by checking its position between these two transistor elements.
>
> Capacitor C_3 (Fig. 3I) is located by following circuit paths from the collector (C) of transistor Q_1, through R_5 to its junction with the center terminal of R_5.
>
> Resistors R_4 and R_5 (Figs. 3J & 3K) both form a junction with the collector as does capacitor C_4 in Figure 3L.

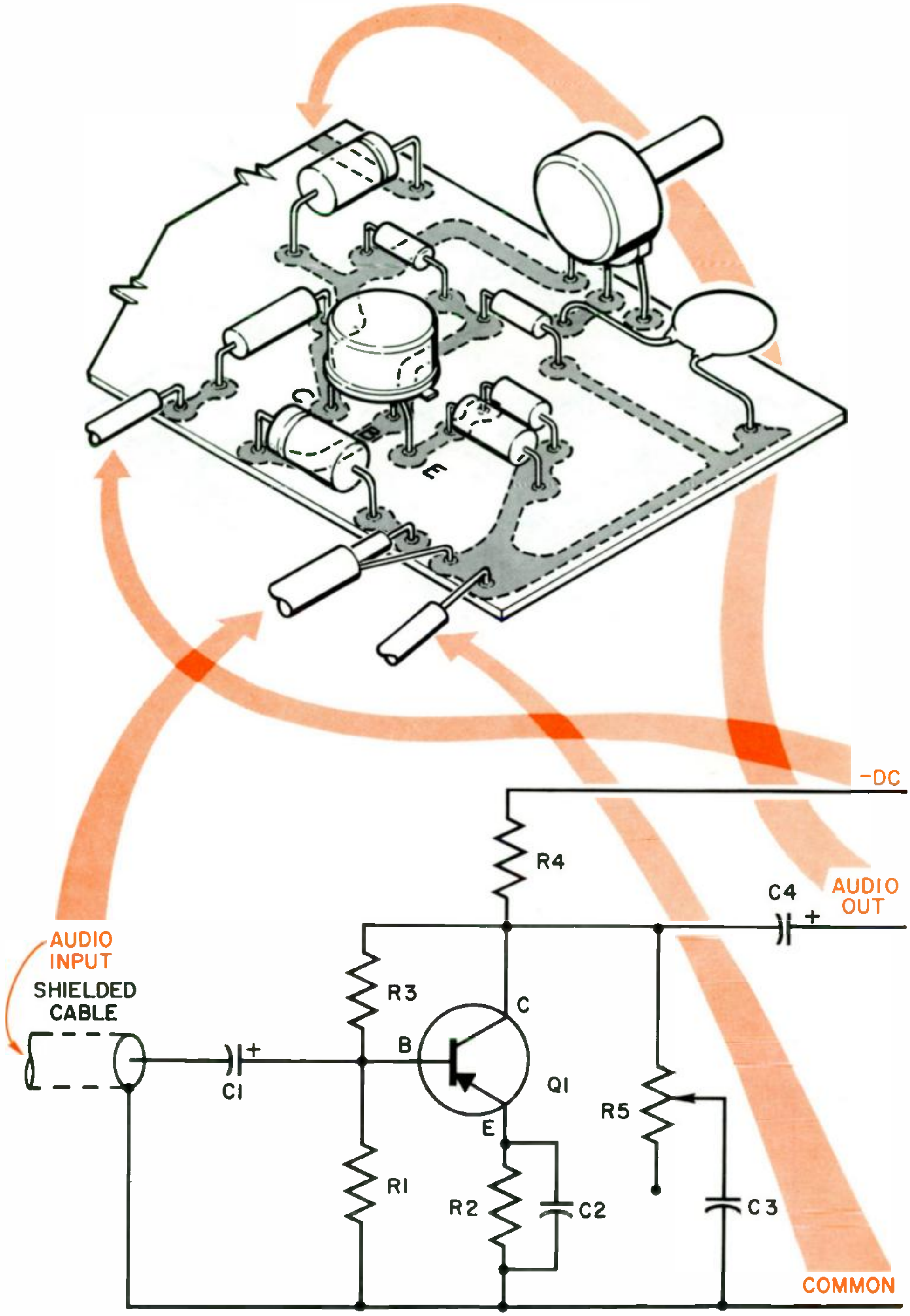
A professional electronic serviceman begins his troubleshooting
9 procedure by first locating the various stages and fixing their locations firmly in his mind. An experienced troubleshooter may need only a few seconds to do this. He then evaluates the symptoms and studies the service literature before any attempt is made to localize the problem. The few minutes spent evaluating possible causes of the problem and eliminating improbable causes can sometimes prevent wasted hours by establishing a logical starting point. The experienced troubleshooter then uses whatever method or methods he finds to be successful in quickly localizing problems and isolating bad parts.

REPLACING COMPONENTS

From time to time you will find it necessary to remove the excess solder from a lug. One method for doing this is shown in Figure 4. This illustration suggests that you place the heated lug in such a position that the solder will fall from it by the force of gravity. Use a small screwdriver to scrape the solder from the lug and from the holes in the lug.

To install a new component once the old one has been removed from a solder lug, use the method illustrated in Figure 5. Crimp the component lead securely before applying solder. Do not allow the lead to move while the solder is cooling or the result will be a poor connection.

For removing parts from printed wiring, the desoldering tool shown in Figure 6 is particularly useful. This is especially true of multilead components such as IC's and component packs.



COURTESY PHILCO-FORD

Figure 3A - Circuitry of an amplifier with its schematic drawing.

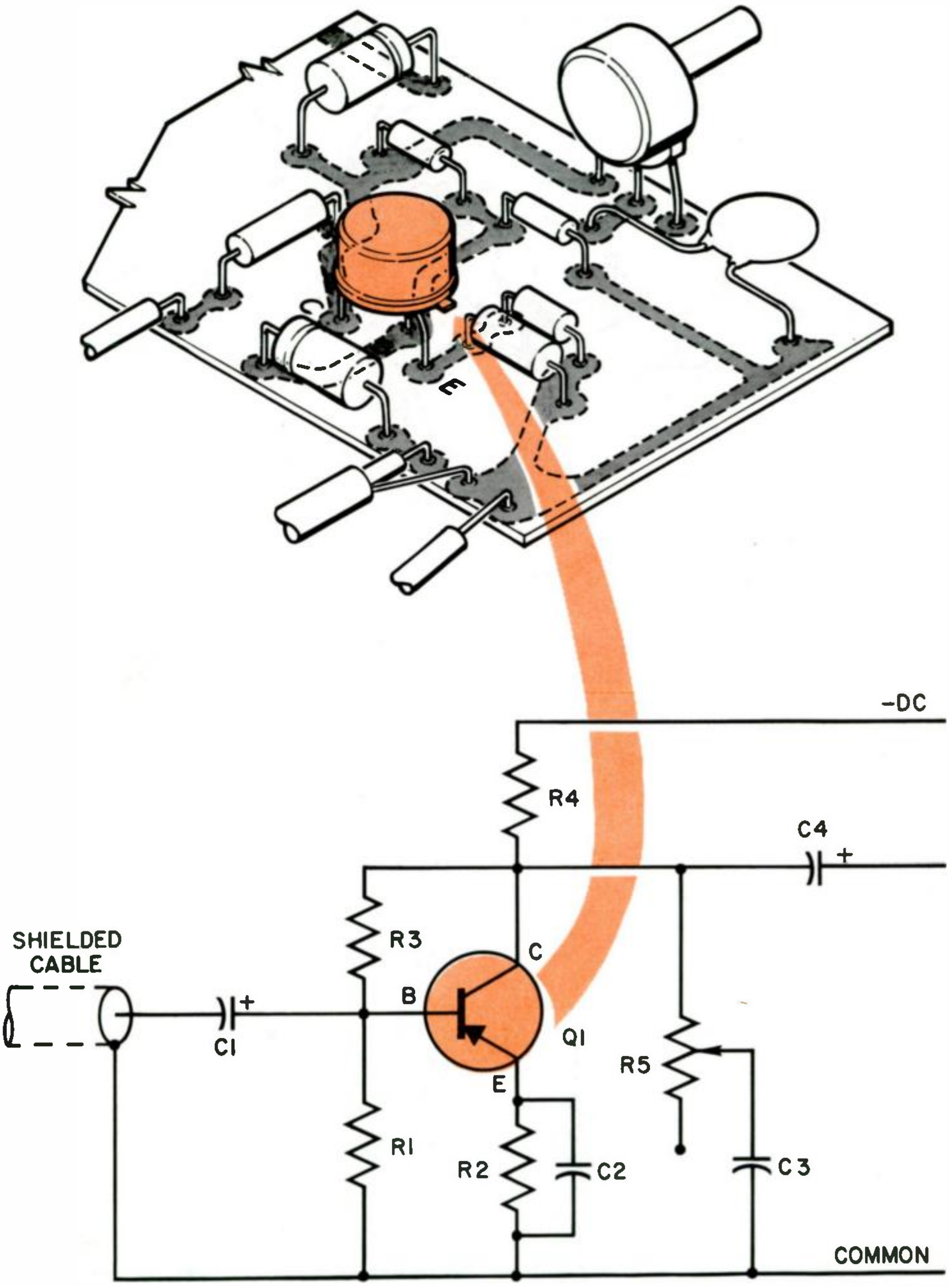


Figure 3B - Location of transistor Q1.

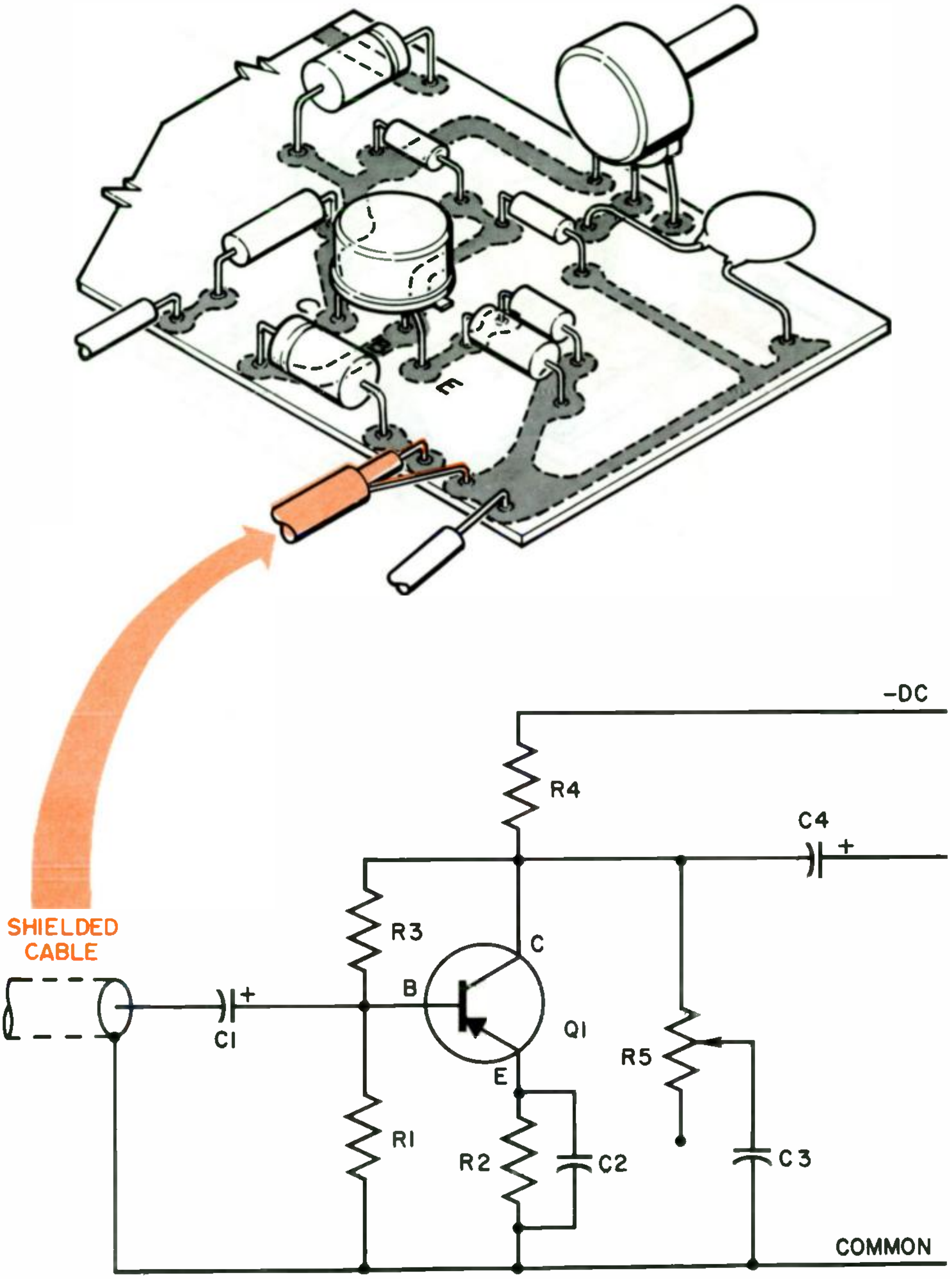


Figure 3C - Shield cable connection at input.

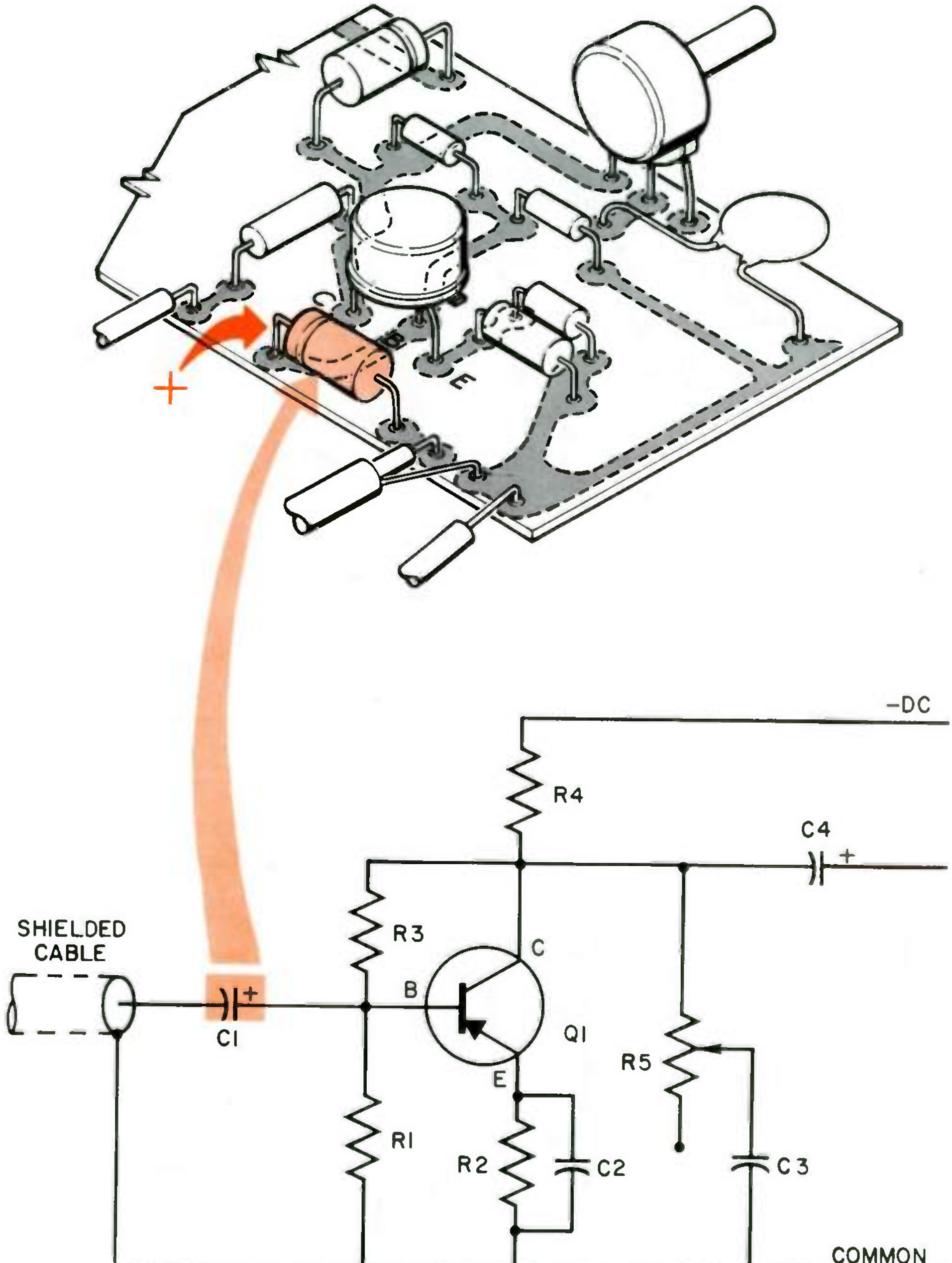


Figure 3D - Location of C1.

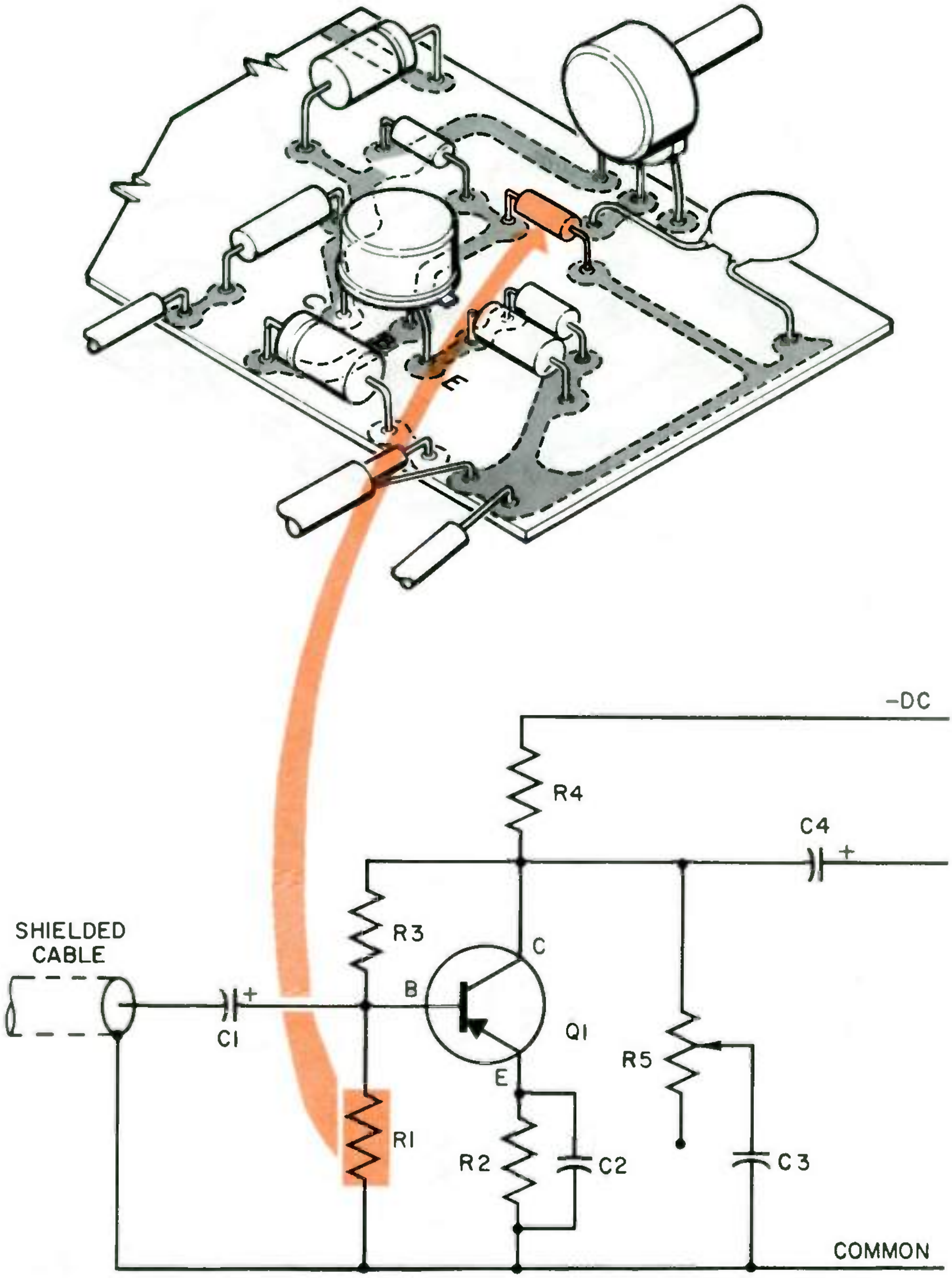


Figure 3E - Location of R1.

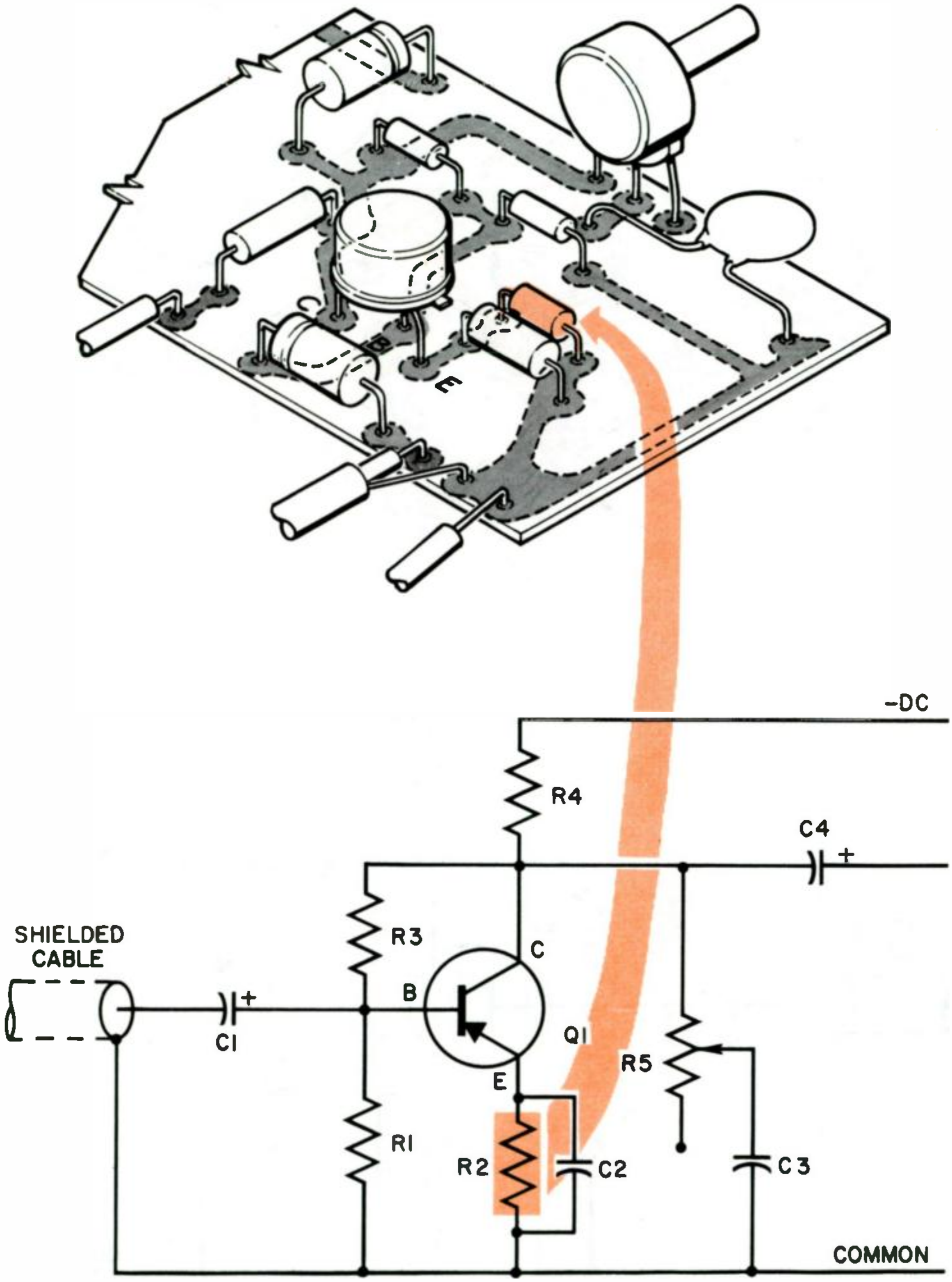


Figure 3F - Location of R2.

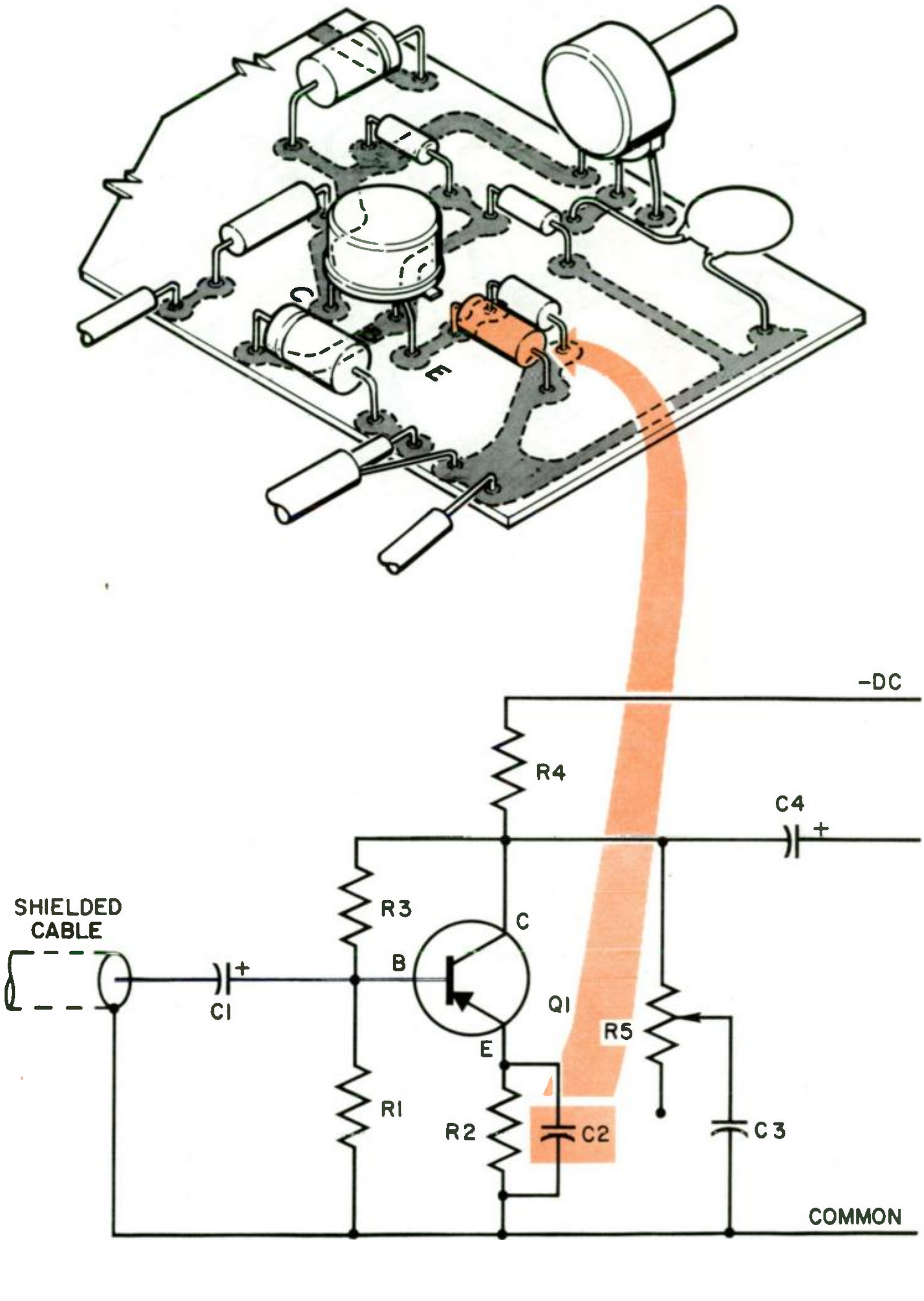


Figure 3G - Location of C2.

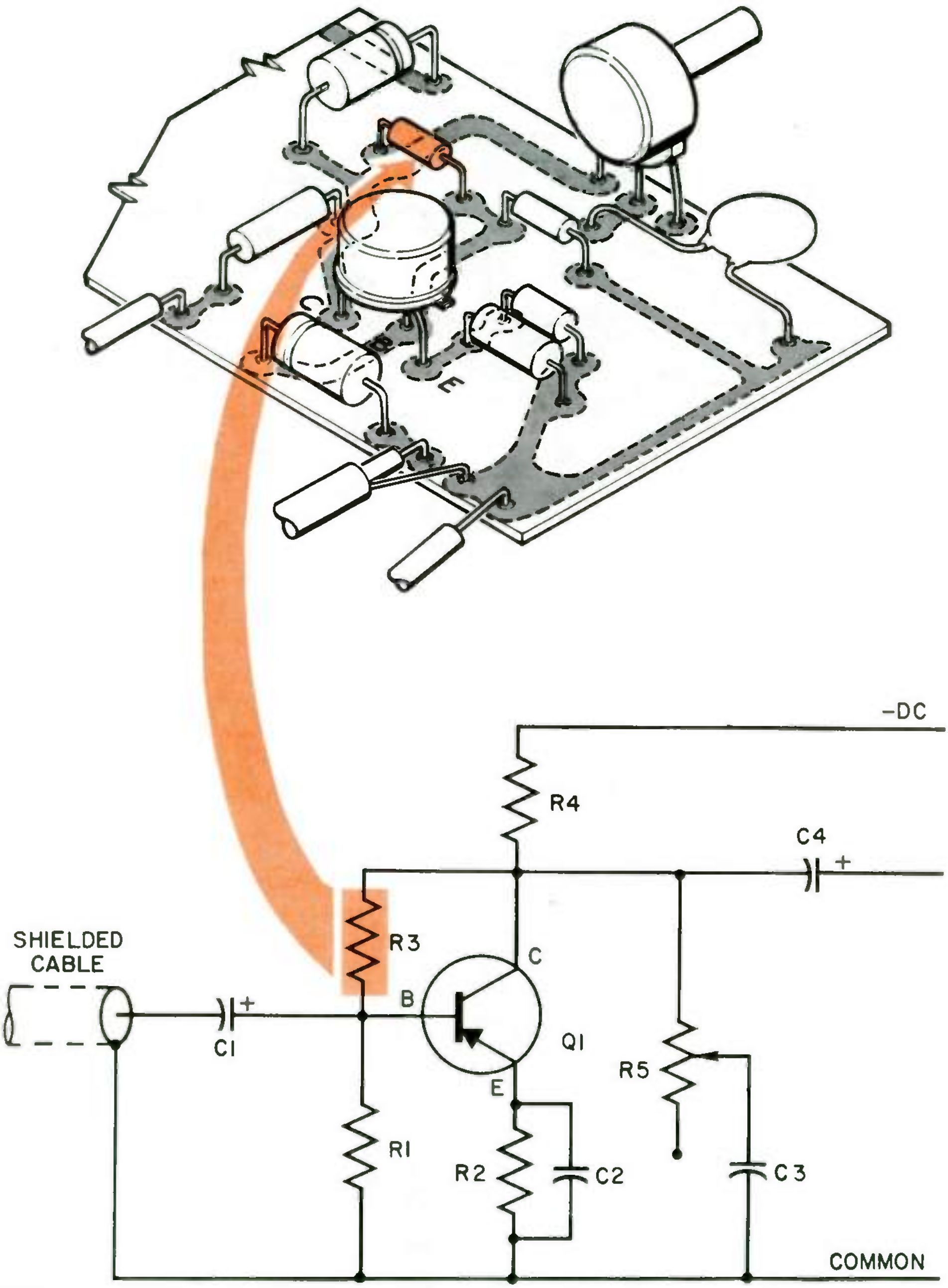


Figure 3H - Location of R3.

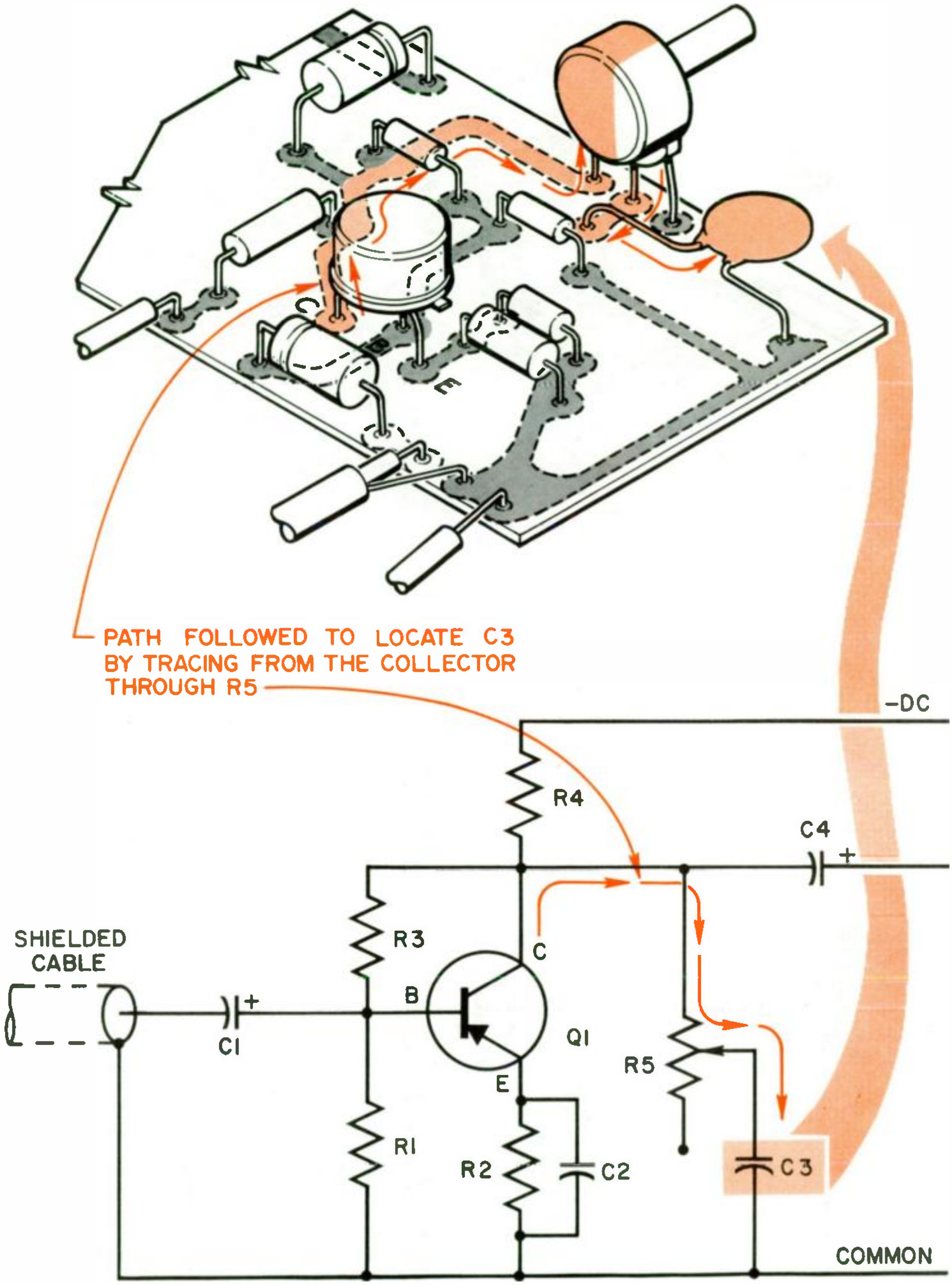


Figure 31 - Location of C3.

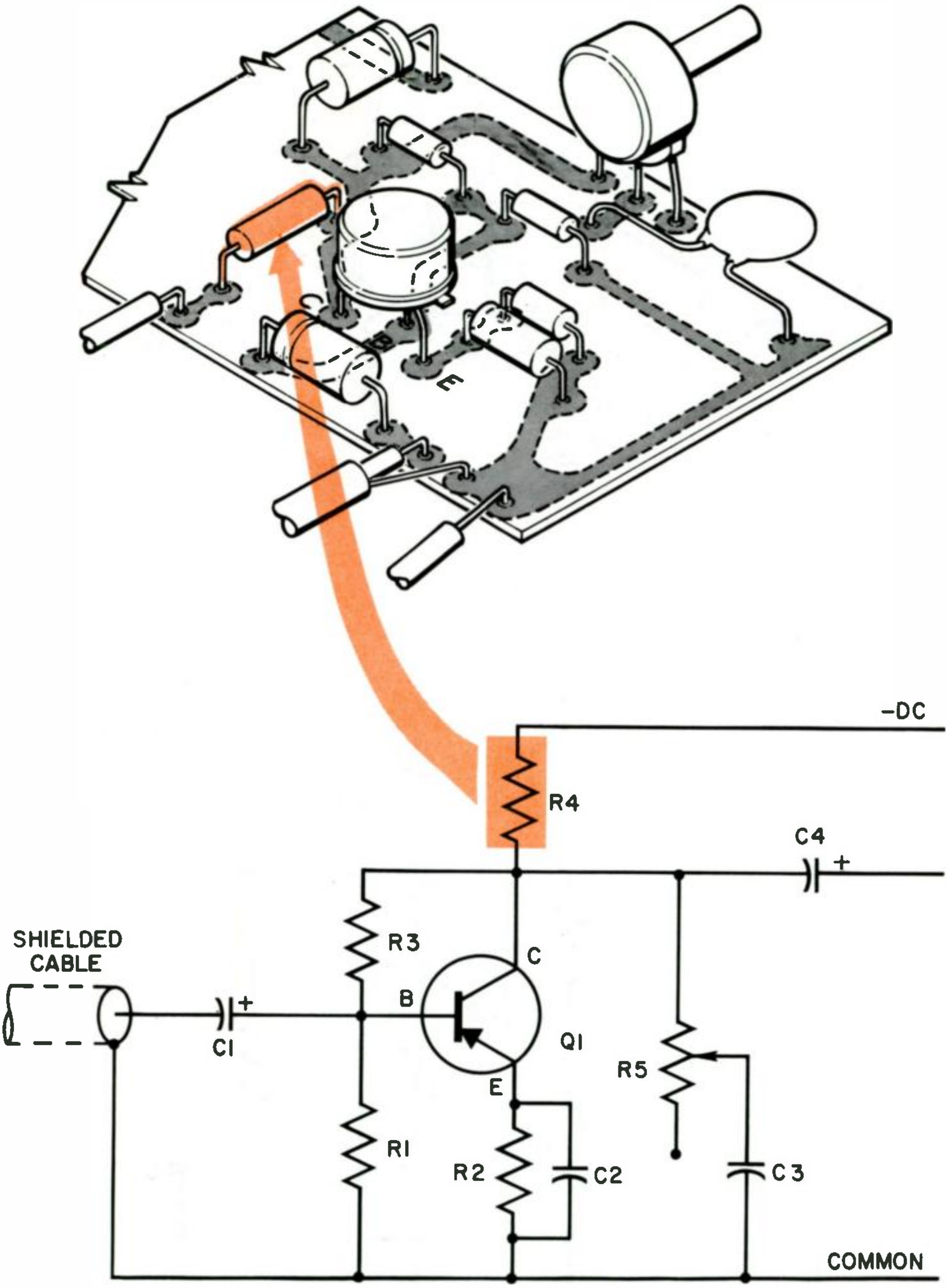


Figure 3J - Location of R4.

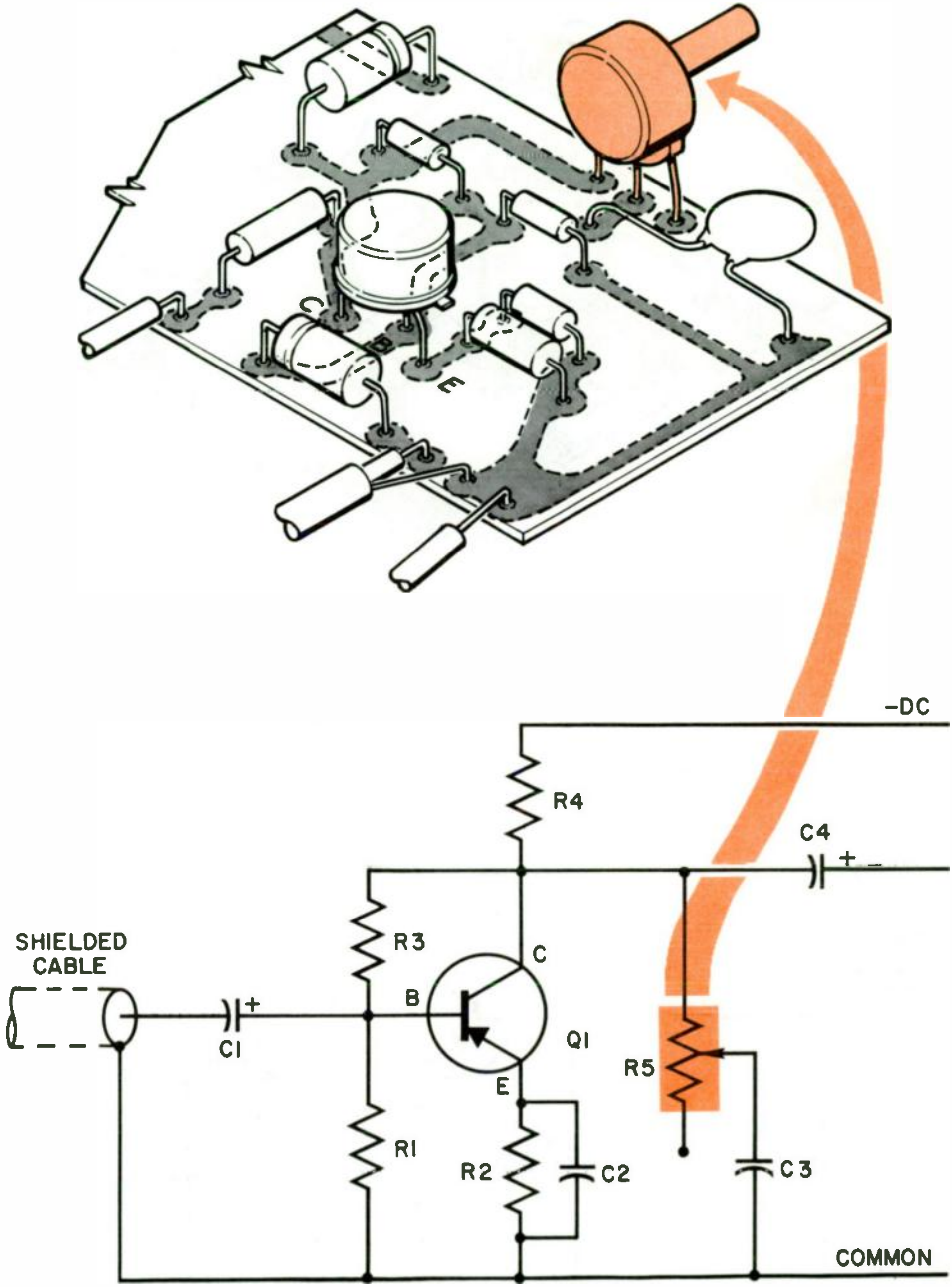


Figure 3K - Location of R5.

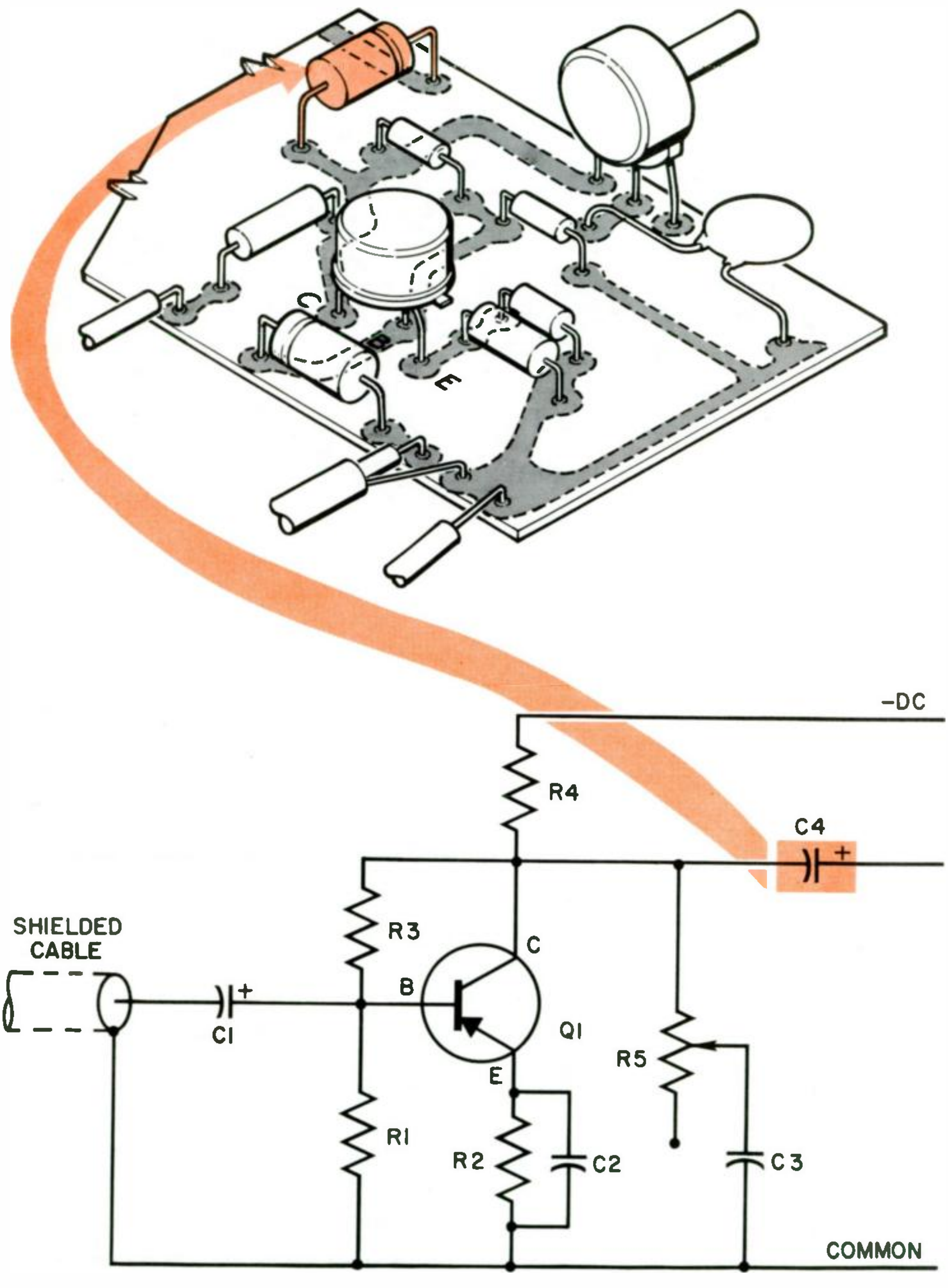


Figure 3L - Location of C4.

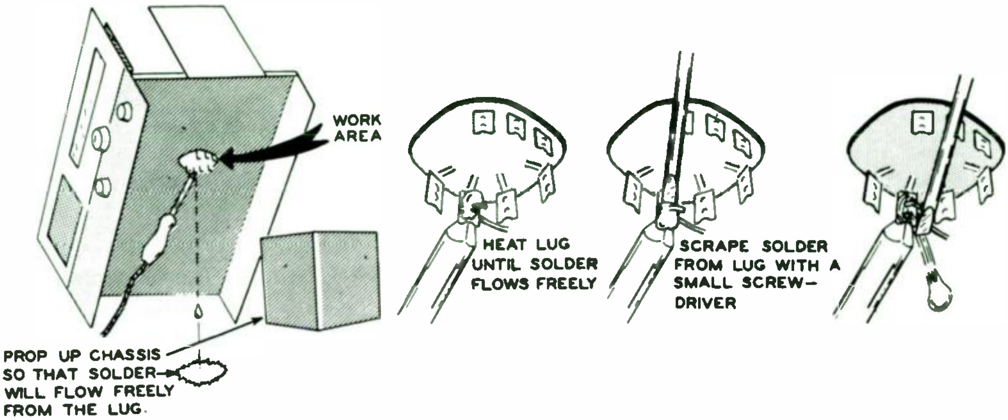


Figure 4 - One method of removing solder from solder terminals. Reproduced with the permission of Heath Company, Benton Harbor, Michigan.

To use one of these tools, apply the iron to the solder joint until the solder is molten. Then squeeze the bulb and release it. The vacuum created by the bulb clears the solder from the connection. This leaves the component lead free for removal. Repeat the operation for each lead of the component and then simply pop the component from the circuit board. In the case of IC's, a small screwdriver may be used as a pry.

To install the replacement component in a circuit board, if necessary, cut and bend leads to the dimensions of those on the old part. Insert the part leads through the holes in the board and bend them slightly to hold the component in place until it is soldered.

Solder all connections securely to the printed circuit with an iron that generates only enough heat to produce a good connection. Excessive heat from massive irons will damage the foil, the component, or both. Use small diameter, resin core solder for printed circuit work.

WARNING! Never use acid core solder on electronic products.

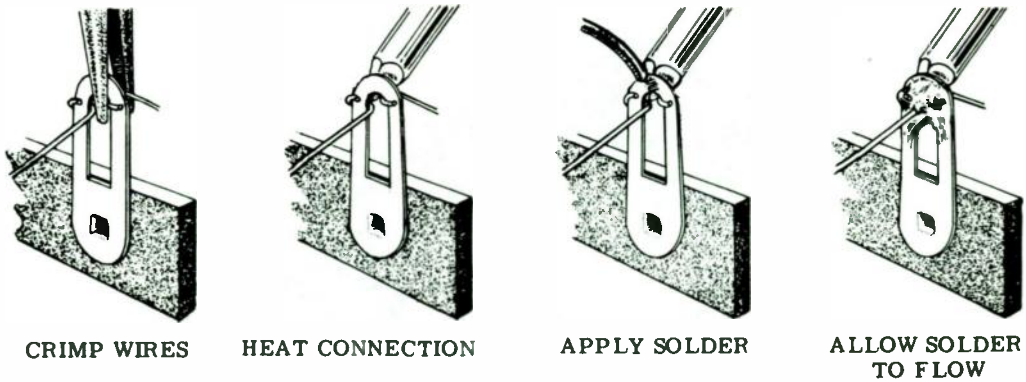


Figure 5 - Connecting a new component to a solder lug. Reproduced with the permission of Heath Company, Benton Harbor, Michigan.

HEAT SINKING OF COMPONENTS

Some solid-state components require protection from excessive heat during soldering. This is especially true of small diodes. Figure 7 illustrates how a pair of long nosed pliers and a rubber band can be used to heat sink a diode during soldering. The same method can be used when soldering transistors. Commercially available heat sinks or alligator clips can also be used.

MECHANICAL ATTACHMENT

It is important when replacing certain components that they be securely mounted. This applies especially to heavy parts that are mounted onto circuit boards. Additional brackets are often used to

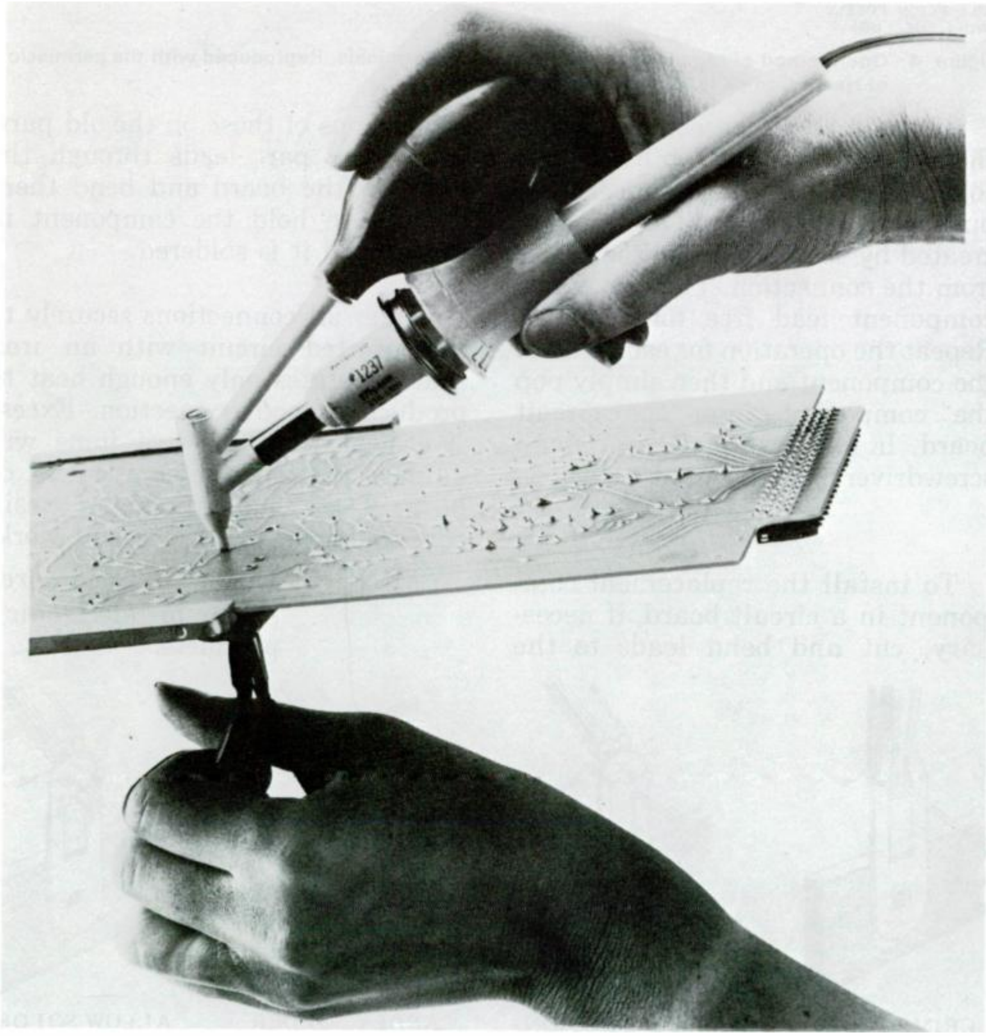


Figure 6 - Desoldering tool. Courtesy of Ungar.

prevent them from flexing and breaking the circuit board. Some of these components are transformers, speakers, and tuning capacitors. When replacing these parts, always replace all the hardware and screws that were removed.

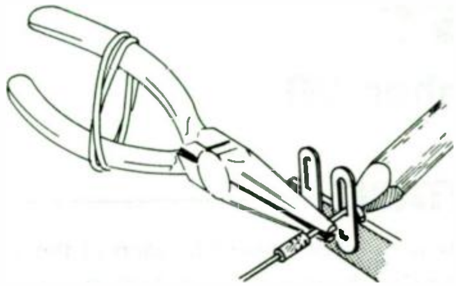


Figure 7 - Protecting a diode from heat damage during soldering with a long nosed pliers. Reproduced with the permission of Heath Company, Benton Harbor, Michigan.

SUMMARY

In all cases, when troubleshooting and repairing electronic products, do it neatly. The customer is paying for professional workmanship and he has a right to expect it. Shoddy repair techniques always lead to trouble. You will either establish a substantial clientele or gain a bad reputation that will cause you to lose business.

TEST

Lesson Number 50

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having the Test Code Number 52-050-1.

1. Troubleshooting procedures
- A. can be trial and error.
- B. should be organized.
- C. are simply a matter of replacing parts until you find the bad one.
- D. can be performed with the schematic of the circuitry without testing components.

2. In order to logically troubleshoot, you must
- A. not use test equipment.
- B. not refer to diagrams.
- C. have sophisticated test equipment.
- D. know something about the circuitry.

3. After locating a bad component the next step is
- A. putting in any component that may work.
- B. obtaining a replacement before removing it.
- C. removing it before finding a replacement.
- D. returning the set to the customer until a replacement part is obtained.

4. Some components have similarities in appearance. Component identification is always possible through
- A. color comparison.
- B. size comparison.
- C. noting lead arrangements.
- D. skilled use of professional service literature.

5. Locating components in a unit
  A. is not possible.
  B. is possible only after years of experience.
  C. can be done with the aid of good service literature.
  D. can always be done because of the components' colors.

6. After reviewing the symptoms and examining service literature, the next step in troubleshooting is
  A. determining the faulty stage.
  B. locating the bad part.
  C. checking all the tubes.
  D. checking all the transistors.

7. If the defective stage in a set has been isolated, you must anticipate what parts may cause the problem and
  A. test them.
  B. change all these parts.
  C. substitute new parts for all those suspected.
  D. replace the tubes or transistors in the stage.

8. Stages are the building blocks of electronic products and consist of resistors, capacitors, inductors and sometimes diodes grouped around a
  A. transformer.
  B. coil.
  C. passive component.
  D. tube, transistor, or other active device.

9. A professional serviceman begins troubleshooting a unit by
  A. randomly checking components.
  B. checking all tubes or transistors.
  C. locating various stages and fixing their locations in his mind.
  D. soldering several replacement components into the circuitry.

10. The first step when replacing a bad component is
  A. unsoldering the leads.
  B. cutting the leads.
  C. prying it from the circuitry.
  D. none of the above.

Notes

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A LITTLE THING — BUT SO IMPORTANT

There is an old poem which states that for want of a horseshoe nail, a horse couldn't deliver a message during a battle, and as a result, a battle and a kingdom were lost.

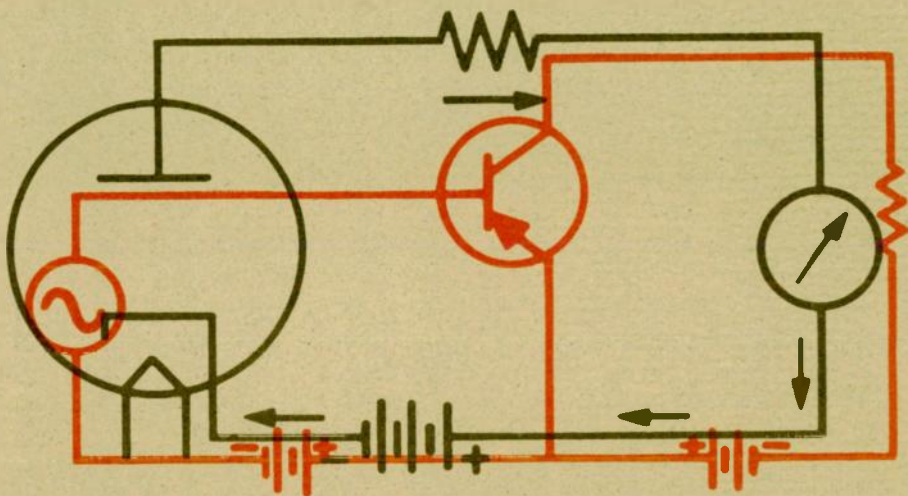
This poem shows how small items can be extremely important. That tiny bit of "extra effort" on a job can be the most critical part of the whole service procedure.

Don't let your servicing kingdom be lost for want of that tiny bit of "extra effort."

S. T. Christensen

LESSON NO. 51

TEST EQUIPMENT



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-051

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ADVANCE SCHOOLS, INC.
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CONTENTS

TEST EQUIPMENT

INTRODUCTION

The primary task of any electronic technician is to troubleshoot equipment. Since most technicians have difficulty in acquiring a reliable method of using test equipment, this lesson will explain one that is used by most good technicians. Some technicians call it systematic troubleshooting; others call it common-sense troubleshooting. The title that seems to embody both names, and the one that will be used in this lesson, is logical troubleshooting with test equipment. There are many methods of troubleshooting other than the one that will be described; however, by comparison these methods have been found to be ineffective and time consuming.

NEED FOR TROUBLESHOOTING AND TEST EQUIPMENT

As you have already determined, troubleshooting is the process of locating the fault that causes a piece of equipment to operate at less than desired or designed performance.

Any equipment operating at less than the best performance requires the services of a troubleshooter with test equipment. A Hi-Fi set that is garbling its highs or lows, even though it has good rated frequency response, has an electronic fault that needs repair. A home radio that begins to pick up two stations at once contains a defect. A TV set that has poor contrast between blacks and whites also needs repair.

The remedy may be no more than the proper adjustment of one or two controls, but the trouble will remain until the appropriate adjustment is located and made.

The need for troubleshooting (locating the cause of faulty performance) exists whenever the equipment fails to meet the rated performance as set forth by the manufacturer.

TROUBLESHOOTING PREREQUISITES

Good troubleshooting is not a talent with which a person is born. It is a skill that can be acquired by anyone with a suitable electronics background. You can become a good troubleshooter if you have:

1. Sufficient electronic knowledge to learn how a piece of equipment works.
2. Suitable skill in reading and interpreting data contained in the technical manual or service folder.

3. Suitable skill in operating test equipment and interpreting test readings.
4. The ability to troubleshoot in a logical manner.

Electronic Knowledge

If you have carefully studied the preceding lessons, and have been able to apply these electronic principles, you are learning how electronic equipment works. As you gain experience, you will encounter many circuits and pieces of equipment that are not familiar. Gaining an understanding of how they work is merely a process of applying what you have already learned.

What is the foundation that can be applied to all electronic devices? The answer is the set of principles you learned about DC and AC electricity and will be applying in this lesson.

The illustration in Figure 1 shows that *all electronic equipment* is made up or based on *selected electronic circuits* which, in turn, operate in accordance with the fundamental principles of voltage and current and the characteristics of inductance, capacitance, and resistance. If you reduce any electronic equipment to the bare essentials, you will find that the equipment operates the way it does because of the circuit arrangement of L, C, and R and their effect on current and voltage.

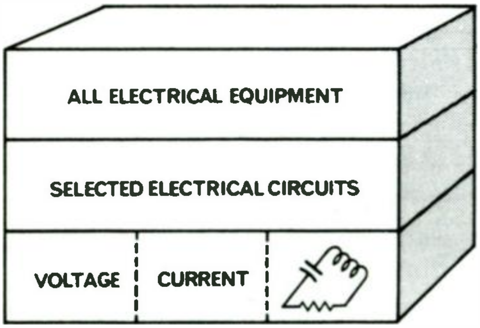


Figure 1 — A basic electronic system.

If you have the foundation for understanding how electronic equipment operates, you need only experience and more study if you wish to become skilled.

Reading and Interpreting Electronic Data

Most electronic devices have operating or servicing manuals, often called technical manuals or instruction books. They contain text, diagrams, and other data required for troubleshooting. Equipment used in the home, such as radios, television receivers, and audio equipment, usually have service folders that contain similar information. These service folders can usually be procured from most local electronic parts supply houses.

Reading Technical Data

Will you be able to read these manuals and folders? Yes. The portions of schematic and block diagrams, the type of circuit descriptions, and the kind of test data that you will encounter are all representative of the information you will find in the manuals and folders.

Test Equipment

You have studied and already used the basic types of test equipment. All other types of test equipment are more or less complex adaptations of those included in these lessons. Like all electronic equipment, their operation is founded on a basic set of principles. Therefore, you have the capability of learning how to operate and use them. Again, experience provides the instruction needed to gain greater skill.

LOGICAL TROUBLESHOOTING

Logical troubleshooting is a systematic, common-sense method of isolating the fault in a malfunctioning piece of equipment. It does not employ the time-wasting or ineffective procedures of trial-and-error methods. The logical troubleshooter uses his knowledge of electronic principles, his ability to extract data from a technical publication, and his skill in using test equipment.

Logical troubleshooting is a time-proven procedure used by all experienced technicians. Most of them have applied the procedure so often that they no longer pay attention to its fine points. Through habit and years of experience, they may have forgotten the specific details.

Probably no two technicians would explain the procedure alike. However, all would agree that logical troubleshooting consists of a series of sequential steps. Each step is based on valid electronic deductions that systematically narrow down the trouble to increasingly smaller areas in the equipment and finally to the faulty part, wire, or connection. Some technicians might list the procedure in two or three steps; others would count a dozen or more. Regardless of the number, the principle is the same.

Five steps are listed below as the most reliable method of learning and

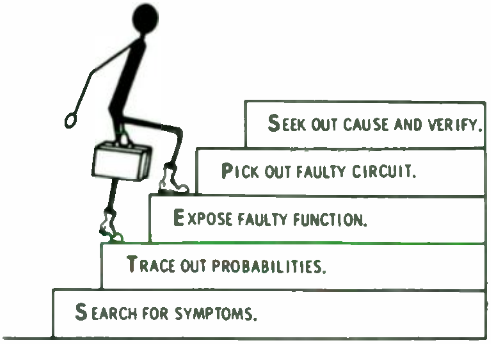


Figure 2 — The steps to success.

applying this procedure. They can be applied to any equipment, regardless of size. The steps in the proper order are:

STEP 1. Search for all trouble symptoms.
STEP 2. Trace out all probable faulty functions.
STEP 3. Expose the single faulty function.
STEP 4. Pick out the faulty circuit.
STEP 5. Seek out and verify the cause of the trouble.

Note that the first letter in each step (read from top to bottom) spells STEPS. This fact will help you remember logical troubleshooting.

STEP 1: SEARCH FOR THE SYMPTOMS

A trouble symptom is an outward indication that a piece of equipment is not working properly. In dead equipment the indication is fairly obvious. A hum in a radio receiver, a distorted picture on a TV set, or harsh, flat notes from a Hi-Fi set are also obvious and make further use of the equipment undesirable. Then there are the less obvious indications as the performance of the equipment slowly degrades over a period of time. These are tolerated until the output becomes obviously distorted or blanked out.

Symptom Indicators

Audible and/or visual outputs of an item of equipment are symptom indicators which, by the use of the front-panel controls, can help you to pinpoint the source of trouble.

Many radio receivers have: two output indicators — a speaker and a light (usually illuminating the dial), and at least two controls — tuning and volume. The change from desired performance can be registered in many ways — hums, squeals, squawks, low volume, two stations instead of one, or no sound at all. The light is either on or off.

The controls can be used to obtain more information about the symptom. How does the audio change, if at all, when the volume control is rotated from one extreme to the other? Does the hum or other noise become louder, or does it remain the same? If there is no undesirable noise, will the control smoothly increase the volume of the station program?

Obtain as much symptom information as you can during Step 1. Learning as much as you can about the trouble symptoms is the only effective way to begin a search for the cause and its source.

A television receiver has an additional output and a greater number of front-panel and rear-panel controls that can be used in searching for trouble symptoms. It has a speaker, a dial light, and a visual output indicator to detect trouble symptoms, and several controls that can be adjusted to observe additional symptoms or changes in output. Another advantage in first looking for all symptoms is that proper adjustment of a control will quite frequently eliminate the trouble. Ragged, slanted lines on the TV screen might be corrected by adjustment of the horizontal hold control. Distortion in height of the picture (large heads and short legs, for example) might be corrected by adjustment of the vertical-linearity control. If these adjustments correct the fault and there are no other symptoms, the troubleshooting job is completed.

STEP 2: TRACE OUT ALL PROBABLE FAULTY FUNCTIONS

As applied to electronic equipment, a *function* is the purpose of the equipment, group of circuits, or circuit. In the narrowing-down feature of logical troubleshooting, the idea is to pick out a few of the several functional circuit groups in which the trouble most probably lies. When this is accomplished, the search is narrowed down to a smaller area.

In smaller equipment, such as the radio receiver illustrated in Figure 3, the number of circuit-group functions may be limited. Further limitations are imposed by the receiver, which has only two controls — tuning and volume. However, the antenna, mixer, oscillator, and IF amplifiers of the set shown can be grouped within a radio-frequency function. The combination of detector, audio amplifier, and speaker is designated as an audio

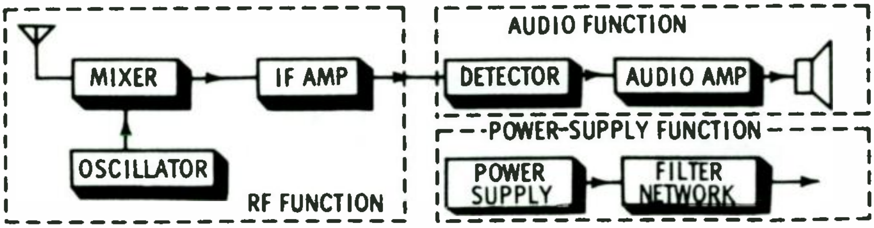


Figure 3 — Receiver block diagram.

function; the power supply, its filter network, and power cord become the power-supply function.

Isolating Faulty Radio Functions

The tuning control of the receiver is connected to the inputs of the mixer and oscillator, and the volume control is connected in the input circuit of the first audio amplifier stage. Information obtained from adjustment of these controls can therefore be associated with the respective functional groups. The purpose of the second step is to trace out and identify the functions whose symptoms indicate a malfunction.

The following is an example of the second step. The original symptom in the radio receiver is weak output. Adjusting the volume control makes little or no difference. The tuning control shows a small but significant difference between loud and weak stations. The dial lamp is on. In which function(s) is the probable location of the trouble? The most probable location is the audio function. The power-supply function is a possibility, but the RF function can almost be eliminated. If you were to list all three functions as probables, based on your technical knowledge of how the receiver works, your answer could be just as correct as the one given. As stated in the title for Step 2, trace out all the probable faulty functions. Place them in the most logical order.

Try another problem. During Step 1, no stations are heard, regardless of where the tuning control is set. The dial lamp is on. Rotation of the volume control causes an increased crackling, rushing noise in the speaker. In which function(s) would you expect to find the trouble?

The most probable location of the trouble in this case is the RF function. The noise heard in the speaker is the normal noise generated by the vacuum tubes in the radio. This noise indicates that the tubes are getting voltage from the power supply and that the audio stages are performing their amplifying function.

Television Functions

A television receiver can be broken down into a large number of sharply defined circuit-group functions. The thirty or forty circuits in one type of television receiver can be visualized in functional circuit groups as shown in Figure 4.

Suppose that during Step 1 you learned the following symptoms. Au-

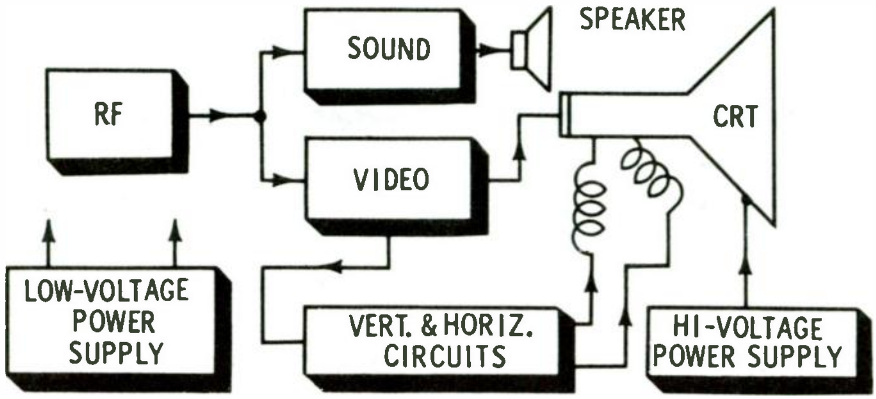


Figure 4 — Functional groups in a TV receiver.

dio appears to be good, but the picture covers only half of the screen vertically. Width appears to be proper. Adjustment of the vertical control makes no apparent change in height, but does cause the picture to roll.

Since audio (sound) and video (picture) appear to be good, the sound and video functions are eliminated. If these are working properly, the RF function must be operating properly. If the high voltage were low or absent, there would be no picture on the screen. The low voltage must be good since the picture, its width, and the sound are good. Logical reasoning indicates that the trouble must be in the vertical and horizontal circuits.

As a result of reaching only the second step in logical troubleshooting, you have limited the trouble to a half-dozen circuits out of a possible thirty or forty. This is much better than checking them all. In addition, the logical deductions you have made have given you a good idea as to the type of trouble you are looking for. Evidently the output voltage of the vertical deflection signal is not large enough to swing the electron beam over the full height of the screen.

Review of Steps 1 and 2

During the first two steps of the 2 logical troubleshooting procedure, analysis is confined to information obtained from outside the equipment.

After obtaining all the information you can about the original trouble symptom(s) by manipulation of front-panel controls and observation of output indicators during Step 1, you proceed to the second step and trace out all probable faulty functions. In Step 2, you use the symptom information to make logical technical deductions and identify the functional areas of the equipment that may contain the trouble. Up to this point you have neither entered the equipment nor used any external test equipment.

While making technical deductions during Step 2, you may find it desirable to obtain additional symptom information. Returning to the procedures of Step 1 will not violate any rules. You may often find it necessary to return to a previous step, or steps, for re-evaluation purposes.

Until you become experienced in troubleshooting, write out the data obtained or conclusions reached during each step. You will find that this procedure reduces the necessity of returning to a previous step for verification.

STEP 3: EXPOSE THE SINGLE FAULTY FUNCTION

In Step 3 you can use test equipment to determine which one of the probable faulty functions contains the trouble.

Radio Application

Refer to one of the radio receiver examples used in the preceding step as the first example. No stations were heard at any frequency. The lighted dial lamp indicated that power was applied. An increase in receiver background noise as the volume control was adjusted, indicated that the audio function was good. It was decided that the radio-frequency function was suspected of being defective.

The only purpose of Step 3 is to locate the single function that is causing the equipment to operate improperly. In the example above, either a scope, VOM, or a VTVM can be used.

From the schematic diagram of the receiver, locate the pin number of the upper diode plate of the detector. Connect the oscilloscope to the proper socket terminal and rotate the tuning control. If no audio-modulated signal is noted at several station settings, the RF function is not operating properly. If an oscilloscope is not available, connect a VTVM at this point. An RF signal will produce negative DC voltage proportional to the signal strength at the antenna input.

If a good, but weaker-than-normal, signal is obtained, deductions made during Step 2 are erroneous. However, the effort made thus far in Step 3 is not wasted. You have added more data to your store of symptom information. You can now go back to Step-2 procedures and the functional block diagram better equipped to select the probable faulty function(s).

Having recorded a weak output for the RF function, you also conclude that the weak signal should have been passed through the audio function if it were good. When a recheck is made of speaker output with the volume control at maximum, background noise this time seems weak. Since both functions are weak, you suspect the power supply of faulty performance.

The new Step-2 conclusion places the probable location of the trouble in the power-supply function. A Step-3 check of the schematic for the receiver indicates that there should be a pulsating DC output of 90V. With a VTVM or VOM, the DC reading shows less than half this value. The faulty function has been confirmed.

TV Receiver Application

The results of the first and second steps for a TV receiver could be the following:

STEP 1. *Symptoms* — Good audio; good picture image, but it covers only half the height of the screen; there is no change noted while adjusting the vertical control.

STEP 2. *Deductions* — The trouble is probably in the vertical and horizontal functions.

The schematic diagram included in the technical manual or servicing folder for the receiver should be used in locating the output test point of the probable faulty function. You will find that a schematic diagram will be your most valuable single item for troubleshooting.

3

The oscilloscope is the best piece of equipment to use for obtaining readings at a suspected trouble point, since you can observe the shape of a waveform as well as measure the amplitude (voltage, in this case). To measure voltage, the oscilloscope screen with its graticule must first be calibrated from a known voltage source. VOM or VTVM AC voltage readings are difficult to use for confirming whether the output is good or bad. TV receiver schematics usually show waveform outputs with peak-to-peak (p-p) voltage values. These are difficult to convert to meter readings.

4

A low reading would substantiate the Step-2 deduction that vertical and horizontal circuits probably contained the fault. However, care should be taken in making this decision. The reading should be substantially lower than that shown in the service data — about half as much in this case. Since there is a variation in part values among pieces of equipment, test values on a diagram are representative only of those found in most equipment of the same model. However, the equipment readings should be within a few percent of those specified. If the output of the vertical section reads low in this example,

Step 3 would be successfully concluded.

If the reading is very close to normal, your conclusion must be that the vertical and horizontal functions are probably not at fault. If the oscilloscope test produced these results, what should you do next? Revert to Step-2 procedures, trace out all probable faulty functions, and then apply the new information you have learned.

In re-evaluating your symptom information on the Step-2 level, you find:

1. Good sound and picture image; therefore, power-supply voltages must be correct.
2. Horizontal width of the picture on the screen seems proper, so that portion of the circuit can be assumed to be good.
3. The verifying test showed that the vertical output was operating as it should. Frequency, shape, and amplitude of the sawtooth output appeared good.

Since deductions and tests show that all other functions are good, the possibility is very strong that the fault is in the vertical-deflection coil, since this is the only remaining part that has any control over the height of the picture.

Now apply Step 3 to a more difficult TV malfunction. This is what you might write down for the first two steps:

STEP 1. *Symptoms*—Sound is good, but weaker than normal. The screen is blank; there is no picture or raster (horizontal lines on the screen when station is not on the air). The adjustment of contrast, brightness, vertical, horizontal, and fine-tuning controls makes no change. Moving the channel-selector switch to other stations has the same results.

STEP 2. *Deductions*—Sound and RF functions are probably good. The low-voltage power supply might be good, since the sound circuits are operating. However, the power supply might be providing just enough voltage for sound and RF, but the output is too low for one or more of the other functions. All the other functions — video, CRT, high-voltage power supply, and horizontal and vertical circuits — are probable causes of trouble.

In the functional block diagram of the TV receiver shown in Figure 5, the suspected functions are marked with PF (probably faulty), and the unsuspected with PG (probably good).

Five functions are suspected of being probably faulty. In which order should they be tested to arrive at a Step-3 conclusion (exposure of the single faulty function)?

Three rules should be applied in answering this question. *First*, make only those tests that are safe to make. *Second*, make the tests in the order of least difficulty. One that requires dismantling a section of the equipment is an example of a difficult test. *Third*, test those functions first that will eliminate one or more of the other functions considered probably faulty. Those that are equal in terms of these rules become a matter of

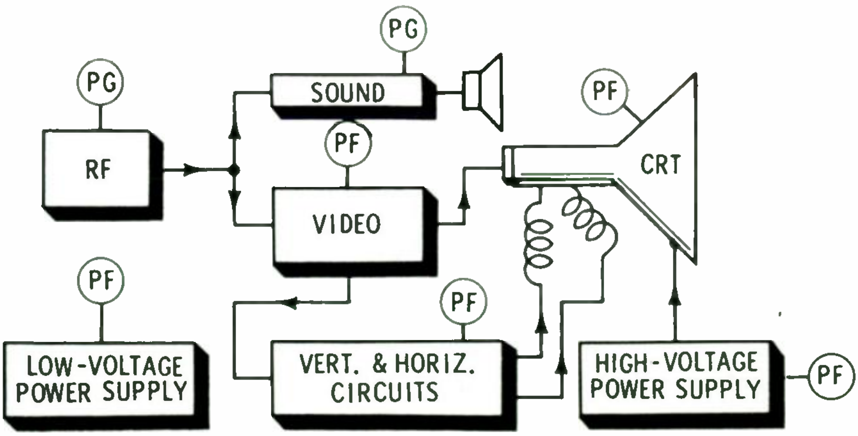


Figure 5 — Suspected functions in a TV receiver.

personal choice in the testing sequence. A good sequence of function tests is the following:

1. *Vertical and horizontal circuit function* — This is selected first because, if it were operating properly, a raster would be present on the screen, whether the video function is sending sync signals to it or not. Under the conditions of a completely blank screen, there is neither a vertical nor a horizontal output, if this is the faulty function. If the function checks as being good with an oscilloscope test of the two outputs, the low-voltage supply is considered good. Sufficient voltage is being applied to operate the sync function.
2. *Cathode-ray tube* — The CRT should be checked before the high-voltage power supply. By looking down into the base of the tube, you can determine whether the heater is working. If it is, there will be a bright glow. Also check for gas. This is determined by a bluish glow within the neck of the CRT. A small blue cloud near the base, although not desirable, will have little effect on the beam and does not explain a blank screen.
3. *Video function* — Although the output of the video function could not be responsible for the missing raster, the function is worth testing. Video output to the CRT is checked for proper values of video and blanking pulse, and the output of the sync function is measured for sync pulses.
4. *High-voltage power supply* — If all the preceding functions have been tested and rated as probably good, the high-voltage power supply could be exposed as the single faulty function by default. A review of the symptoms and test results makes this a logical deduction. If high voltage is missing from the CRT, the electron beam will not reach the screen. As a result, neither a raster nor a picture will appear.

Review of Steps 1, 2, and 3

The STEPS procedure has been three-fifths completed. The approach has quickly narrowed the trouble to a single function among several by making logical technical deductions on the basis of accumulated data.

STEP 4: PICK OUT THE FAULTY CIRCUIT

The narrowing-down process continues in the fourth step by working toward the faulty circuit within a functional group. The procedure is carried out by making technical deductions from accumulated symptom and test data. These deductions result from studying the servicing block diagram and then closing in on the malfunctioning circuit.

The Block Diagram

This is a diagram that you have used many times in these lessons. It consists of individual blocks representing each circuit within the functional group. The blocks are interconnected to show the direction of signal flow, and input and output test points are indicated. Some servicing block diagrams include waveform data at significant points within the diagram.

Quite often, the equipment you will be troubleshooting may not have a servicing block diagram. The schematic diagram can be used instead. However, until you become accustomed to visualizing the schematic of individual circuits as a simple functional block without the distracting influence of its parts, you should draw your own block diagram.

A complete servicing block diagram for a radio receiver is shown in Figure 6.

With waveforms shown between stages and input and output test points identified, a servicing block diagram can be used for isolating a faulty circuit. In the diagram below, V_1, V_2, and V_{3A} are included in the RF function, and V_{3B} and V_4 in the audio function. V_5 is the power-supply tube.

Closing-in Procedure

When picking out the faulty circuit in Step 4, it is neither desirable nor necessary to check the inputs and outputs of each circuit contained in the faulty function. Some functions may have two or three, and others a dozen or more stages. Finding the faulty circuit with a minimum number of tests is accomplished by using a *closing-in*, or *bracketing*, process.

When working from a servicing block diagram that contains the faulty function identified in Step 3, enclosing indicators are placed at the inputs and outputs of the functional group. These can be pencil marks as shown in Figure 7, G or B, or they can be small weights to eliminate damage from repeated erasures. You can even depend on your memory for locating and recalling the enclosing marks. A G

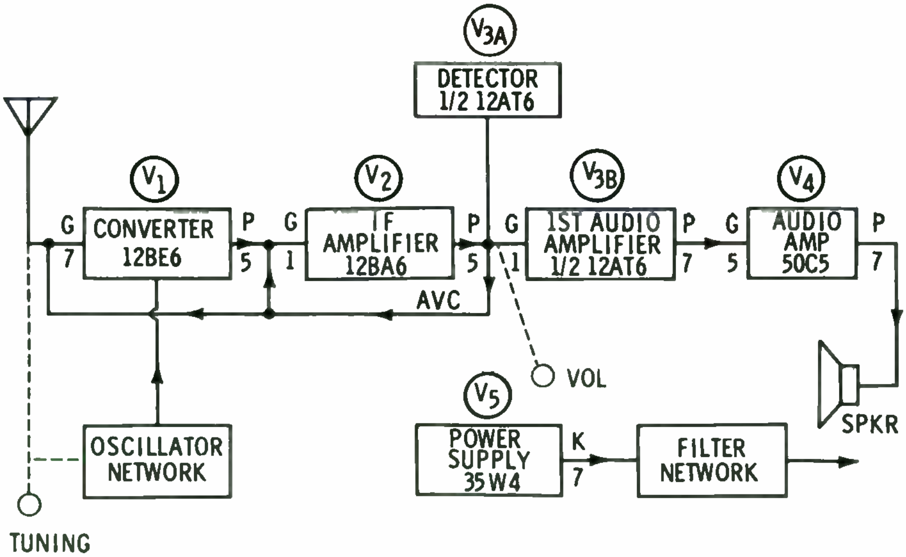


Figure 6 — Servicing block diagram.

(good) mark at the input(s) indicates that this point has been tested and found to be satisfactory. A B (bad) mark at the output(s) indicates a test has revealed the output waveform is improper or nonexistent.

Linear Circuits

Figure 7 shows circuits following each other in a line. Such an arrangement is known as a *linear signal path.* Marks on the diagram show a good input and a bad output. The concept of Step 4 is to isolate the one faulty circuit among the five with the fewest tests.

To minimize the number of circuit tests required, the first check with an oscilloscope or signal tracer is made at either the input or output of the middle tube in the group, V_{10}. A good or bad indication eliminates the necessity of checking about half of the circuits. It is usually acceptable to check the output of V_9 or the input of V_{11}, since the waveforms at these points are essentially the same as the input or output of V_{10}, respectively.

This procedure of dividing a linear string of circuits for testing purposes is known as the *half-split method.* If the test is made at the output of V_{10} and reveals an improper or nonexistent waveform, the bad indicator should be moved to that point (see Figure 8). Step 4 enables you to pick out the faulty circuit.

The faulty circuit is now located between the input of V_8 and the output of V_{10}. If the scope test is properly made, V_{11} and V_{12} are considered good. If the test reveals a proper waveform, the good mark is moved as shown in Figure 9. With the good mark at the output of V_{10}, circuits V_8 through V_{10} are no longer suspects; the faulty circuit is thus V_{11} or V_{12}.

By moving either the good or bad mark, depending on the result of the test, the faulty circuit is restricted to a smaller enclosure. By half-splitting again between the new G and B marks, the enclosure is made even smaller. In the second example, a test at the output of V_{11} identifies the faulty circuit. Depending on the results of the test, G or B is moved to that point, and either V_{11} or V_{12} is pinpointed as the faulty circuit.

Take a dead receiver as a practical example. The only symptom obtained in Step 1 is either no sound output or no electrical power reaching the power supply. In Step 2 all functions

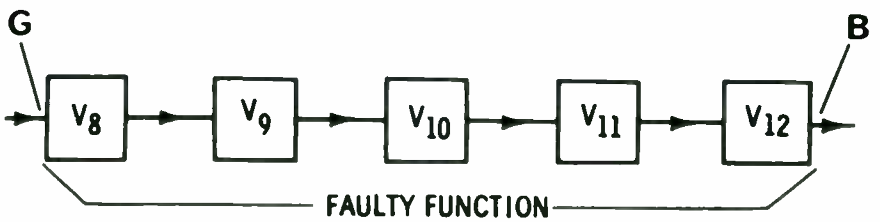


Figure 7 — Linear signal path.

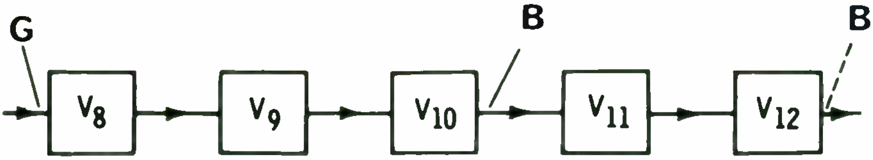


Figure 8 — Half-split method.

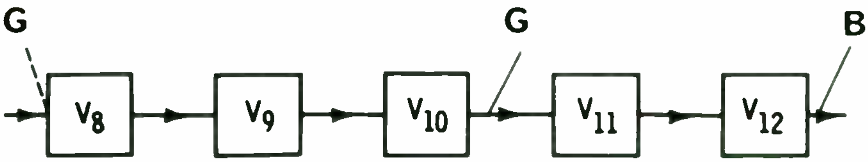


Figure 9 — Moving the marks.

are listed as probables. Step 3 reveals the following information.

Good test indications are made at the input of V1, the input of V3B, and the output of the filter network in the power supply (see Figure 10). A bad test is identified at the speaker input.

The audio function is therefore suspected of being faulty. The first test of Step 4 should be made at the grid (pin 5) of V4 or the plate (pin 7) of V3B.

Convergent Circuits

There are circuit combinations other than linear. One of these is called *convergent.* As the name implies, a convergent circuit is one in which the outputs of two or more circuits converge (join) to feed a single circuit.

Figure 11 shows the test results of Step 3. Inputs to both channels of the function are good, but the single output is bad. The decision of where to make the first Step-4 test depends on the nature of the bad output.

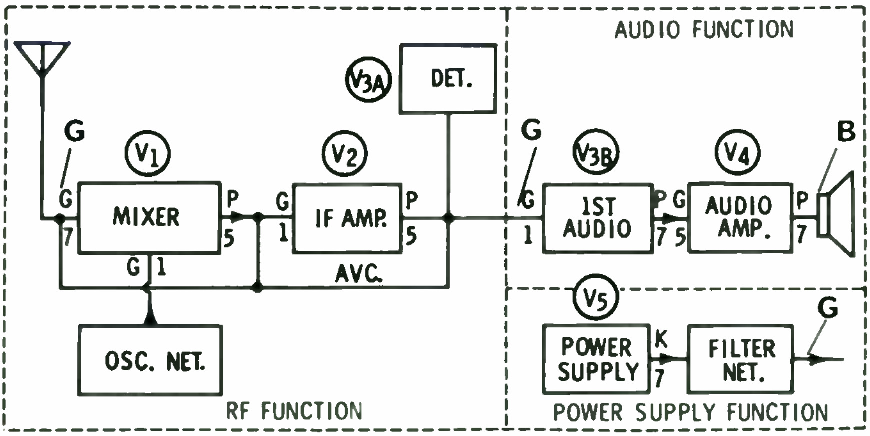


Figure 10 — Signal tracing in an AM receiver.

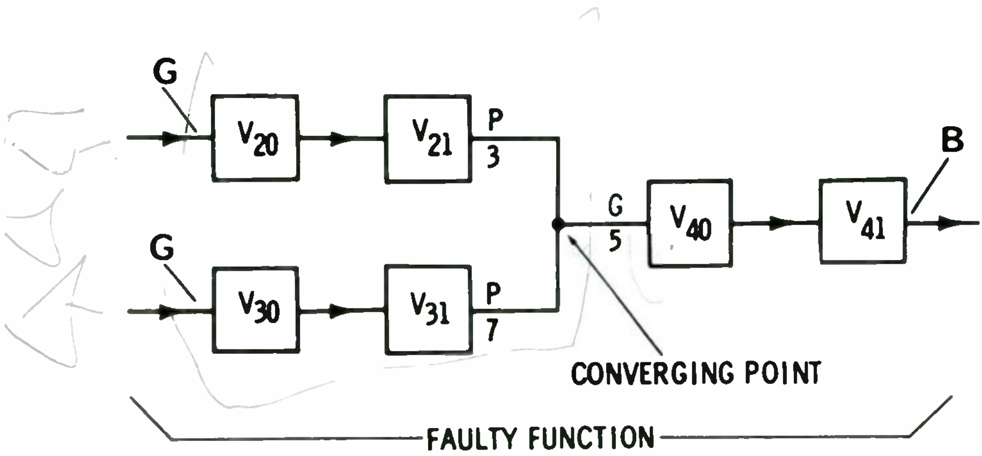


Figure 11 — Convergent circuit.

First, assume that there is no output signal of any kind. After checking the function of V40, it is learned that this circuit does not operate unless the outputs of both channels are received. This is called a *gating* circuit. To minimize the number of tests, where should the first check be made?

The first test should be made at the converging point. A waveform reading at the input of V40 will reveal the nature of the outputs from V21 and V31. If both waveforms were there and of the proper shape, the G could be moved to the converging point, thus limiting the remainder of the search to V40 and V41.

It is not probable that both output signals are missing or improper. Therefore, the check at the converging point, if not good, identifies which channel is bad. B is then moved to that output, reducing the number of faulty circuits to one. In cases where the convergent circuit passes either output signal as long as it appears on the grid, the approach to testing is a little different. Note these output waveforms in Figure 12.

The first test should be made at the converging point (G3 of V40). A comparison of the two output waveforms — the measured waveform and the correct waveform — indicates that the 1-microsecond pulse is missing. A proper deduction shows that the small pulse does not leave V31; therefore it is correct to make a test at the output of V31.

If the above deduction is verified, B is moved to the output of V31. A single circuit is enclosed, and Step 4 is satisfactorily completed. But, if the test is good, the lower G is moved to the converging point, leaving V40 and V41 as probables. It is already known that the square wave from V21 is passing through the complete functional group. One more test between V40 and V41 isolates the faulty circuit.

Divergent Circuits

A divergent circuit is the opposite of a convergent circuit: the output of a single circuit feeds into inputs of two or more other stages (see Figure 13).

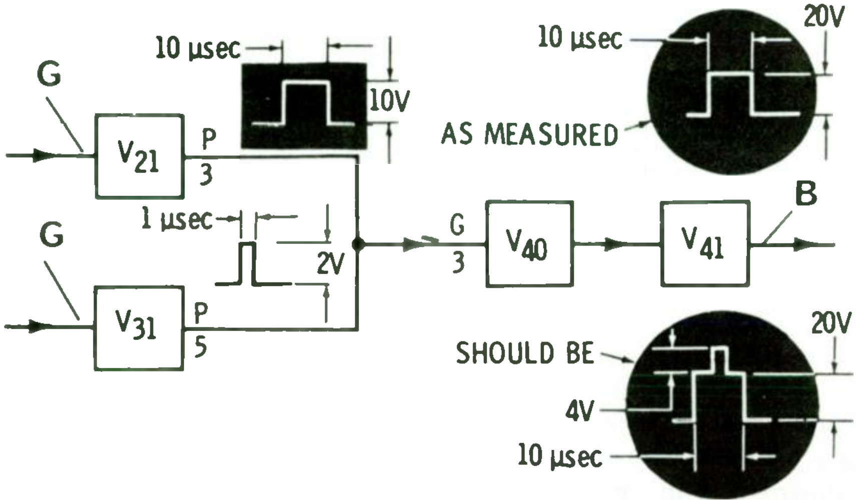


Figure 12 — Waveforms in a TV convergent circuit.

Figure 13 shows that the input to the divergent circuit (V_{52}) is good and that the output should be a 30-Hz sine wave at 10 volts peak-to-peak. If the B indicates no output at either point, the first test should be made at the output (pin 3) of V_{52}. If there is no output at this point, enclose V_{52} with a G and a B, and Step 4 is concluded.

Suppose that the divergent circuit conditions were the following (see Figure 14). Actual measured waveforms are shown at the appropriate points as a result of Step-3 testing.

The output **G** of the channel containing V_{53} and V_{54} indicates they are operating properly. Since the output of V_{54} is a good signal, V_{52} is probably in good operating condition. The first Step-4 test should be made at the output of V_{60} or the input of V_{61}. If the test is favorable, the **G** is moved up, and V_{61} is enclosed with a **G** and a **B**. If the test requires that a **B** be moved to the output of V_{60}, a second test at this input encloses either V_{60} or V_{52} as the faulty circuit. If it is found that V_{52} is producing the improper waveform, then the **G** analysis of the square-

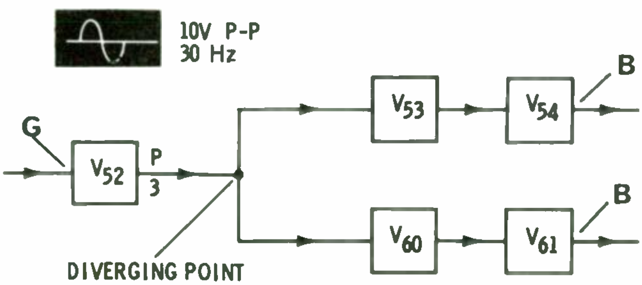


Figure 13 — Divergent circuit.

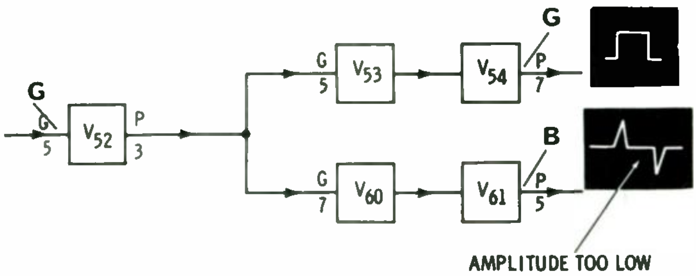


Figure 14 — Defective divergent circuit.

wave output from V_{54} is not very accurate, or the faulty output of V_{52} is sufficient as an input to that channel.

Switching Circuits

In many types of equipment, two or more circuits or channels may be switched individually to another channel, as illustrated in Figure 15.

With switch S_1 in position A, Step-3 tests reveal good inputs to V_3 and V_4 but a bad output from V_6. The first test to make in Step 4 is a reading at the output of V_6 with S_1 in position B. If the reading is what it should be, V_5 and V_6 are good and the B can be moved to the output of V_3.

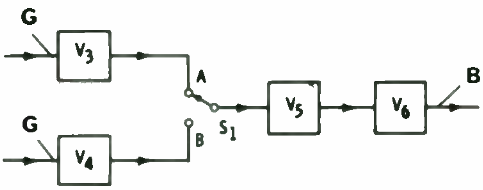


Figure 15 — Input switching circuit.

If the V_6 output is found to be bad, none of the enclosing marks can be moved, but additional information has been obtained about the probable location of the fault. It is improbable that both V_3 and V_4 would go bad simultaneously. This conclusion is verified by making the next test at the input of V_5. If, as suspected, the check is good, then either V_5 or V_6 is faulty, and the obvious enclosing test is made.

The switching-circuit channels also appear in reverse order (as in Figure 16), such as a single channel capable of being switched into one of two or more channels. The switching circuit in Figure 16 is mechanically operated. A relay is an electro-mechanical switch. However, total electronic switches are becoming more common.

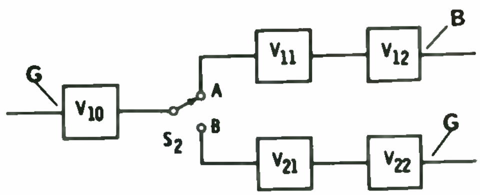


Figure 16 — Output switching circuit.

In the diagram above, when S_2 is switched to position B, the conditions indicate that V_{10}, V_{21}, and V_{22} are good. This leaves V_{11} and V_{12} in the circuit group as the only suspects. The quickest way to determine which is bad is by testing between them.

These are the typical circuit combinations that you will encounter while troubleshooting. You have seen that, by combining technical knowledge with common sense, the number of enclosing tests to isolate a faulty circuit in a functional group can be kept at a minimum.

Enclosing a TV Receiver Function

Assume that the vertical and horizontal function of a TV receiver has proven to be faulty. Circuit conditions are shown in Figure 17. Horizontal- and vertical-sync pulses appear at the grid of V13, where they are amplified. The sync separator separates the vertical-sync pulses from the horizontal-sync pulses.

The vertical and horizontal channels generate waveforms of the proper frequency, shape, and amplitude to cause the electron beam in the CRT to sweep the required horizontal lines on the screen. Oscillations continue whether sync pulses are received or not. This is the reason for the raster appearing on the screen when a station is not tuned in.

The purpose of the sync pulses is to time the start of each line with corresponding events in the TV camera. If this were not done, the picture on the screen would be greatly distorted and unrecognizable.

The symptom noted in Step 1 of the troubleshooting procedure was a thin horizontal line across the face of the screen. Sound was good, and the condition repeated itself on all channels.

Steps 2 and 3 earmarked the vertical and horizontal function as being faulty. In the testing process, the input of sync pulses to V13 appeared good. So did the output of the horizontal channel. (N4 is a network of capacitors and resistors that sharpen the shape of the waveform.) There is no measurable waveform at the output of V16. Appropriate enclosure marks are shown on the diagram.

V13 and V14 are apparently operating properly in accordance with the tests shown. At least the horizontal portion of V14 appears to be good. The first test should be made at the input to V15. This allows the G or B to be moved to that point, depending on test results. From there, only one more test must be made to isolate the

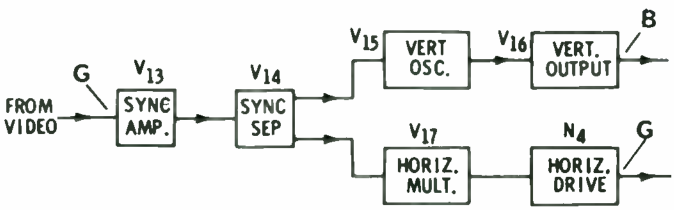


Figure 17 — TV sweep function.

single faulty circuit. If the input to V15 or the corresponding output from V14 is good, the next test should be made at the V15 output or V16 input.

Review of Step 4

When picking out the faulty stage of a circuit group, symptoms and data from the first three steps are used in making deductions from a study of a servicing block diagram. Enclosure marks employing pencil, weights, or memory are placed at function inputs and outputs to show whether previous tests were good or bad. The enclosure marks are moved in accordance with circuit input or output tests made as the result of a technical and common-sense analysis of the circuit types, which are linear, convergent, divergent, or switching.

STEP 5: SEEK OUT AND VERIFY THE CAUSE

The troubleshooting procedure thus far has narrowed the trouble to a single circuit, consisting of a few electronic parts. The *seek-out* portion of the final step suggests that the faulty part be found and verified as the cause of the trouble symptoms.

Analyzing the Output Waveform

The trouble can be narrowed down by analyzing the output waveform of the circuit, making voltage or resistance checks, and/or substituting a good part for one that is suspected of being bad.

Comparing the output waveform actually measured against that of the proper waveform often provides clues as to the location and/or cause of the trouble. Figure 18, for example, shows the good and bad outputs of an amplifier. From your knowledge of how an amplifier circuit works, the trouble seems to be in the grid or cathode sections. Thus, examine that portion of the circuit.

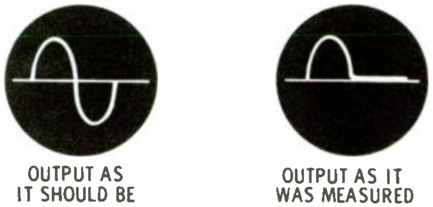


Figure 18 — Output waveform.

Shown in Figure 19 is a faulty full-wave rectifier circuit with measured input and output waveforms. The proper output waveform is also included. Half of the output cycle is missing. A study of the schematic diagram and the waveforms reveal that you should concentrate your search in the lower plate section of the diode.

This type of waveform analysis in most cases will help you limit your search to a small area of a circuit. Of equal or even greater importance, a knowledge of the nature of the distortion in an improper waveform will assist you in verifying that the located fault is the actual cause of the trouble.

Making Voltage and Resistance Checks

If an analysis of the output waveform provides a probable location, or if there is no waveform to be

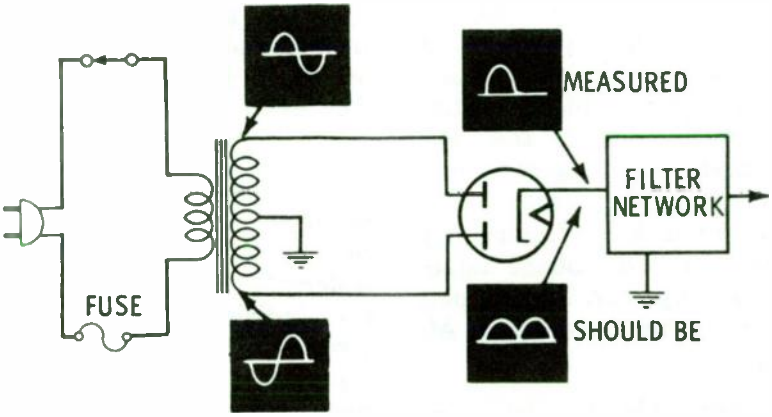


Figure 19 — Retifier waveform.

analyzed, the next procedure involves making voltage and resistance checks. Some schematics provide both voltage and resistance readings in chart form. If the measured values of a suspected part are not reasonably close to those indicated in the diagram or chart, you have narrowed down the trouble.

In nearly all examples, the elements of a tube are marked with their pin numbers, as shown in Figure 20. Transistor leads are identified by the elements shown in the schematic. A notation on the diagram identifies the type of instrument used in making the measurements. For example, DC voltage measurements are taken with a 20,000-ohms-per-volt meter and AC voltages with a 1,000-ohms-per-volt meter.

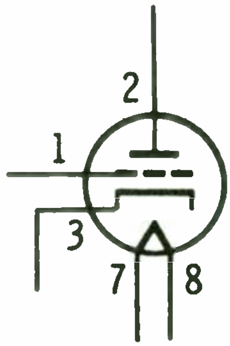


Figure 20 — Tube pin numbers.

The diagram may also include the following notations:

Pin numbers are counted in a clockwise direction when viewed from the bottom of the tube socket.
Measured values are from pin socket to ground, unless otherwise indicated.
Controls are set for normal operation.
Component values are given in ohms and micromicrofarads, unless otherwise stated.

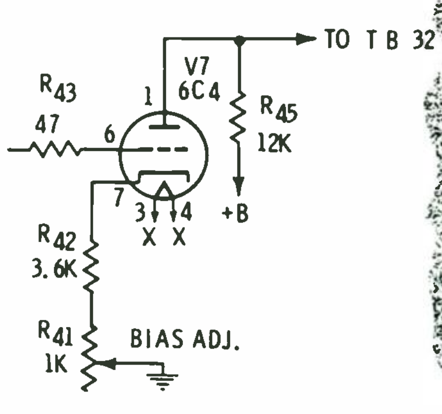
It is generally better to take voltage readings first and resistance readings second, if they are required. If voltages are to be read at all pin numbers, it is best to take them in sequence of voltage values rather than pin numbers. For example, start with a high scale on the voltmeter and measure the pin having the highest voltage. In this case, it would be the plate, pin 1 (refer to Figure 21). Use a scale that will permit a higher reading than the 250V shown; this will prevent damage to the meter in case the actual voltage is much higher. Next, measure pins 6 and7, since they are supposed to have voltage values relatively close together. Finally, pins 3 and 4 can be measured on an AC voltage range.

If you are able to determine suspected sections of the circuit from an analysis of the improper output waveform, take voltage readings at these sections first. For example, if your deduction indicated that the waveform was being distorted by improper grid-to-cathode bias, these would be the pin voltages to check first. If the pin-6 measurement is the proper 72V but pin 7 is 80V, your deduction would be confirmed and the trouble fairly well isolated.

In another type of presentation for voltage and resistance readings, voltages are placed near the tube elements, and resistance measurements are shown in chart form (as in Figure 22).

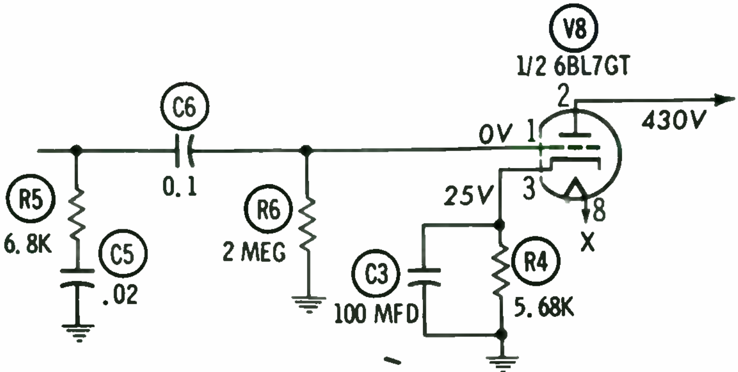
As in the previous example, part numbers and their values are shown on the schematic. If the trouble is isolated to one section of the circuit, the individual parts can then be measured. If, for example, something other than 25V and 920 ohms were read from pin 3 to ground, either C3 or R4 would be suspected of causing the trouble.

If R4 is to be measured, one of the capacitor leads must be separated from the resistor. Otherwise, if ohmmeter test leads were placed across the resistor, they would still measure the parallel resistance of the two parts. In this case, a capacitor lead could be unsoldered from ground or the tube-socket pin. If R4 does not measure close to 5.68K, it may be the cause of the trouble.



ELEMENT	PIN NO.	VOLTAGE	RESISTANCE
PLATE	1	+250V	130K
FILAMENT	3	3.15VAC	0
FILAMENT	4	3.15VAC	0
GRID	6	+72V	80K
CATHODE	7	+76V	5K

Figure 21 — E & R on tube pins



RESISTANCE MEASUREMENTS

STAGE	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8
V8	6BL7GT	2 MEG	3.5K	920	2.4 MEG	2.6 MEG	0	0	0.1

Figure 22 — Resistance data at tube pins.

Part Substitution

It is often necessary to substitute a known good part for one suspected of being faulty. C3 in Figure 22 could be such a case. Replacing it with a new capacitor of the same value will confirm whether it is good or bad. The same reasoning applies to other parts, including tubes and transistors. The only valid method of checking a faulty tube is by substituting a known good tube.

Verifying the Cause

Although a faulty part can actually be located by the preceding methods, Step 5 is not completed. The nature of the fault must be compared with and verified by the trouble symptoms obtained in preceding steps. If an open resistor, shorted capacitor, weak tube, etc., adequately explain the improper waveforms and trouble symptoms, then you can feel reasonably sure that you have found the cause of the trouble and can make the necessary repair.

However, if the nature of the trouble does not substantiate the distorted waveforms or other trouble symptoms, you have not found the faulty component or, in some cases, you have found only one of the faulty components. For example, a slight change in the value of a plate resistor does not explain the loss or flattening of a half cycle in an amplified sine wave.

The faulty component you have isolated may have been the result of a fault in another part of the circuit or even in an adjacent circuit. The narrowing-down procedure may have uncovered a cathode resistor whose measured resistance deviates greatly from its rated value. In addition, if the resistor is badly charred, it is evident that the resistor has been passing an excessive amount of current. The cause could have been a gradual decrease in resistance over a period of time, allowing more and more current to pass until the charred condition resulted. However, the increase in current could also have been caused by a faulty component in another part of the circuit. A decrease in the plate or screen resistance would also cause excessive current to flow and damage the cathode resistor.

If, in such a case, the cathode resistor were replaced without verifying the cause of the trouble, the same trouble symptoms would repeat themselves after a period of time. Always verify that the isolated fault explains the trouble symptom(s) and that it is the actual cause of the malfunction.

REPAIR

You may have noted that the word *repair* was not included in the troubleshooting steps. Replacing a part, resetting an adjustment, or restoring a connection is actually not a part of troubleshooting. Troubleshooting includes all the processes required to isolate the faulty condition. Once the trouble is found and verified, then the repair can be made.

SUMMARY

1. Troubleshooting is the process of locating a fault in a piece of equipment.

2. To become a good troubleshooter, you must:

   (a) Know enough about electronic principles to use them in determining how equipment operates.

   (b) Know enough about the use of test equipment to make and interpret test readings properly.

   (c) Know enough about electronics to extract desired information from a technical manual or service folder.

   (d) Know enough about the logical troubleshooting procedure, STEPS, to apply it well.

3. A good method of troubleshooting is a systematic, orderly process called logical troubleshooting.

4. The logical troubleshooting procedure consists of five parts. The initial letters of these parts spell the word STEPS.

STEP 1. Search for all trouble symptoms.

STEP 2. Trace out all probable faulty functions.

STEP 3. Expose the single faulty function.

STEP 4. Pick out the faulty circuit.

STEP 5. Seek out and verify the cause of the trouble.

TEST

Lesson Number 51

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-051-1.

1. The need for troubleshooting exists whenever the equipment
   A. warrantee expires.
   B. fails to meet the manufacturer's rated performance.
   C. has been exposed to high heat or moisture.
   D. has been operated for more than 2500 hours.

2. In the first two steps of logical troubleshooting, analysis is obtained from
   A. a VOM.
   B. the block diagram.
   C. outside of the equipment.
   D. the schematic diagram.

3. What is the most valuable single item for troubleshooting?
   A. An oscilloscope
   B. A VOM
   C. A Block diagram
   D. The schematic diagram

4. What test equipment would you use to check the waveform at a test point in a TV receiver?
   A. Signal generator
   B. Signal tracer
   C. VTVM
   D. Oscilloscope

5. What is the concept of step four?
- A. To reduce time required to locate a faulty function
- B. To isolate one faulty circuit among many circuits
- C. To seek out and verify the cause of the trouble
- D. all of the above

6. A convergent circuit is
- A. a linear circuit.
- 13 B. only used in a TV receiver.
- C. an audio amplifier.
- D. a circuit composed of two or more inputs joining to feed a single input.

7. What does Step 4 enable you to do?
- A. Use your VTVM
- B. Understand wave form
- 11 C. Pick out the faulty circuit
- D. Understand the application of an oscilloscope

8. To logically troubleshoot electronic systems, how many steps should you perform?
- A. Only three
- 22 B. At least eight
- C. Not more than ten
- D. Five

9. A divergent circuit
- A. is a switching circuit.
- B. is used only in a TV receiver.
- 14 C. is the opposite of a convergent circuit.
- D. must be used with a convergent circuit.

10. A switching circuit is
- A. mechanically operated.
- B. electro-mechanically operated.
- C. electronically operated.
- D. all of the above.

Notes

Notes

Portions of this lesson from
Understanding & Using Test Equipment (Vol. 4)
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"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

TWO SIDES TO A STORY

In business, there are only two sides to a story — Mr. Customer's and Mrs. Customer's.

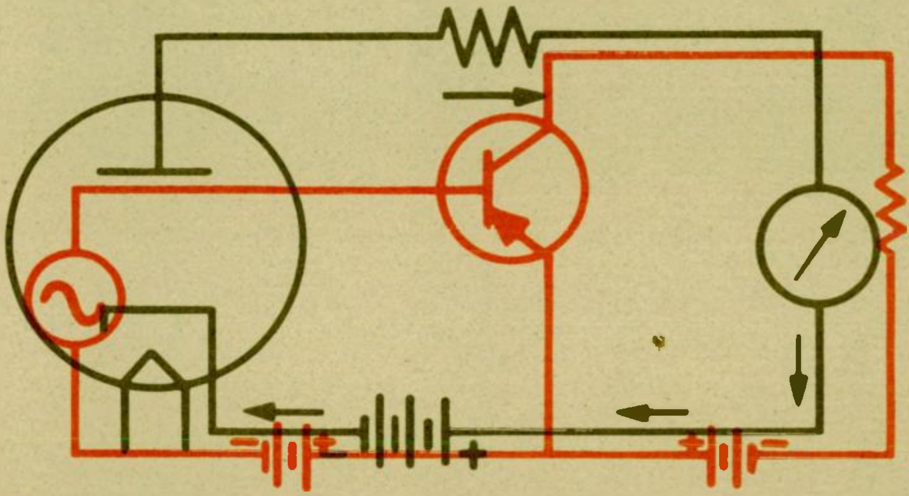
If you make it a practice to include a third side — yours — you may wind up with an empty shop.

Carefully listen to your customers as they voice their complaints. Never slough over their problems as being unimportant. If their problems are serious enough to call you, then they deserve a considerate, courteous answer.

S. T. Christensen

LESSON NO. 52

VOM AND VTVM



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CONTENTS

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52-052

VOM AND VTVM

INTRODUCTION

In the past, the volt-ohm-milliammeter (VOM) and the vacuum-tube voltmeter (VTVM) have been the test instruments used most widely in electrical and electronic work. The VTVM differs from the VOM in that the VTVM includes vacuum-tube circuits for amplification of low-level signals and for otherwise adding to the versatility of the instrument. In recent years, other forms of electronic voltmeters have appeared and have become widely used. These more recent instruments employ transistors rather than vacuum tubes, and generally are battery-operated (or offer the choice of either battery or power-line operation); thus they are advantageous to use when portability is required. The electronic instruments which employ solid-state devices (transistors) are known by such names as "electronic voltmeters" (EVM), "solid-state voltmeters" (SSVM), "field-effect-transistor-voltmeters" (FET VM), "field-effect-transistor volt-ohm-milliammeters" (FET VOM), and so on.

Because of the widespread use of all these instruments, it is important to have a thorough knowledge of their features, use, and operation. The main purpose of this lesson is to provide as much of this knowledge as possible. Included are discussions of the circuits and their uses. The major features of the various types are covered, with the advantages and disadvantages described. The section on transistor instruments, has been written to reflect recent developments in service-type measuring equipment.

The most widely used test instrument in electronics work is the volt-ohm-milliameter (VOM). This instrument is used by electricians, technicians, experimenters, teachers, scientists, engineers, inventors, and students. VOMs find wide application in troubleshooting, electrical maintenance, design, production work, radio, TV, and appliance servicing, and in many other areas. Vacuum-tube voltmeters (VTVMs) and other electronic voltmeters (EVMs) are not quite so widely used as the VOM, but eventually almost every worker in electronics—and many in electrical work—has a need for an electronic measuring instrument such as the VTVM.

BASIC VOM SYSTEM

The basic components of the VOM, as shown in Figure 1, are a meter, test leads, a function switch, and voltage current- and resistance-measuring circuits.

In some VOMs the switch is not included—in this case, it is necessary

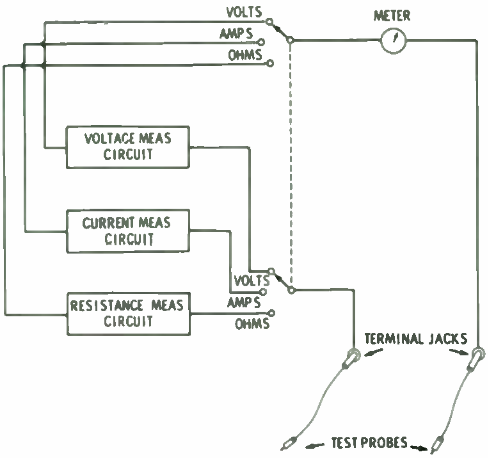


Figure 1 - Basic components of the VOM.

Courtesy Triplett Electrical Instrument Co.

Figure 2 - Triplett Model 630 VOM.

to move one of the test leads each time a different function is to be performed by the meter. In Figure 1 if there were no switch, the right-hand test lead would be left where it is at all times, and the left-hand would be plugged into a jack connecting to the resistance-, current-, or voltage-measuring network, as desired. However, most VOMs do include the function switch, and for this reason it is shown here. In some VOMs that include the function switch, one test lead is still moved to a different jack when the type of measurement being made is changed. An example of one such VOM is shown in Figure 2. The large switch knob located at the lower center is used to select any one of several ranges of AC or DC voltage, DC current, or ohms.

To understand the VOM, it is necessary first to understand its components. The first one to consider is the meter.

Meter of VOM

The meter includes a scale and a pointer, or indicator. The pointer is attached to a mechanism called a movement. When the VOM is not being used, the pointer remains at the 0 side of the calibrated scale of the meter as in Figure 2. When current flows through the movement, the pointer moves to some position and remains there (if the flow of the current is steady) until the current changes in value. Just how much the pointer is moved, or deflected depends on how much current is flowing through the movement.

It should be kept in mind that whether voltage, current, or resistance is being measured, it is always current that deflects the pointer.

Principle of Meter Movement

The type of meter movement used in most VOMs is known as the D'Arsonval movement. This movement includes a permanent magnet and a coil to which a pointer is attached, which rotates in the field of the magnet when current passes through the turns of the coil. The principle of the D'Arsonval movement is shown in Figure 3. The coil is wound about a soft iron core. The current to be

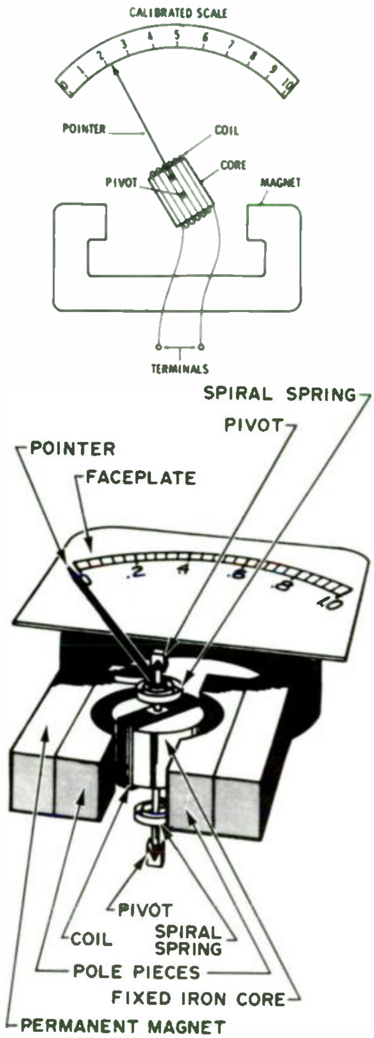


Figure 3 - Construction details of D'Arsonval movement.

measured flows through the coil, setting up a magnetic field around the coil, which opposes the field of the magnet. The coil is rotated clockwise by these repelling fields, pulling against a spring which, when no current is passing through the coil, holds the pointer at zero on the calibrated scale. The greater the current is, the greater the force turning the coil.

Pole pieces on the permanent magnet decrease the magnetic gap between the magnet and the coil core. Spiral springs hold the pointer, which is fastened to the coil, at zero when no current is flowing. The core of the coil does not rotate; it is stationary in order to keep the pointer assembly as light in weight as possible. The pivot usually rides in jewel bearings to reduce friction.

CURRENT-MEASURING CIRCUIT

If it is desired to use a meter movement alone to measure current in a circuit, it may be done if the amount of current flowing does not exceed the rated current of the meter movement. To illustrate, a 50-microampere meter in the circuit of Figure 4 will be deflected to ½-scale. Thirty volts applied to 1,200,000 ohms (the 1,195,000 ohm resistor and the 5,000 ohms of the meter movement) causes 25 microamperes to flow through the meter. This is expressed as:

$$I = \frac{E}{R}$$

$$= \frac{30}{1{,}200{,}000}$$

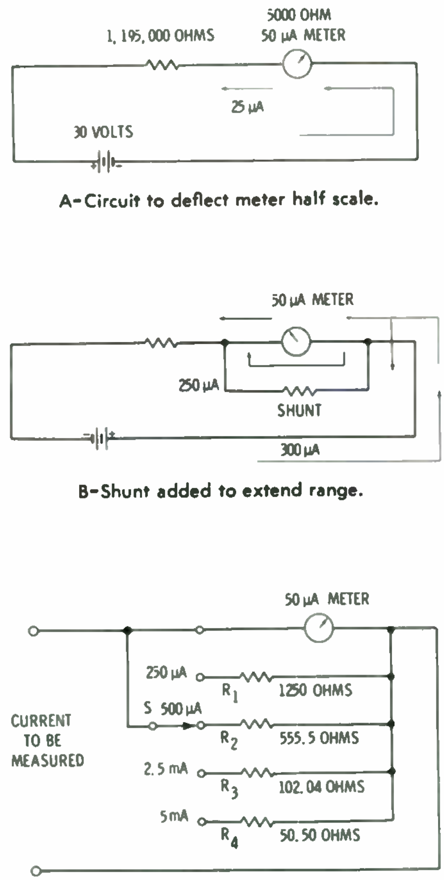
$$= 25 \text{ microamperes}$$

If the battery should be reduced to 15 volts, the meter will be deflected to ¼-full scale; if it is reduced to 7.5 volts the meter will deflect to 1/8 its full-scale reading. This process can be continued until the voltage applied will become so low that the movement of the pointer will no longer be discernible. The lowest voltage at which the movement of the meter pointer is significant will be the lower limit of usefulness of the meter. The upper limit of usefulness of the meter is, of course, the point where the battery voltage exceeds 60 volts, since beyond this voltage level the current flowing in the circuit will exceed the maximum rating of the meter. Permitting too much current to flow through a meter can cause the coil to burn out or the meter to be otherwise damaged.

Extending Current Range of Meter Movement

The meter in the circuit of Figure 4A can be used to measure currents greater than 50 microamperes. To do this, a shunt or parallel path is provided around the meter to carry a known portion of the current, so that the current through the meter is 50 microamperes or less. This shunt is a resistor as shown in Figure 4B, whose value must be accurately selected. For example, if a shunt of 1,000 ohms is placed across the meter (Fig. 4B) five times as much current will pass through the shunt as will pass through the meter, since the resistance of the meter is 5,000 ohms. Thus, if the meter is reading full scale, a 50-microampere current is going through the meter, 50 x 5 or 250 microamperes is going through the shunt; and the total current is 300 microamperes. Similarly, if the shunt has a value 1/50 that of the meter, or 100 ohms, the current through the shunt will be 50 x 50, or 2,500 microamperes at full scale, and the total circuit current will be 2,550 microamperes.

In an actual VOM, any one of several shunts can be switched into the current-measuring circuit, as shown in Figure 4C. This is basically the scheme used in the VOM that you might now be using, or the one you might use in the future. The selection of values of 1,250 ohms for shunt R_1, 555.5 ohms for R_2, 102.04 ohms for R_3, and 50.5 ohms for R_4, provides additional ranges of 0 to 250 microamperes, 0 to 500 microamperes, 0 to 2.5 milliamperes, and 0 to 5.0 milliamperes, respectively. In many practical VOMs, the shunt-switching arrangement makes it possible to measure DC currents as high as 10, 12, 15 amperes or more. For these higher ranges, the shunts are pieces of wire or strap whose resistances are accurately selected.



A-Circuit to deflect meter half scale.

B-Shunt added to extend range.

C-Switch system for selecting one of several shunts.

Figure 4 - Method of using meter for current measurements.

DC VOLTAGE-MEASURING CIRCUIT

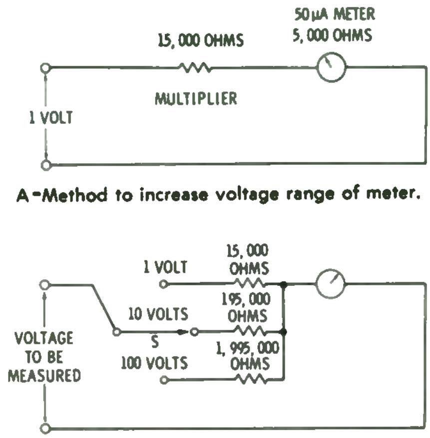
If 250 millivolts is applied to the terminals of a 50 microampere meter movement having a resistance of 5,000 ohms, the meter will deflect full scale. The meter could be used by itself to measure voltages up to 250 millivolts. If a voltage is applied to the meter terminals and the pointer deflects to its halfway point, it can be assumed that the voltage has a value of 125 millivolts.

Of course, with a typical VOM it is possible to measure voltages much greater than 250 millivolts. Extending the voltage-measuring capability of a meter movement is made possible by adding a multiplier resistor in series with the meter. In Figure 5A, the multiplier resisitor shown has a value of 15,000 ohms. This added to the 5,000 ohms of the meter totals 20,000 ohms. Since the meter requires 50 microamperes for full-scale deflection, it can easily be determined that the voltage required to provide this full-scale deflection is:

$$E = I \times R = 0.00005 \times 20{,}000 = 1 \text{ volt}$$

Thus, with the 15,000 ohm multiplier a meter circuit capable of measuring up to 1 volt full scale is obtained. To add a range for measuring up to 10 volts, the total resistance of the circuit must be increased 10 times, or to 200,000 ohms. The value of the multiplier then would be 200,000 — 5,000 or 195,000 ohms. Similarly, for a 100-volt full-scale range the multiplier must have a value of 2,000,000 — 5,000 or 1,995,000 ohms. A switch is normally used, as in Figure 5B, for selecting the desired full scale voltage ranges of 1 volt, 10 volts, and 100 volts.

In a practical VOM, series multiplier resistors are used to make it possible to measure voltages up to 5,000 or 6,000 DC volts or more. Measurement of voltages even higher than this is possible, but usually this is not provided in a VOM because of the danger of breakdown of components, arc-over between components and wiring, and danger to the user. The range of a VOM can be increased to measure higher voltages by use of a high-voltage probe, as will be explained later in this lesson.



A-Method to increase voltage range of meter.

B-Switch permits selection of desired voltage-range multiplier resistor.

Figure 5 - Basic VOM voltage-measuring circuit.

CIRCUIT FOR MEASURING OF AC VOLTAGE

In a VOM, the basic circuit generally used for measuring AC voltage is essentially the same as that for measuring DC voltage. The main difference is that, for AC voltage measurement, a rectifier is included in the circuit.

The rectifier may be either a half-wave rectifier as in Figure 6A or a full-wave rectifier. Often a bridge circuit is used as in Figure 6B, or a double half-wave rectifier as in Figure 6C. Usually, but not always, a copper-oxide rectifier is employed rather than the selenium, silicon, germanium, or vacuum tube types.

A rectifier permits current flow almost entirely in one direction only. Therefore it changes the AC voltage to be measured in the form of a series of half sine waves. Thus, current flows through the D'Arsonval meter in one direction only, just as for DC measurement.

Because of the additional resistance of the rectifier in the circuit and because the current is not continuous for AC measurement, it is usually necessary for the designer of a VOM to use different multipliers in the AC voltage-measuring circuit than those for DC voltage measurement. This

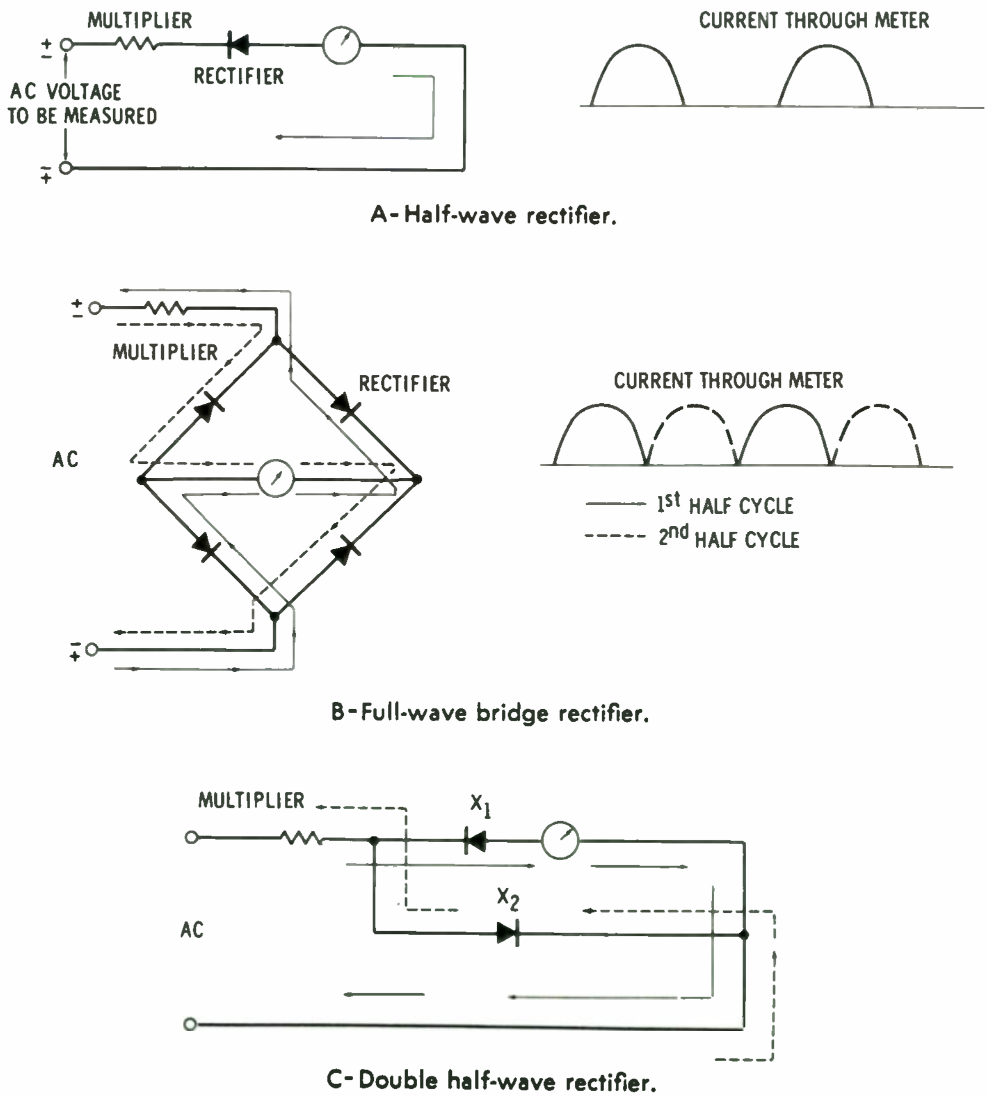


Figure 6 - Basic rectifier circuits used in measurement of AC voltage.

would not be necessary if different calibrated scales on the faceplate of the meter were used for DC and AC. However, there would be a possibility of confusion when using a VOM if it were necessary to search through a maze of calibrations on the faceplate for the desired AC or DC scale. Thus, it is generally agreed that it is preferable to design the meter so that the same voltage scales can be used for both AC and DC.

The half-wave rectifier circuit shown in Figure 6A is actually seldom employed in a high-quality VOM. The only important reason for this is that copper-oxide and other solid-state rectifiers conduct some current on the negative half-cycles. Assume that a certain copper-oxide rectifier has a resistance of 200 ohms in one direction. This is the direction in which it would best conduct on the positive half-cycles. Then, typically, it would have a resistance of 100,000 ohms in the other direction. On negative half-cycles it would, therefore, in most circuits, conduct very little current. But in a VOM circuit, on all but the lowest voltage ranges, the multiplier resistors have fairly high values, and the reverse current may be appreciable compared to the forward current.

To illustrate, in Figure 6A, on the 100-volt range, the resistance of the multiplier, rectifier, and meter in the forward direction might be 2,000,200 ohms, and in the reverse direction the resistance might be 2,100,000 ohms. Then on positive half-cycles, the current would be very close to 50 microamperes, but on negative half-cycles, instead of the current being practically zero, it would be $\frac{100}{2,100,000}$ or approximately 48 microamperes. The 50 microamperes going through the meter for all the

Courtesy EICO Electronic Instrument Co., Inc.

Figure 7 - A 1,000-ohms-per-volt VOM.

positive half-cycles would tend to deflect the pointer to full scale and the 48 microamperes going the opposite direction through the meter on negative half-cycles would tend to swing the pointer nearly as much in the other direction. The two opposing forces would be occurring only 1/120 of a second apart, so the net effect on the meter reading would be the difference between the forward and reverse currents, or 50 - 48 = 2 microamperes. Rather than the meter indicating 100 volts then, this 2 microamperes would cause the pointer to indicate only 4 volts on the 100-volt scale.

Whenever half-wave rectifier circuits are employed in VOMs they are often the double half-wave type shown in Figure 6C. For this circuit, the overall measuring circuit has approximately the same resistance for both the half cycles of measured AC, but on the reverse, or negative, half-cycles, the second rectifier (X2) shunts the reverse current around the meter, thus preventing any appreciable part of the forward, or positive, half-cycles from being cancelled.

BASIC VOM CIRCUITS FOR RESISTANCE MEASUREMENT

The basic circuits used in VOMs for measuring DC current and DC and AC voltage have been discussed. The remaining major function of a VOM is to measure resistance. Since resistance is measured in ohms, a resistance-measuring circuit is called an ohmmeter circuit. There are two types of ohmmeter circuits: the series-ohmmeter circuit and the shunt-ohmmeter circuit. Either one or both may be found in a typical good quality VOM.

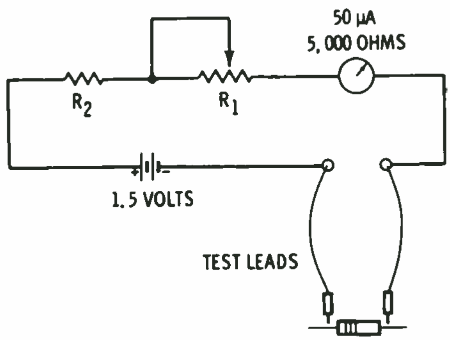


Figure 8 - Series ohmmeter circuit.

The series-ohmmeter circuit includes a source of power (usually a battery), a calibrated meter, a fixed current-limiting resistor, and a variable resistor as shown in Figure 8. Also, of course, a pair of test leads connects to this resistance-measuring circuit.

For the purpose of discussion here, assume that a 50 microampere meter having a resistance of 5,000 ohms is used, that the value of the current-limiting resistor R_2 is 22,000 ohms, that R_1 is a 0-5,000 ohm potentiometer adjusted to a value of 3,000 ohms, and that the battery is 1.5 volts. With a total resistance of 30,000 ohms, and with 1.5 volts applied to the circuit, if the resistance being measured is zero ohms, the circuit current should be exactly the 50 microamperes required by the meter to read full scale. In fact, this is essentially how an ohmmeter is calibrated for zero ohms. The tips of the test probes are held together, and the variable resistor is adjusted until the meter reads exactly full scale, corresponding to zero ohms. Now, if the test probes are placed across the terminals of a resistor with a higher value than zero ohms, the deflection of the pointer will not reach the zero-ohms point on the scale. Assume further that the resistance being measured has a value of 30,000 ohms, the same as the measuring circuit. The meter now will be deflected to 1/2 full-scale value, since with twice the resistance, the current will be 1/2 as great. If the probes are placed across the leads of other resistors whose values are greater or less than 30,000 ohms, the indication will be either below or above the 1/2-scale reading of the meter, respectively, by an amount that depends on the difference of the resistance value. Thus, the meter faceplate can be calibrated to read various values of resistance.

Theoretically, this circuit will respond to any value of resistance between 0 and infinity. But in practice, with the values suggested here, resistances less than 1,000 ohms and above 500,000 ohms cannot be measured accurately. This is because these values of about 1,000 ohms and 500,000 ohms are very small and very large respectively, compared to the measuring-circuit total resistance of 30,000 ohms. The 1,000-ohm resistor would cause a deflection of about 97 percent of full scale, and the 500,000-ohm resistor would cause a fairly feeble deflection; neither could be read very accurately.

SENSITIVITY OF A VOM

One of the most important characteristics of a VOM is its sensitivity rating. This is specified in terms of *ohms per volt.* The higher the ohms-per-volt rating, the more sensitive is the VOM. The sensitivity rating is usually shown on the face of the meter or given in the instruction manual. It can also be determined by using one of the following formulas:

$$\text{Sensitivity ohms per volt} = \frac{1}{E_{fs}} \times R_m = \frac{1{,}000{,}000}{A}$$

where,

E_{fs} is the voltage required for deflecting the meter full scale,

R_m is the resistance of the meter movement,

A is the current in microamperes required for full-scale deflection of the meter.

The sensitivity may also be determined in dividing the total resistance of the circuit for the range in use by the voltage value of that range. To illustrate, suppose the 0-12 volt DC range is in use, and for this position of the range switch there are 240,000 ohms in the measuring circuit. The sensitivity of the measuring circuit is then:

$$\frac{240{,}000}{12} = 20{,}000 \text{ ohms per volt}$$

The same ohms-per-volt rating would apply to all DC ranges of the VOM. For the AC ranges, however, the sensitivity is usually rated lower. The lower rating is due to the leakage resistance of the rectifier in the reverse direction, and the fact that the rectified current is not continuous. The AC sensitivity of the VOM of Figure 2 is 5,000 ohms per volt. In practice, it is usually important to have a high DC sensitivity rating, the AC sensitivity rating not being quite so important. In many applications, however, a VOM having a sensitivity of only 1,000 ohms per volt will be satisfactory. Such a VOM is shown in Figure 7. A 1,000 ohms-per-volt VOM is much less expensive than one of 20,000 ohms per volt, and the measurements made with the less expensive instrument will be just as accurate when these voltage measurements are made across resistances or impedances of relatively low value.

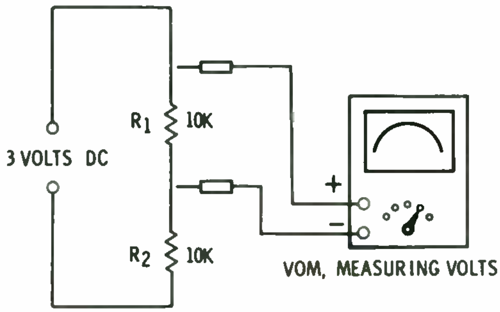


Figure 9 - Circuit showing loading effect caused by VOM.

Loading Effect of Meter

The need for using a high-sensitivity VOM for voltage measurements in high-impedance circuits becomes apparent if the results are examined when one with low-sensitivity is used.

For instance, in the circuit of Figure 9 with 3-volts DC applied across two 10,000-ohm resistors (R_1 and R_2) in series, the drop across each resistor is 1.5 volts, and the circuit current is:

$$I = \frac{3}{20{,}000} = 0.00015 \text{ ampere}$$

Now assume the use of the 3-volt range on a 1,000 ohms-per-volt meter to measure the voltage across R_1. On the 3-volt range, the total internal resistance of the VOM is only 3,000 ohms.

As soon as the VOM test leads are connected across R_1, the 3,000-ohm resistance of the meter in parallel with the 10,000 ohms of R_1 has an effective value of approximately 2,300 ohms changing the total circuit resistance to 10,000 plus 2,300 or 12,300 ohms.

The circuit current now becomes:

$$I = \frac{3}{12{,}300} = 0.000243 \text{ ampere}$$

And the voltage drop across the terminals of R_1 to which the VOM leads are connected is:

$$E = 2{,}300 \times 0.000243 = 0.56 \text{ volt}$$

This is the value the meter will read instead of 1.5 volts, which will actually be the voltage across R_1 when the VOM is not connected.

The change in circuit conditions caused by connecting a meter to a circuit is called the *loading effect* of the meter. It is apparent that in the example just shown, the loading effect of the 1,000 ohms-per-volt meter was considerable. If now a 20,000 ohms-per-volt VOM is used to measure the voltage across R_1 in Figure 9, the loading effect is considerably less. On the 3-volt range, a 20,000 ohms-per-volt instrument has an internal resistance of 60,000 ohms. This 60,000 ohms across the 10,000 ohms of R_1 gives a combined resistance of approximately 8,600 ohms. Then, by calculation as before, the voltage across R_1 with the 20,000 ohms-per-volt VOM connected is approximately 1.4 volts. Although this represents an error of about 7 percent, it is a considerable improvement over the reading of .56 volt obtained with the 1,000 ohms-per-volt instrument.

Of course, a 1,000 ohms-per-volt VOM does not have a serious loading effect on every circuit. For instance, the use of the 150-volt range to measure 100 volts across a 1,000-ohm resistor would give highly accurate results. The 150-volt range has a resistance of 150,000 ohms. This 150,000 ohms across the 1,000 ohms of the circuit under test would have a negligible effect. Conversely, neither is a 20,000 ohms-per-volt instrument the final answer to measurements in all high-impedance circuits. If such a VOM is used on the 1.5-volt range to measure 1 volt across 100,000 ohms, the loading effect of the 30,000-ohm meter resistance on this range would be quite serious. However, for a high
4 percentage of the measurements in electronics work, the 20,000 ohms-per-volt instrument provides accurate results. For the remaining percentage, either a higher-resistance VOM is required, or more often, a VTVM is employed. The advantage of the VTVM with respect to circuit loading is considered later in this lesson.

High-Voltage Test Probe

Many VOMs are designed to measure up to 5,000 to 6,000 volts or more, with the test leads provided. No attempt should ever be made to
5 measure voltage any higher than that for which the meter was designed, unless a high-voltage probe is employed (Fig. 10). It is better to obtain a high-voltage probe made for your instrument rather than to construct one or adapt one made for another VOM.

The voltage-dropping or multiplier resistor contained in the specially designed handle of a high-voltage probe, makes it possible to adapt a VOM for measuring higher voltages.

Courtesy Triplett Electrical Instrument Co.

Figure 10 - High-voltage test probe.

The resistor value is selected by the manufacturer to match the voltmeter ranges and sensitivity. Instructions, accompanying the high-voltage probe, list the ranges and multiplying factors for interpreting the readings.

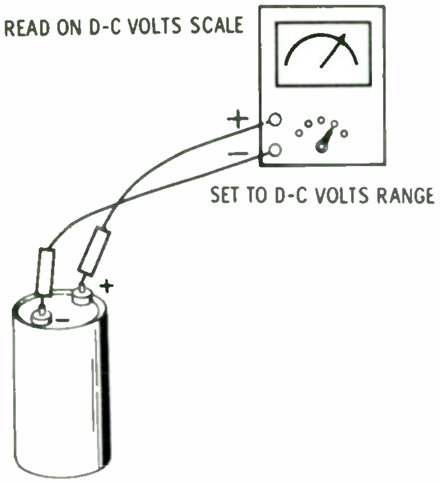
The method of operation of a high-voltage test probe is fairly simple. Suppose a particular meter is rated at 20,000 ohms per volt. Then, on the 3-volt range the VOM has a resistance of 60,000 ohms. To measure up to 30,000 volts when the VOM is set to the 3-volt range, a total measuring-circuit resistance of 30,000 x 20,000, or 600 megohms is required. The multiplying resistor in the handle of the probe must then have a value of 600,000,000 − 60,000, or 599,940,000 ohms. In use, the common lead of the VOM would be connected to one side of the high-voltage source and the tip of the high-voltage probe to the other side. With the range switch set to 3 volts, the reading is obtained from the 3-volt scale, multiplying the reading obtained by 30,000/3, or 10,000. However, rather than dealing with the cumbersome multiplier 10,000, you could use the 3-volt range setting of the selector switch, reading from the 300-volt scale and multiplying the reading by 100. The high-voltage probe can be adapted for use at other high-voltage ranges by employing other settings of the range-selector switch, other scales on the meter, or both.

An important feature of a high-voltage probe is that it is designed to protect the user from shock. The flange located near the upper end of the handle (Fig. 10) is to prevent the user from placing his hand too close to the high-voltage end of the voltage-dropping resistor or too close to the high-voltage circuit being measured. The dropping resistor is made physically long (or consists of several resistors in series) to distribute the voltage gradient over a path as long as possible. This long path helps to prevent arcing in the resistor and reduces the danger of shock to the user.

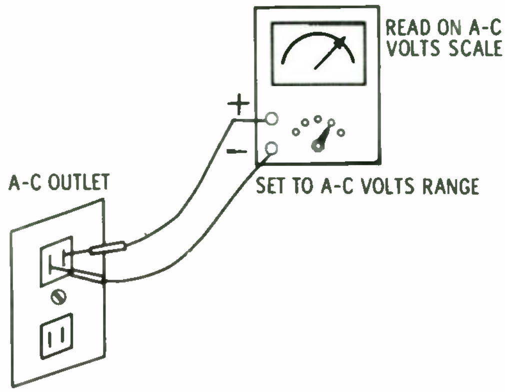
DC VOLTAGE MEASUREMENTS

In preparing to make a DC voltage measurement, first be sure that the two test leads are in the proper jacks. Usually, the black test lead should be in the common or minus (−) jack, and in most VOMs the red test lead should be plugged into the Plus (+) or Volts jack. If there is a switch marked volts-amps-ohms, or AC/DC, be sure that the switch (or switches) is set to volts and DC.

Next, from a schematic or another source, estimate what the voltage to be measured is. Then, with the range switch, select a range that is considerably above this voltage. Turn off the circuit being measured and make sure that no charged capacitors are in the circuit; then connect the test leads across the two points or source of voltage to be measured, as in Figure 11. Connect the black test lead to the



A - Dc measurements.



B - Ac measurements.

Figure 11 - DC and AC voltage measurements.

minus side of the circuit and the red test lead to the positive side. Then, standing clear, turn the circuit or equipment on, and note the reading. If the pointer appears to be deflecting backwards, either the polarity of the voltage is opposite to what you had assumed, or you have the test leads reversed in the circuit. You must turn off the equipment, reverse the leads, turn it on again, and once more note the reading. If the pointer does not come to rest in the upper 2/3 of the scale, turn the range switch to the next lower voltage position; if the pointer is still below the 2/3 point, move the switch to the next lower setting, and so on. Then, making sure that you are looking at the correct scale for the range you have selected, note the value that the pointer is indicating. For some ranges, the value can be read directly from the scale; for others, it will be necessary to multiply the reading by 10 or 100. For instance, on the 300-volt DC range, if the associated scale is labeled from 0 to 30 and the pointer indicates 25 (Fig. 12), you are actually reading 250 volts. Similarly, if the same 0-to-30 scale is used for the 0-to-3 volt range and a reading of 25 is obtained, the voltage is actually 2.5 volts.

In many meters, however, there is a printed scale for each of the ranges provided; thus multiplying, dividing, or interpreting the readings obtained is seldom necessary.

Voltage measurements can be made in many cases without turning off the equipment or circuit, if the technician has gained sufficient experience to exercise the proper precautions.

AC VOLTAGE MEASUREMENTS

The procedure for making AC voltage measurements is similar to that for DC voltage. Begin by making sure the pointer is at zero; plug the black lead into the minus jack, the red lead into the plus or AC jack; set the AC/DC switch (if there is one) to AC, and set the range switch to an AC range somewhat higher than the rms

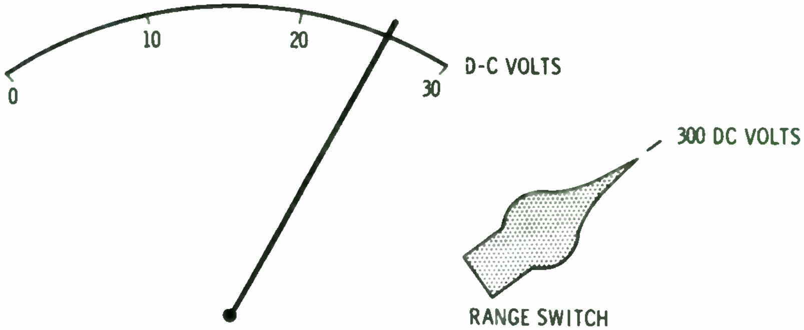


Figure 12 - Setting of range switch and position of pointer for measuring 250 volts DC.

value of the estimated voltage to be measured. Check to see that the equipment is turned off. Connect the test leads across the points at which the voltage is to be measured, as in Figure 11B; then turn on the equipment and observe the pointer. If there is no deflection, or only a little deflection, set the range switch to the next lower range, as required, until the pointer is in the upper 2/3 of the scale.

On many VOMs there may be some difference between the AC scales and the DC scales, so make sure that you use the correct scale or scales for AC. Note in Figure 13 that although the ranges provided for DC measurements are the same as for AC measurements, a different set of scales is provided for each on the meter faceplate. The

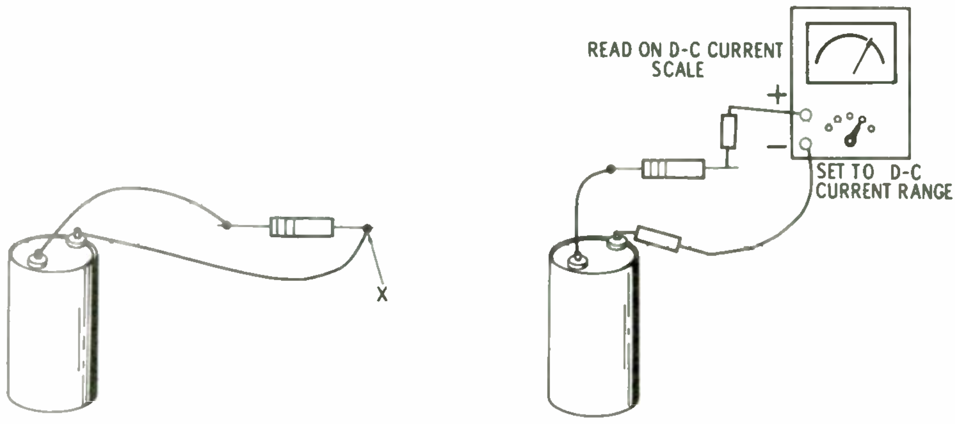
Courtesy Triplett Electrical Instrument Co.

Figure 13 - Difference between AC and DC scales at lower voltage values.

corresponding markings substantially coincide for the high values on both ranges, but for the lower values they do not coincide, as shown by the broken line. Also, as shown, a completely separate scale is provided for the 3-volt AC range. After practice it should be easy to automatically select the proper set of scales for AC or DC measurement.

DC CURRENT MEASUREMENT

For measuring DC current with a VOM, the circuit in which the current is flowing first must be turned off, and then opened; such as at point X in Figure 14. The range switch of the VOM should be set to the current range required. The test leads are then connected in series with the break in the circuit, as shown in Figure 14, and the equipment turned on. The current is read on the DC voltage scale. If the meter indicates somewhat below 2/3 deflection, the range switch should be set to the next lower current range. If a backward reading is obtained, the test leads should be reversed, or, if a polarity switch is provided, it should be turned to the opposite direction. When a VOM is set for measuring current, NEVER connect the test leads across a live component or source of voltage; this could burn out the meter movement.



A-Breaking circuit under test.

B-Insertion of meter in circuit.

Figure 14- Reading current.

As previously mentioned, most VOMs do not provide for AC current measurement.

MEASUREMENT OF RESISTANCE

To measure resistance, the range switch is rotated to the correct ohms range, depending on the value of the resistance to be measured. For example, if the ohms mid-scale value is 5 ohms, and the estimated value of the resistor being measured is 300 ohms, the range switch should be set to R x 100. If no R x 100 range is provided, the most suitable range is selected to obtain a pointer deflection near mid-scale.

Before making the resistance measurement, short the tips of the test probes or clips together, and adjust the ohms zero knob for exactly 0 ohms reading at the extreme right of the scale. Next, connect the test probes across the resistor as shown in Figure 15. When measuring a resistor in a circuit, at least one end of the resistor should be disconnected from that circuit so that other components in the circuit will not affect the resistance value indicated on the VOM. If it is necessary to change the ohms range, the pointer should again be set to zero ohms while touching the probe tips together. This calibrates the range in use and assures greater accuracy.

The same scale is used for all resistance readings, with the scale values multiplied by 1, 10, 100, etc.; these multipliers are determined by the setting of the range switch. On the higher resistance ranges, touching the ends of the resistor or test-probes with the hands can affect the resistance reading. This is because the body is then connected across the resistor being measured and this parallel resistance lowers the effective value. For high-resistance measurements, touching the resistor or probes should be avoided. One method of preventing this in resistance measurements is to use clips rather than probes to connect to the resistor, thus permitting you to be entirely free of the measurement.

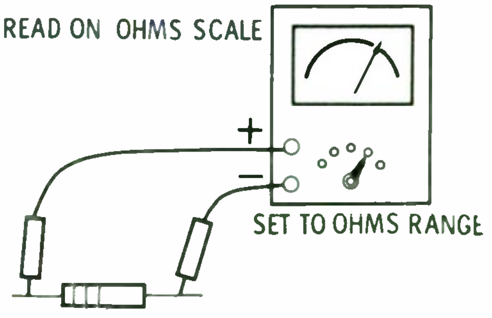


Figure 15 - Reading resistance.

OUTPUT MEASUREMENT

The output-measurement facility of a VOM is utilized in measuring the audio output voltage from an amplifier across a speaker, or at the input to an amplifier stage. The output measurement is taken in the same way as an AC measurement, except that, if an AC/DC output switch is provided on the VOM, it should be set to output. This inserts a capacitor in series with one of the test leads, which blocks out any DC present in the circuit that is being measured. The associated AC scale is read for the output value.

Sometimes it is desired to interpret the AC output value obtained in terms of decibels (db). If the VOM includes a db scale, the value in db can be interpreted from that scale. The db value depends on the AC range being used. For example, for the VOM of Figure 13, if the 3-volt AC range is used, read the db value directly from the db scale; when the 12-volt AC range is being used, read the value from the db scale, and add 12 db; if the 60-volt range is being used, read the value from the db scale, and add 26 db, and so on. Note that these instructions are provided in the lower right corner of the meter faceplate. This particular VOM has been calibrated so that the value of 0 db is 1 milliwatt on a 600-ohm line. The db values are, therefore, only relative if the measurement is not on a 600-ohm circuit. The db values may be converted to a standard reference of 6 milliwatts in a 500-ohm line by subtracting 7 db from the readings obtained by the methods just described.

PRECAUTIONS IN USE OF VOM

Caution is essential when working on, or when using the VOM to make measurements on, electrical and electronic equipment. You should always be alert to the possibility that the same cause of faulty operation might also cause dangerously high voltage to be present at places least expected.

A good practice is to work with one hand behind you or in your pocket. This is some protection against getting across points of potential difference. Be sure to avoid standing on conductive, damp, or wet surfaces when making measurements; instead, if possible, stand on a dry board. Try to stand clear of the equipment, so that other points on your body do not touch the equipment when you are connecting or disconnecting a test lead.

When making resistance measurements, be sure the power is off and that all capacitors that might hold a charge have been discharged by shorting across their terminals with an insulated test lead or a screwdriver having an insulated handle.

Fuse Replacement

Should the fuse in the VOM blow, it should be replaced only by an identical fuse. If the fuse is one with a conventional element, it should never be replaced by a slow-blow type of fuse, for this reduces the margin of protection to the meter movement. A fuse in a typical VOM will be a 1-ampere, 250-volt, 3AG type; fuses of other ratings may also be encountered in some meters.

If the VOM fails to respond on all functions, it is possible that either the fuse is open, one of the test leads is open, or there is a break in the wiring to one of the jacks. The meter movement may be defective if there is no response on any function.

THE VTVM: HOW IT WORKS

An important part of the operating principle of the vacuum-tube voltmeter (VTVM) is the same as that of the VOM. Current flowing through a d'Arsonval meter movement causes a pointer deflection proportional to the intensity of the current.

VTVMs are also much like VOMs in appearance. Examples are shown in Figures 16 and 17. The unit in Figure 16 is typical of moderate-cost but reliable VTVMs of good performance. The one in Figure 17 is representative of VTVMs designed for maximum versatility and usefulness, and is somewhat more costly. These two units represent the extremes of VTVMs that the average user employs for measurements in servicing and troubleshooting.

In addition to commercially built VTVMs, there are kit types that the purchaser can build from parts provided by the manufacturer. An example is shown in Figure 18. Assembling a kit can save the purchaser a good percentage of the cost of a VTVM, if he has the time to assemble it. Assuming that the directions are followed carefully for assembly and calibration, and good soldering practices are employed, a kit VTVM can approach the best commercial models in performance.

Courtesy EICO Electronic Instrument Co., Inc.

Figure 16 - EICO model 235 VTVM.

Courtesy Radio Corporation of America

Figure 17 - RCA WV-87B Master VoltOhmyst.

ADVANTAGES AND DISADVANTAGES OF THE VTVM

The major difference between the VOM and the VTVM is that in the

Reproduced with the permission of Heath Company, Benton Harbor, Michigan.

Figure 18 - Heathkit Model IM-13 VTVM.

VTVM one or more vacuum tubes are employed in the circuit. This has the following advantages, as compared with the VOM:

8
1. Higher input resistance.
2. Lower input capacitance.
3. Greater sensitivity.
4. Less sensitive, lower-cost meter movement is used.

The higher input resistance permits measurement in circuits having high impedance or resistance with less loading effect than with the typical VOM. The lower input capacitance of the VTVM makes possible measurement of AC voltage at higher frequencies than are possible with the VOM. The greater sensitivity of the VTVM, provided by one or more stages of amplification, makes possible the measurement of lower values of voltage and higher values of resistance. The use of the less-sensitive, lower-cost meter movement is made possible by the amplification provided in the VTVM circuit.

These advantages are of sufficient importance, in many cases, to overlook some disadvantages of the VTVM, which are:

1. The VTVM is less stable than the VOM; the VTVM requires a warm-up time for its greatest accuracy.
2. It must be calibrated more frequently.
7
3. An external source of power is usually required.
4. The more complex circuitry is subject to more frequent trouble.

The reason for some of these advantages and disadvantages will become apparent later when the circuits of VTVMs are discussed.

VTVM PRINCIPLE

Basically, the VTVM consists of an input circuit, an amplifier, and a meter movement, as shown in Figure 19. It is because a vacuum-tube amplifier has a high input resistance that a VTVM causes less loading when it is connected to a circuit for voltage measurement. The input resistance for typical VTVMs is 10 or 11 megohms or more, on most of the voltage ranges.

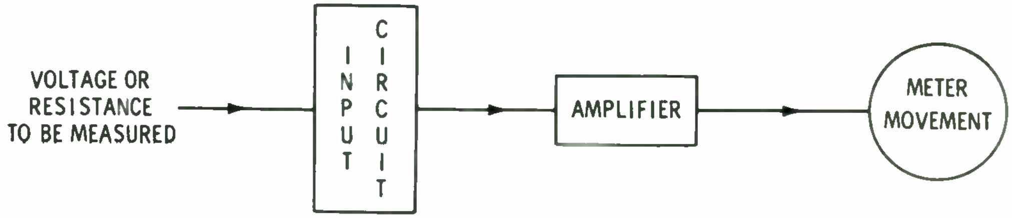


Figure 19 - Block diagram of VTVM circuit.

Simple VTVM

The simplest type of VTVM for measuring DC voltage is shown in Figure 20. The 1-megohm resistor built into the probe is mainly responsible for minimizing the VTVM input capacitance, or capacitive loading effect. It serves to isolate the VTVM circuits from the circuit being measured. The input resistance of this VTVM circuit consists of the 1-megohm probe resistor and the 10 megohm grid resistor, a total of 11 megohms. The battery provides a bias for the triode amplifier tube, keeping it at cutoff until the test leads are placed across a positive or an AC source of voltage.

If the voltage being measured is DC, the positive voltage contacted by the probe lowers the bias on the amplifier grid and causes current to flow through the tube and meter movement in proportion to the amplitude of the positive voltage.

If the voltage being measured is AC, the negative half-cycles of the AC voltage have no effect on the amplifier and meter current, since the amplifier is biased at cutoff and the negative AC alternations will increase the bias even further. On positive half-cycles, however, amplifier current will flow, the average amount of current causing a proportional deflection of the meter pointer.

This simple triode circuit is not used in practical VTVMs however, mainly because if the voltage to be measured exceeded the bias voltage,

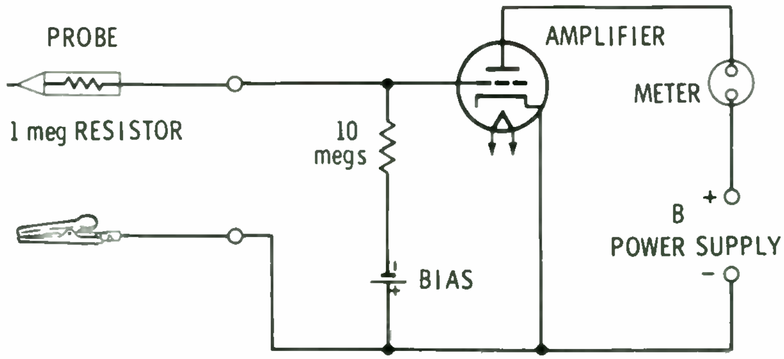


Figure 20 - Schematic of basic VTVM circuit.

the grid would draw current, loading the circuit under test, and resulting in an inaccurate indication on the meter. Another reason is that the probe may be connected only to a positive voltage; there is no provision for measuring negative voltage.

Practical VTVM Circuit

The basic circuit used in many VTVMs is shown in Figure 21. The arrangement in Figure 21A is for measurement of positive voltage. The circuit in Figure 21B (the same as the one in Figure 21A except for the point to which the probe is connected) is for measurement of negative voltage.

The basic vacuum-tube voltmeter circuit of Figure 21 is known as a bridge circuit — the meter movement
9 is "bridged" between the plates of two identical vacuum-tube circuits. Suppose no voltage is being measured; the grids of V1 and V2 are at the same potential with no grid voltage applied to V1. Under this condition the currents through the tubes are equal, and their plates are at the same potential. With the same potential at each side of the meter, no current flows through the meter, so the pointer indicates zero. If it does not indicate zero, the ZERO ADJUST control is adjusted so that the indication is zero.

VTVM DC VOLTAGE MEASUREMENT

When the test leads in Figure 21A are connected across a source of voltage, with the probe connected to the more positive point, the current through V_1 increases, causing a voltage drop in R_2, thus decreasing the voltage on the left side of the meter movement. With the right side of the meter now more positive than the left, current flows through the meter, its value proportional to the voltage applied to the grid of V_1. The current in V_2 does not change, since its grid is grounded. The calibration (CAL) control in series with the meter is not an operating control; it is adjusted only at the time of calibration of the meter for exact indication of the pointer.

For measurement of negative voltage, a switching circuit in the VTVM usually transfers the test leads to the opposite triode, V_2, and grounds the grid of triode V_1, as shown in Figure 21B. Now, with a negative voltage on the probe tip, the current in V_2 decreases, the voltage at right side of the meter increases, and current again flows through the meter in the same direction as that for the circuit in Figure 21A.

As is shown in the schematic, the voltage being measured is applied to the input of each of the vacuum tubes, not to the meter itself. Thus, the meter is isolated from the circuit under test and is relatively safe from damage due to overload.

VTVM MEASUREMENT OF AC VOLTAGE

For the measurement of AC voltage, the same circuit of Figure 21 is used but is preceded by a rectifier circuit (Fig. 22A). When AC voltage at the probe swings positive, diode V conducts through resistance R, at the same time charging capacitor C_2 to the peak value of the AC input voltage. Resistor R is of high value, so C_2 does not discharge completely before the next half-cycle charges it again. The voltage to the grid of the bridge amplifier is approximately

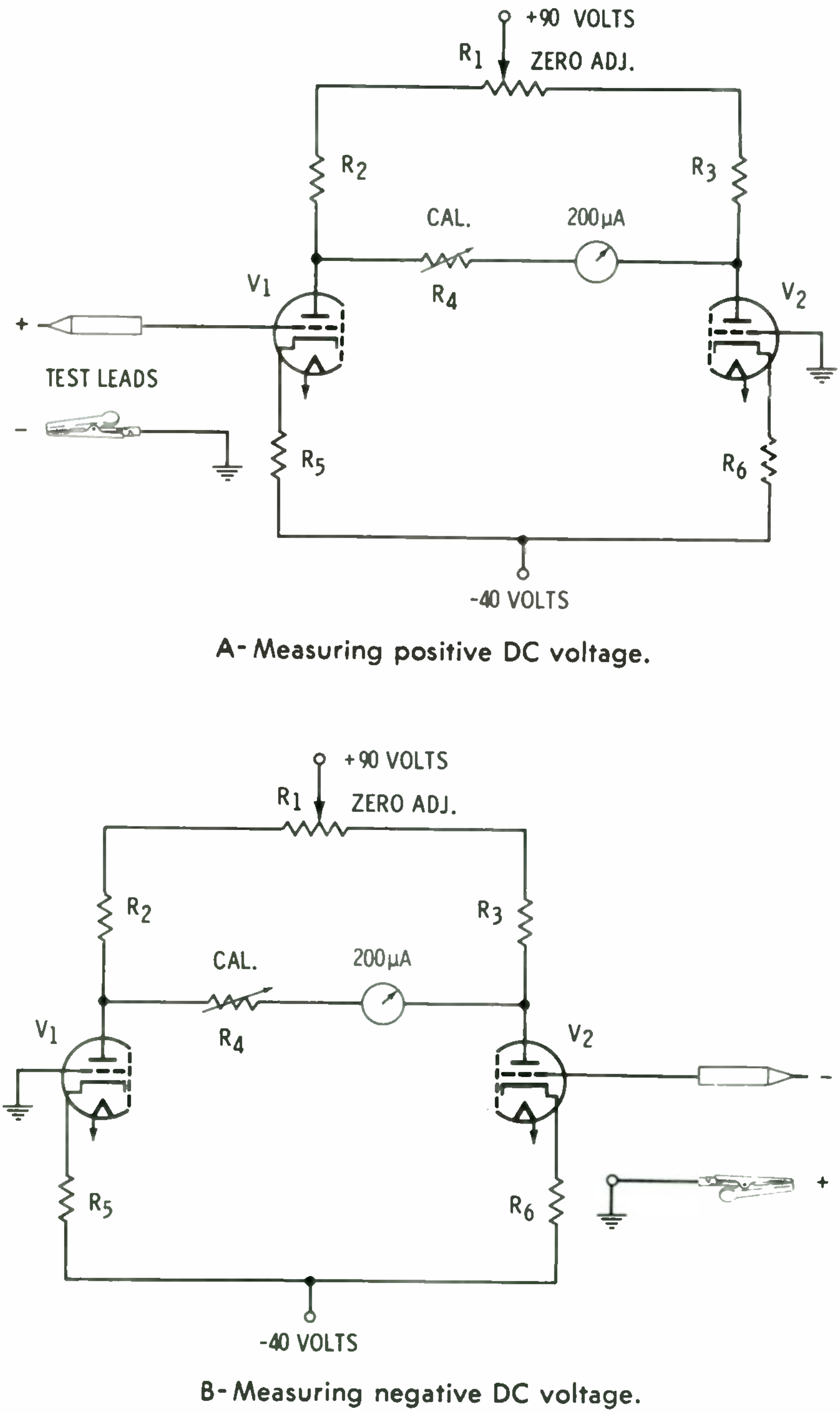
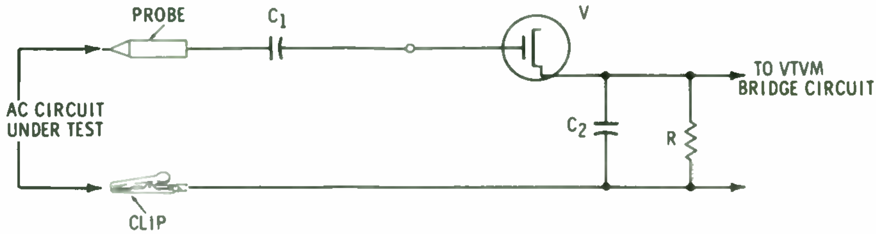
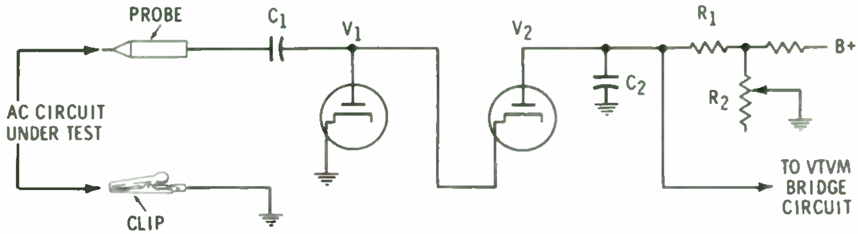


Figure 21 - Practical amplifier circuit for VTVM.



A- Basic half-wave rectifier circuit.



B-Voltage-doubler rectifier circuit.

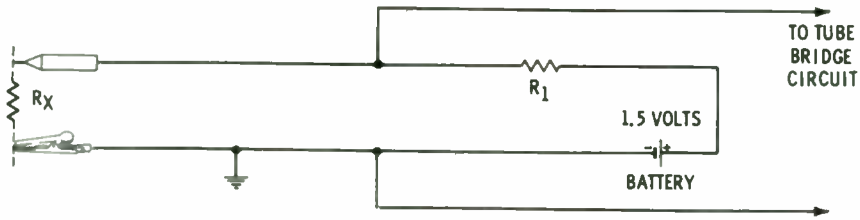
Figure 22 - VTVM rectifier circuits for AC voltage measurement.

equal to the peak value of the AC input voltage.

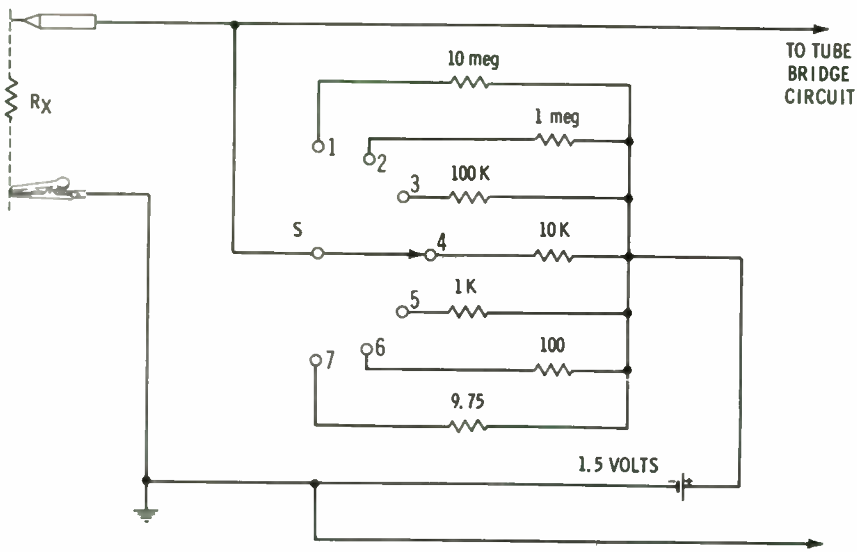
Often the rectifier for AC voltage measurement in a VTVM is a twin-diode voltage-doubler rectifier, similar to that shown in Figure 22B. When the AC input voltage goes positive, capacitor C_1 charges through diode V_1 to the peak value of the positive voltage. As the AC voltage swings through zero toward negative, V_1 stops conducting; C_1 remains charged to the peak voltage, since it has no discharge path. With the input signal now negative, C_1 discharges through diode V_2 which conducts through C_2. The charging voltage for C_2 is now the sum of the input voltage and that of C_1, or the total of the positive and negative peaks. Thus, the rectifier circuit provides the grid or input of the bridge circuit with a peak-to-peak voltage for the deflection of the meter movement. The scale, however, will be calibrated in terms of rms for sine-wave voltage and, sometimes, for peak and peak-to-peak values. Potentiometer R_2 permits adjustment for zero deflection of the pointer when a zero-volt input is applied.

VTVM RESISTANCE MEASUREMENT

For measurement of resistance, the input circuit to the VTVM bridge is basically that shown in Figure 23A. When the test leads are shorted together, there will be no deflection of the pointer—a zero-ohms calibration control (not shown here) is adjusted for 0 ohms reading. Then, with the test leads open, the 1.5-volt battery in series with R_1 is across the input circuit, and the meter is deflected full scale (adjusted exactly by means of an OHMS ADJUST control, not shown here). When the test leads are then connected across an unknown resistor R_x, the deflection of the pointer will be in proportion to the value of R_x. Thus, in the VTVM,



A-Basic VTVM ohmmeter circuit.



B-Switch and range resistors added.

Figure 23 - VTVM resistance-measuring circuit.

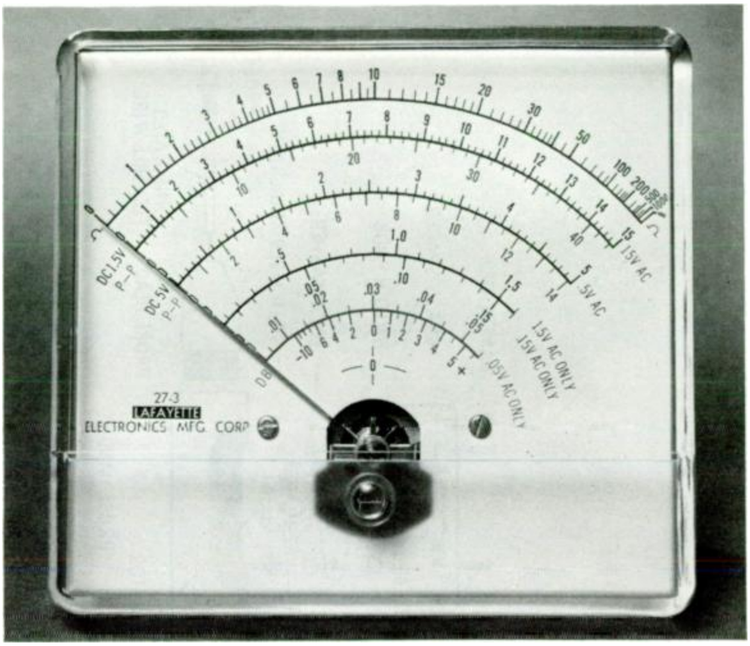
as is apparent on the Ohms (top) scale of the VTVM faceplate of Figure 24, the greater the resistance, the greater the deflection. This is opposite to the effect in the VOM, where deflection of the pointer is less when the resistance value of the unknown resistance is increased.

In Figure 23A, when the unknown has the same value as R_1, the deflection is midscale, since R_1 and R_x then form a 2:1 voltage divider that applies half the battery voltage to the input circuit of the bridge.

Shown in Figure 23B is the same circuit, but with a switch and additional resistors added for providing 7 resistance-measurement ranges. In position 1 of Switch S, the midscale reading of the VTVM is 10 megohms; in position 2, the midscale reading is 1 megohm; in position 3 it is 100K, and so on to the lowest range.

VTVM CURRENT MEASUREMENT

The facility to measure current is not usually provided in a VTVM, although some models do include this facility. One of the advantages of a VTVM is that a less-sensitive meter



Courtesy Lafayette Electronics Mfg. Corp.

Figure 24 - Example of VTVM meter faceplate showing differences from the VOM.

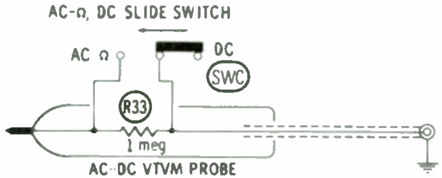
movement is relatively safe from accidental overload. VTVMs that are not designed for current measurement cannot usually measure current. In this type of VTVM, attempting to measure current greatly increases the chance of damage to the meter movement.

In some of the late-model VTVMs, protection to the meter is provided in the form of a zener diode across the movement, or a fuse in series with the movement.

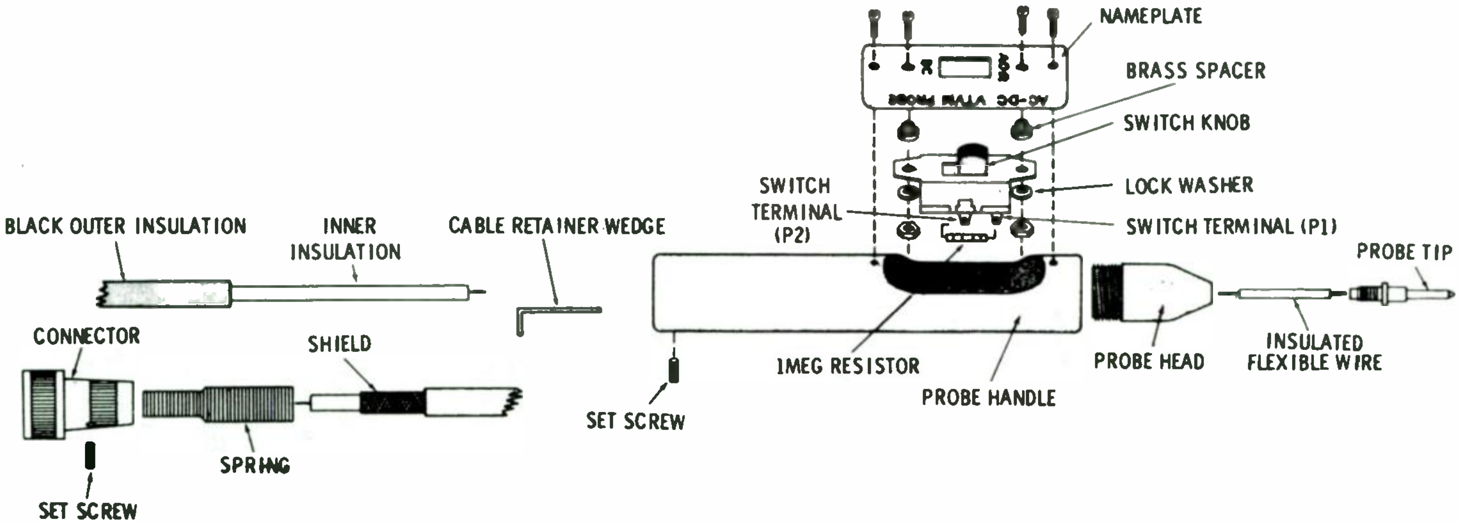
VTVM PROBES

The basic probe for most VTVMs is as previously described. For DC voltage measurement it consists of a housing that contains a 1-megohm resistor in series with the test lead. For the measurement of AC voltage and for the measurement of resistance, the 1-megohm series resistor is not used. So either another probe is used, or a switch is included in the probe for shorting out the 1-megohm resistor in the AC-voltage and ohms functions. The circuit of a typical probe is shown in Figure 25A, with the switch in the DC-volts position (1-megohm resistor in the circuit). In the opposite position of the switch, used for AC and ohms, the 1-megohm resistor is shorted out. An assembly view of this probe is shown in Figure 25B. The assembled probe is shown in Figure 26. A coaxial connector is used for the shielded probe lead.

For the measurement of high-frequency AC voltage, an additional probe that is called an RF probe may be utilized with a VTVM. In an RF probe, a diode is built directly into



A- Circuit of VTVM probe.



B-Assembly view.

Courtesy Precision Apparatus Div. of Dynascan Corp.

Figure 25 - Probe for measurement of AC, DC, and ohms.

Courtesy Precision Apparatus Div. of Dynascan Corp.

Figure 26 - VTVM single probe for AC, DC and ohms.

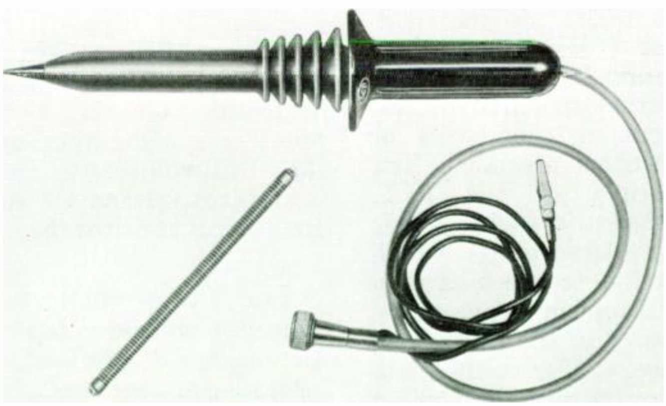
the probe. In this way, capacitive loading from the VTVM on the circuit under test is kept at a minimum; also, the VTVM is able to measure a higher frequency range since the output from the probe diode is DC voltage. Therefore, the capacitance of the cable and the VTVM input circuit has no reactive attenuating effect on the signal being measured.

The VTVM, like the VOM, can also be used to measure voltages greater than those for which it was basically designed. This is done by means of a high-voltage multiplier probe (Fig. 27). This probe is similar to the VOM high-voltage probe described earlier. Because of the higher average input resistance of the VTVM, a VTVM high-voltage probe has considerably less loading effect on a high-resistance, high-voltage circuit than does the VOM high-voltage probe.

For a VTVM having an 11-megohm input resistance, the value of the series multiplier resistor, which is in the handle of the high-voltage probe, is 1,089 megohms for a 100:1 voltage reduction. The 1,089 megohms adds to the 11-megohm input resistance of the VTVM, giving a voltage divider having 1,100-megohms total input resistance. The input to the 11-megohm VTVM measuring circuit is 1/100 of the high voltage being measured. The probe may be used on any of the VTVM voltage ranges where the input resistance is 11 megohms.

SOLID-STATE ELECTRONIC VOM

Transistor electronic volt-ohm-milliammeters, an example of which is shown in Figure 28, are being used in substantial numbers. Eventually, they probably will replace the VTVM to a great extent and the VOM to a lesser extent, since they offer most of the advantages of both of these instruments: they are small, lightweight, compact, battery-operated, portable,



Courtesy Radio Corporation of America

Figure 27 - High-Voltage probe and high-voltage multiplier resistor.

Courtesy Sencore, Inc.

Figure 28 - Sencore Model FE16 FET VOM.

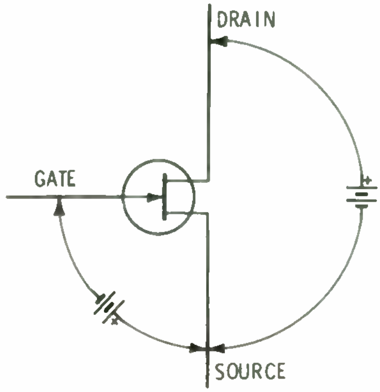


Figure 29 - Voltages applied to FET.

versatile, and they require no warmup time.

Most transistor VOMs are designed around circuits which use the field-effect transistor (FET), but others employ conventional transistors especially selected for particular characteristics. Sometimes matched pairs or groups of transistors are used. The operating principle of the FET, schematically shown in Figure 29, is as follows. A negative voltage, which is similar in action to the bias of a vacuum tube, is applied between the *gate* and the *source* of the FET. Also, a positive voltage, similar to the plate voltage of a vacuum tube, is applied between the *drain* and the source, establishing a current between source and drain. When the gate is biased negatively enough, "pinch-off" (like "cutoff"in a tube) occurs, stopping the drain current. With typical operating voltages applied to the gate, source, and drain, a more-negative gate bias results in less drain current, and a less-negative gate bias results in more drain current. The negative voltage between the gate and source results in neglible gate current; thus the gate-to-source impedance is high. The input signal is normally connected between the gate and source. It is it's high input impedance which makes the FET popular in solid-state measuring instruments.

A simplified solid-state metering circuit is shown in Figure 30. Transistor Q_1 is a FET which provides a high-impedance input for the DC voltage to be measured. Transistors Q_2 and Q_3 are part of the amplifier that drives the meter, M_1.

For the measurement of AC voltages, the same basic circuit may be employed, but with the addition of a rectifier circuit as for the VOM and VTVM. For the lowest-range AC measurement, sometimes an additional amplifier stage is added.

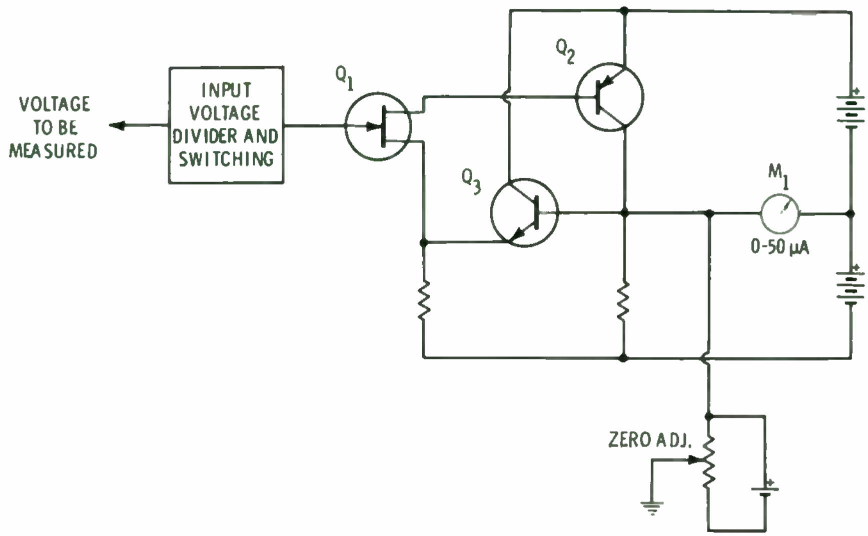


Figure 30 - Simplified solid-state metering circuit.

A solid-state ohmmeter circuit also can be based on the arrangement of Figure 30. In most respects, it is similar to the ohmmeter circuits of the VOM and VTVM.

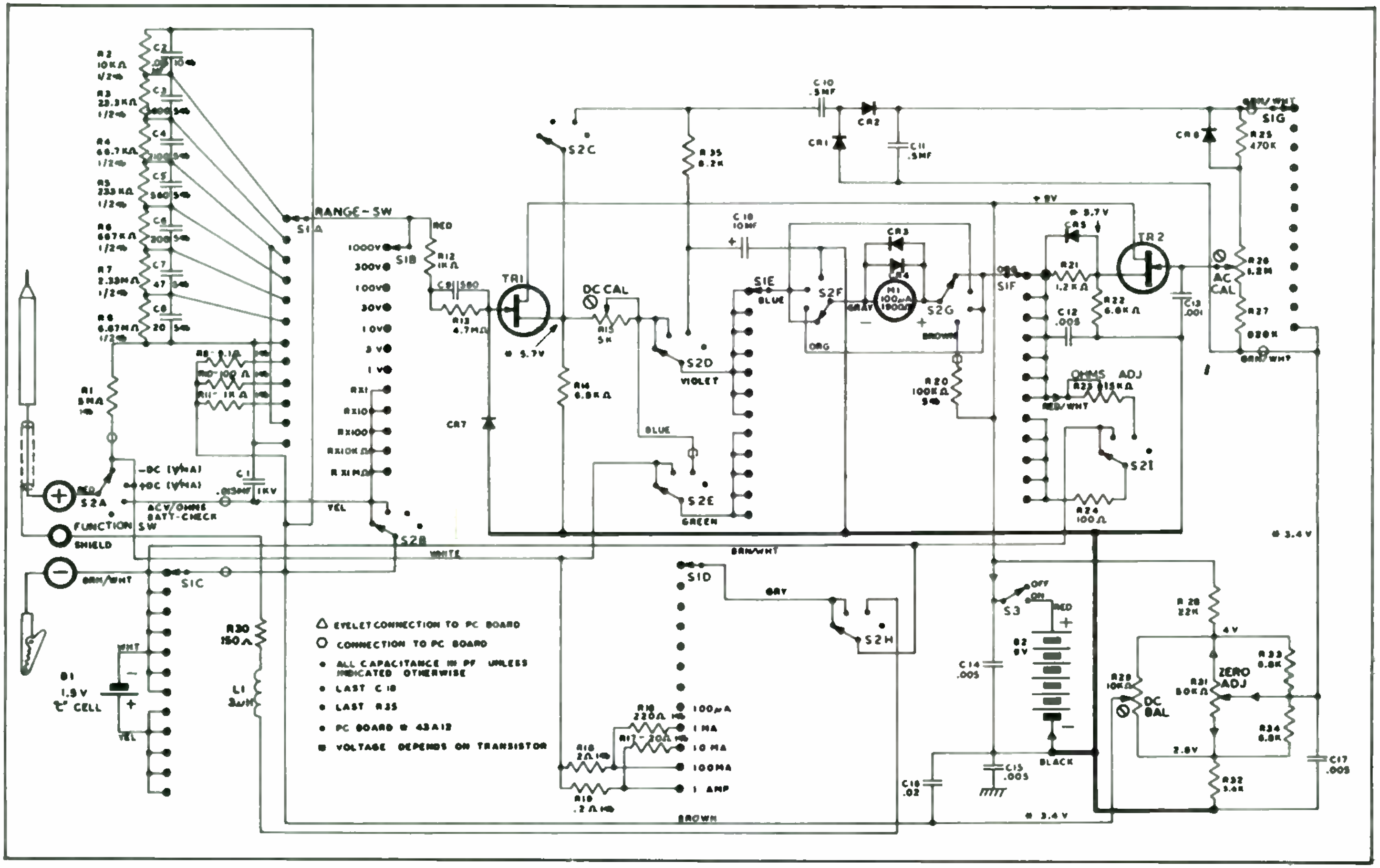
SPECIAL FEATURES OF SOLID-STATE INSTRUMENTS

Aside from offering most of the usual measurement facilities of typical VOMs and VTVMs, a particular solid-state meter often will include special features or characteristics of its own. For example, on the instrument of Figure 28, the function switch (lower left) includes a "Batt" position for checking the condition of the batteries powering the solid-state circuit. Other features include 10-megohm input impedance for AC voltage measurement, 15-megohm input impedance for DC voltage measurement, peak-to-peak AC ranges, zero-center ranges, DC current ranges, mirrored scale for greater accuracy of reading, overload protection of meter circuit, and circuit protection from accidental connection to wrong voltages.

CIRCUIT OF SENCORE FE16

The circuit of the Sencore FE16 FET meter is shown in Figure 31. The following description of the circuit operation is adapted from the manufacturer's service manual.

Field-effect transistors TR1 and TR2 in the differential amplifier circuit are for DC-volts and ohms measurements. With no voltage applied to the input of TR1, the ZERO ADJ control (R31) is set so that the voltages developed across source resistors R14 and R22 are equal; then there is no current through the meter. The DC BAL control (R29) is an internal adjustment that serves the same purpose as the ZERO ADJ control. It is used to compensate for component tolerances. When a DC voltage is applied to the input of TR1, the balance between TR1 and TR2 is



Courtesy Sencore, Inc.

Figure 31 - Schematic of Sencore Model FE16 FET meter.

upset, and the meter is deflected in proportion to the voltage applied. Seven DC and AC ranges are provided with the input divider, R1 through R8. Capacitors C2 through C8 compensate the divider, for AC voltages. The DC CAL control (R15) is an internal adjustment used to calibrate the meter when a known DC voltage is applied to the input. When a very high voltage is applied to the gate of TR1 (Range switch set incorrectly), diode CR7 conducts and limits the voltage applied to TR1 to a safe level to prevent destruction of the transistor.

Even though field-effect transistors are "solid-state," they perform like vacuum tubes. The gate (grid) controls the current between the source (cathode) and drain (plate) by the effect of the electrostatic field between the gate and the source (bias). There is no gate current; therefore, the input impedance is extremely high. Since the FET does not have a cathode to "wear out," the FET meter is more stable and less subject to change than the conventional VTVM.

Resistance measurements are made by forming a voltage divider with an unknown and a known resistor. The voltage that is developed across the known resistor is directly proportional to the unknown resistance. In Figure 31, R9 is the known resistor for the R x 1 range, R10 for the R x 10 range, etc. By reading the voltage drop across R9, R10, etc. we can determine the value of an unknown resistance, across the probes. Initially, with leads shorted together, the OHMS ADJ control (R23) is set so that the meter reads at full scale with full potential from B1 applied to TR1. As external resistance is placed between the leads, the amount of meter deflection is reduced. The top scale of the meter is calibrated in ohms.

For AC voltage measurements, the voltage is applied to TR1 through divider R2-R8, as with DC volts. The output of TR1 is fed to a peak-to-peak detector consisting of C10, C11, CR1, and CR2. The DC voltage developed at the source of TR2, and consequently the meter indication, is proportional to the peak-to-peak AC voltage applied to TR1. Diodes CR5 and CR6 compensate for changes in temperature so that meter indications remain accurate over a wide temperature range.

DC current measurements are made using the meter and shunt resistors R16 though R19. The transistors and associated circuitry are not used. On the 100-microampere range, the meter is connected directly into the circuit. Diodes CR3 and CR4 protect the meter movement from overloads up to several amperes. The diodes are protected with resistor R24, which will burn out if the maximum current rating of the diodes is exceeded; R24 is a 100-ohm, ½-watt unit.

FEATURES OF RCA WV-500A SOLID-STATE VOLTOHMYST

Another example of a typical solid-state instrument is the RCA WV-500A solid-state *VoltOhmyst*, shown in Figure 32.

Available accessories which extend the usefulness of the instrument include a crystal-diode probe for increasing the frequency range to 250 MHz, a high-voltage probe for increasing the DC voltage range to 50,000 volts, and a current measuring adapter for current measurement from 1 microampere to 5 amperes in six ranges.

The design of the RCA WV-500A is based on a linear, stable four-transis-

Courtesy Radio Corporation of America

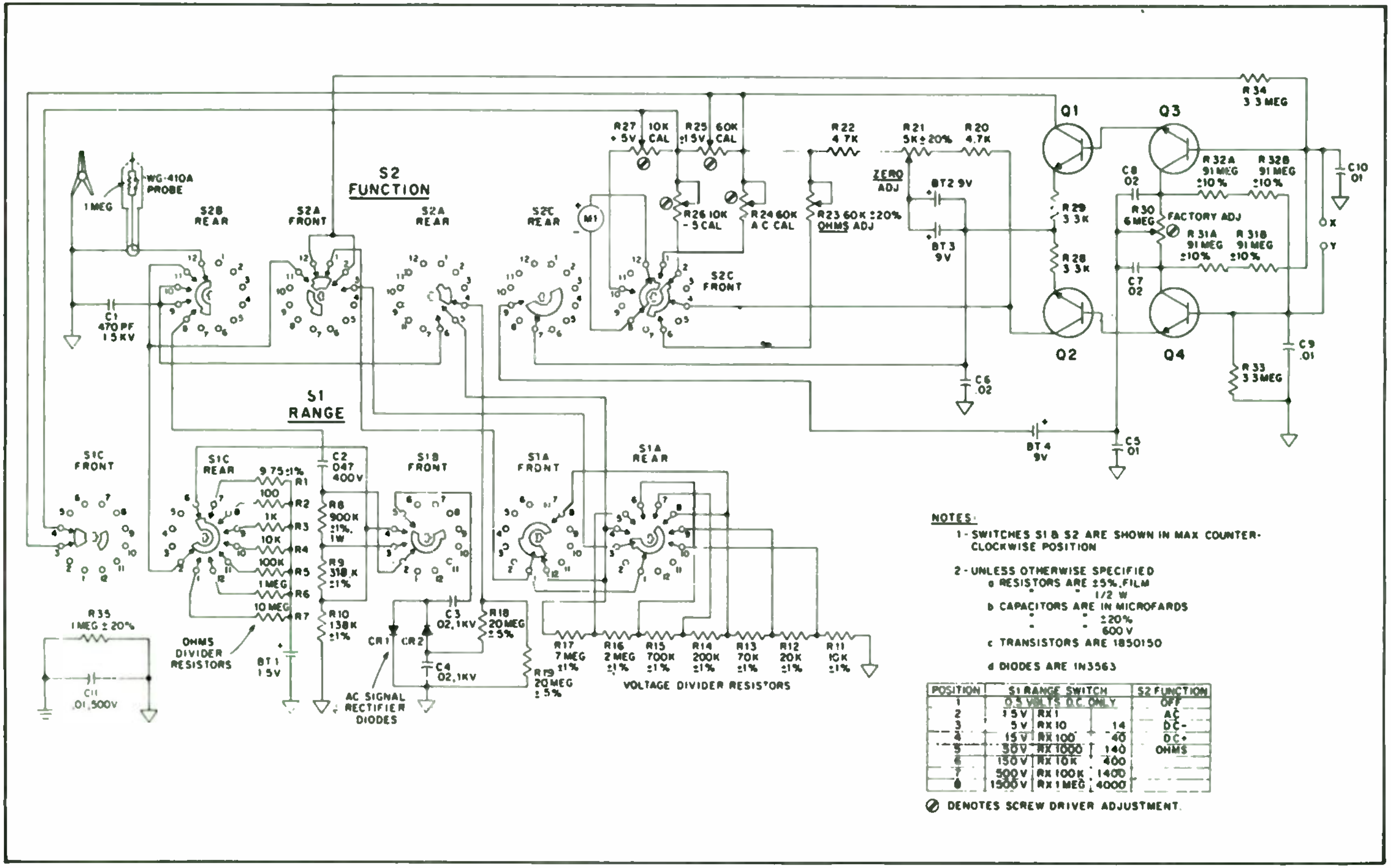
Figure 32 - RCA WV-500A solid-state VoltOhmyst.

tor amplifier circuit of high input impedance (Fig. 33). The input voltage to be measured, from the voltage or Ohms divider, is applied between the bases of Q3 and Q4, positive to the Q3 base and negative to the Q4 base. These transistors provide a very high input impedance which is achieved through a positive-feedback network, R31A, R31B, R32A, and R32B. Transistors Q3 and Q4 serve as preamplifiers driving the bases of Q1 and Q2. In effect, transistors Q3 and Q1 amplify the positive portion of the signal, and Q4 and Q2 amplify the negative portion of the signal.

Negative feedback through R28 and R29 results in high impedance at the Q1 and Q2 bases to prevent loading the Q3 and Q4 emitters. The output of Q1 and Q2 drives the meter.

Potentiometer R30, factory-adjusted, balances the Q3-Q4 input. The front panel ZERO control, R21, balances the amplifier output with no input signal applied.

Resistors R33 and R34 isolate and protect the amplifier circuit. Bypass capacitors C5 though C10 prevent AC signals from affecting the metering circuit.



POSITION	S1 RANGE SWITCH			S2 FUNCTION
1	0.5 VOLTS D.C. ONLY			OFF
2	1.5 V	RX 1		AC
3	5 V	RX 10	14	DC-
4	15 V	RX 100	40	DC+
5	50 V	RX 1000	140	OHMS
6	150 V	RX 10K	400	
7	500 V	RX 100K	1400	
8	1500 V	RX 1 MEG	4000	

Courtesy Radio Corporation of America

Figure 33 - Schematic of RCA WV-500A solid state VoltOhmyst.

Accuracy is maintained throughout the usable life of the batteries. Two 9-volt supply batteries, BT2 and BT3, in parallel assure long life. Total battery drain is about 1 mA. The other 9-volt battery, BT4, powers driver transistors Q3 and Q4, and provides bias to the bases of Q1 and Q2. The current drain from this battery is a few microamperes.

DC voltage input is applied through the 1-megohm isolation resistor in the probe to the voltage-divider network, resistors R11 through R17. The voltage from the divider network is then connected to the transistorized metering circuit.

When the instrument is used to measure AC voltage, the signal is first rectified by diodes CR1 and CR2. The circuit components are chosen to provide a long time constant. When the signal swings positive, C3 is charged through CR1 to the peak value of the voltage. As the input signal starts in a negative direction, C4 charges to a value equal to the sum of the positive and negative peaks. Because of the relative time constant, the voltage across C4 will be maintained at very nearly the peak-to-peak value of the AC signal. The resulting DC voltage is fed through the voltage-divider network to the metering circuit.

The voltage from battery BT1, 1.5 volts, is applied through the selected ohms divider resistor (R1 through R7) to the external resistance under test. A voltage divider is formed by the range resistor and the external resistance. The output of this divider is fed to the metering circuit.

CARE OF SOLID-STATE INSTRUMENTS

Solid-state instruments require the same careful handling as the VOM and VTVM, since they contain the same type of meter movement. Also, they are affected by extremes of temperature and humidity.

Batteries in solid-state instruments can be expected to last six months to one year or more; the instrument usually should be turned off when not in use to extend battery life. Batteries may have their useful life shortened somewhat if they are operated in abnormally warm surroundings. If operated in cool or cold surroundings, batteries will last longer, but at about 0° F and below, battery capacity will decrease; below about − 20° F dry-cell batteries will provide no output.

When batteries are replaced, care should be used to be sure that proper polarity is observed. In some instruments, the batteries are soldered into the circuit to ensure proper and continuous contact. When soldering leads to batteries, first "tin" the battery terminals, that is, apply a small coating of solder to the positive and negative terminals. Then it will be easier to solder the leads to the terminals. Instruction manuals for various solid-state instruments contain further directions for determining when batteries should be replaced and how they should be installed or connected.

TEST

Lesson Number 52

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-052-1.

1. The most widely used test instrument in electronic and electrical work is the
A. VTVM.
B. VOM.
C. SSVOM.
D. FET VOM.

2. VOMs can measure
3 - 8 A. current.
B. voltage.
C. resistance.
D. all of the above.

3. The sensitivity of a VOM is defined in terms of
9 A. ohms per volt.
B. volts per ohm.
C. amps per ohm.
D. ohms per amp.

4. Which of the VOMs listed below would produce the smallest *loading effect* on a particular circuit.
10 A. A meter with 3,000 ohms per volt sensitivity.
B. A meter with 20,000 ohms per volt sensitivity.
C. A meter with 30,000 ohms per volt sensitivity.
D. All meters produce the same loading effect.

5. The voltage ranges of a VOM can be extended to measure several thousand volts
A. with current shunts.
10 B. with a high voltage probe.
C. by changing the meter.
D. with a detector probe.

6. **When measuring an unknown DC voltage the range selector should be set to**
   A. the highest voltage range.
   11 B. the lowest voltage range.
   C. AC voltage.
   D. DC current.

7. **VOMs have several advantages over VTVMs. One of these advantages is:**
   A. VOMs have higher input impedances
   17 B. VOMs have greater sensitivities
   C. VOMs require no external power sources
   D. VOMs have more complex circuitry

8. **The major advantage of VTVMs over VOMs is**
   17 A. VTVMs have higher input impedances.
   B. VTVMs are more rugged.
   C. VTVMs are more stable.
   D. VTVMs have higher input capacitance.

9. **In practical VTVM circuits the meter is bridged between two**
   19 A. diodes.
   B. vacuum tubes.
   C. FETs.
   D. transistors.

10. **Major advantages of solid-state VOMs over VTVMs are that solid-state VOMs are**
    A. compact and light weight.
    25 B. battery operated and portable.
    C. versatile and require no warm up.
    D. all of the above.

Portions of this lesson from
Know Your VOM – VTVM
by Joseph A. Risse
Courtesy of Howard W. Sams, Inc.

"School Without Walls"
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SERVICE YOUR BUSINESS

For an electronic technician like yourself, "service your business" means customer satisfaction. Provide the customer with first class repair work and then follow-up with an unexpected courtesy call to see if the customer is happy with your service.

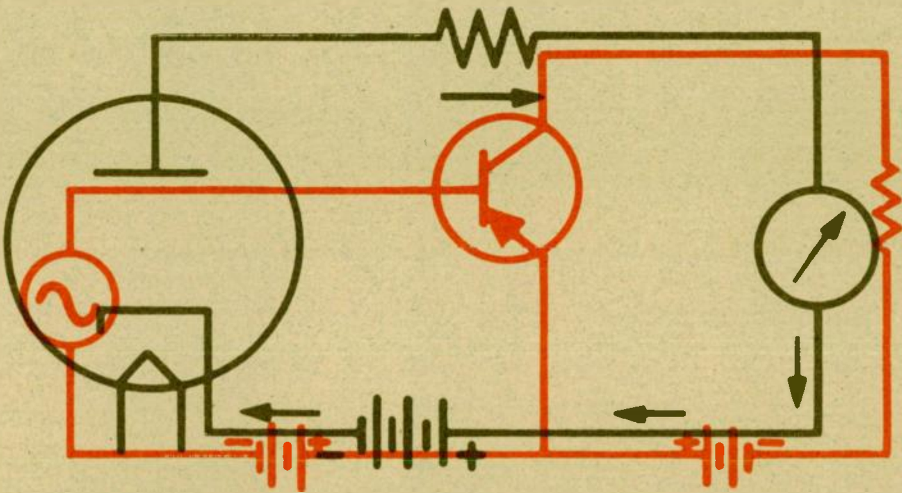
Customer relations are an important part of your service business. Always keep this in mind and make it a habitual part of your business.

Good customer relations can only lead to increased business and profit!

S. T. Christensen

LESSON NO. 53

REVIEW FILM OF LESSONS 49 THROUGH 52



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-053

404

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 4/73
Reprinted April 1974

REVIEW FILM TEST

LESSON NUMBER 53

The ten questions enclosed are review questions of lessons 49, 50, 51, & 52 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER: YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

Lesson Number 53

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having the Test Code Number 52-053-1.

1. The most common outline for a power transistor is the
- A. TO-3
- B. TO-5
- C. TO-10
- D. TO-18

2. Locating a specific component in a circuit from a schematic is usually accomplished by
- A. trial and error.
- B. checking each part.
- C. locating the active device and checking the area about it.
- D. none of the above.

3. Heat sinks that were removed from a circuit during a component replacement
- A. may be discarded.
- B. must be replaced in their original position.
- C. should always be grounded.
- D. none of the above.

4. A VOM
- A. is better than VTVM.
- B. is not as good as a VTVM.
- C. is the same as a VTVM.
- D. shouldn't be compared to a VTVM.

5. The primary purpose of test equipment is to
- A. have an impressive looking workbench.
- B. eliminate troubleshooting.
- C. save time in troubleshooting.
- D. none of the above.

6. The AC/DC probe of a VTVM has a one megohm resistor in series with the
- A. AC lead.
- B. DC lead.
- C. Ohms lead.
- D. db lead.

7. If a VOM or a VTVM won't zero on the ohms setting,
- A. the meter is defective.
- B. the wrong probe is being used.
- C. the battery is weak.
- D. the line cord is not plugged in.

8. If the VOM will indicate voltage and current but will not indicate resistance, the
- A. meter movement is defective.
- B. battery is probably dead.
- C. fuse is blown.
- D. switch is defective.

9. Reading voltage in the ohms position of a VOM will
- A. destroy the battery.
- B. destroy the meter movement.
- C. destroy the rectifier diode.
- D. burn out resistors in the circuit being tested.

10. The heart of the VTVM is
- A. a shunt resistor across the meter.
- B. a series resistor network before the meter.
- C. a meter bridge circuit.
- D. none of the above.

Notes

asi

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A SUCCESSFUL MAN'S TOOLS

AMBITION, ENTHUSIASM,
WILLINGNESS TO WORK . . .

. . . are the successful man's tools.

Knowledge gained from training and practical experience lead you to success.

Take your ASI training, your own experiences, and the ambition, enthusiasm and willingness displayed in your lesson progress and it all adds up to success.

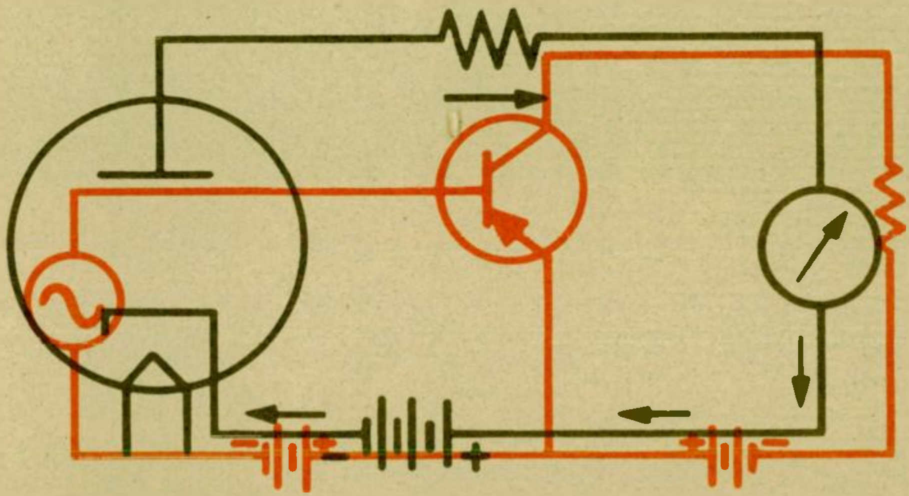
Keep up the good work!

S. T. Christensen

S. T. Christensen

LESSON NO. 54

SIGNAL TRACERS



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-054
407

ADVANCE SCHOOLS, INC.
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CONTENTS

SIGNAL TRACERS

INTRODUCTION

A signal tracer is a versatile test instrument in the hands of a skilled serviceman. The simpler types of signal tracers are usually small enough to fit into a tool box for ready availability, while the more complex units are generally used in service shops.

Although the transistorized signal
4 tracers are small and are battery powered, they are designed to trace both RF and AF signals. A representative type (Fig. 1) will have a separate input for the RF signals and an input for the AF signals. If the flexible leads from the signal tracer are connected for an RF input, all parts of the circuit *before* the detector may be checked. When the leads are connected to the AF input section of the signal tracer, all parts of the circuit *after* the detector may be checked. The radio under repair may be partially operable, or if it is not working, a signal generator may be used to inject a signal into the radio. This injected signal from the generator may then be traced through the radio until there is no longer a signal, which, of course, localizes the trouble spot. The specific circuit used in a signal tracer will vary with the specific units, but the operation is the same.

CIRCUIT TRACING

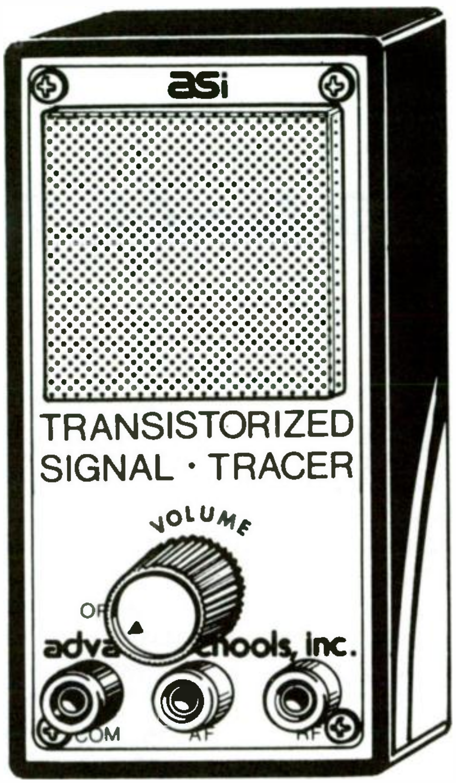
Many of the previous lessons have used either block diagrams or complete schematic diagrams to illustrate the actions taking place in an electronic circuit. These circuit actions can generally be divided into high frequencies which are grouped under the term RF, while the lower audio frequencies are grouped under the term AF (Fig. 2).

One of the first determinations to be made about a defective radio is to learn whether the trouble is in the AF section or the RF section. It is generally better to start searching for the trouble in the AF section. If the initial check has indicated that power is being supplied to each part of the circuit, the signal tracer and the signal generator will have to be used to localize the difficulty (Fig. 3).

Preliminary Inspection

Before any use is made of signal tracing equipment, a preliminary inspection of the radio should be

A PICTORIAL



B SCHEMATIC

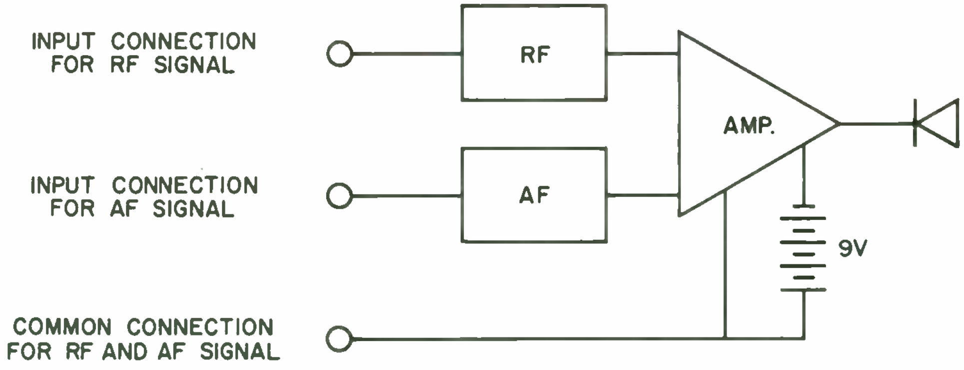


Figure 1 — A representative signal tracer.

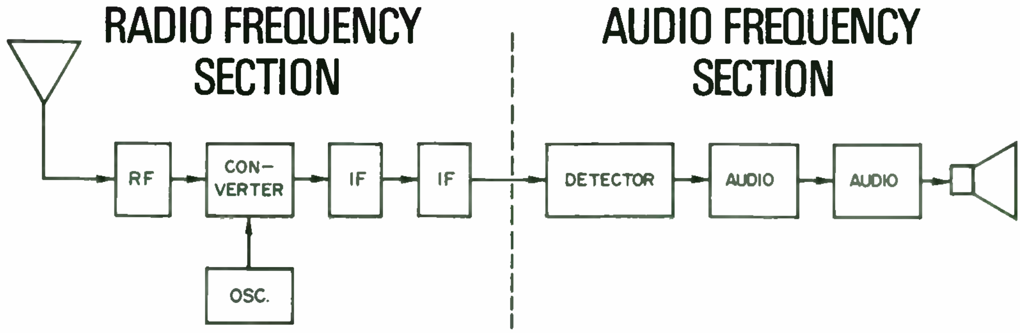
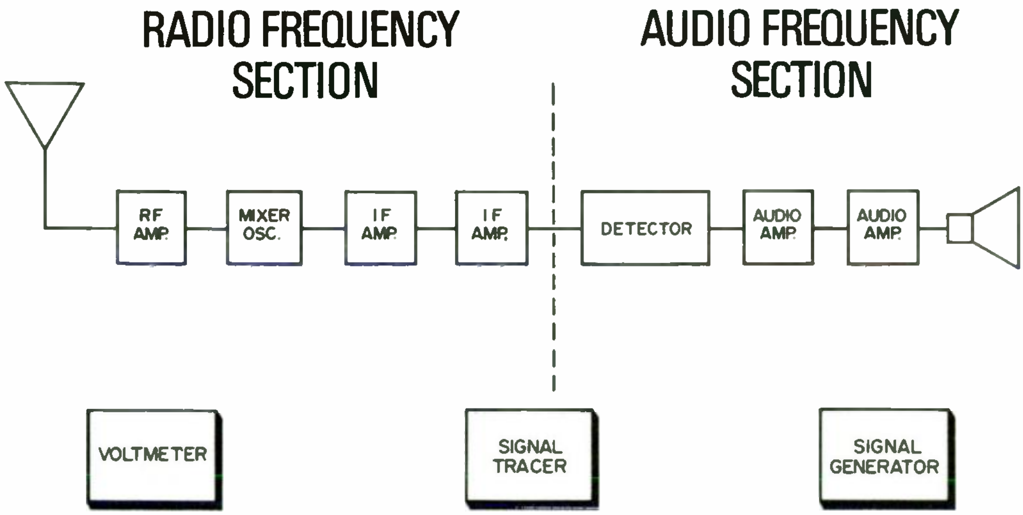


Figure 2 — The two basic sections of a radio receiver.



FIRST STEP

Use the voltmeter to be certain that the correct voltages are being applied at the proper points in the circuit.

SECOND STEP

If the correct values of DC voltages are applied to the proper points in the circuit, then the incoming signal may be heard on the signal tracer. The incoming signal is traced from left to right.

THIRD STEP

If the signal still cannot be heard, connect the signal tracer at the speaker. Use the signal generator to produce a signal at the last audio stage, and then move the input probe gradually to the left until this signal is lost at the defective point in the circuit.

Figure 3 — Steps to be followed in localizing circuit defects.

made. Most of the inspection techniques described here for a radio are also applicable to recorders, stereos, and TVs, even though the directions to be given will refer mostly to a radio. In addition, the initial part of the inspection instructions will refer to radios using vacuum tubes.

With the radio plugged in, it should be turned on to see if all of the tubes light up. This will indicate that the filament circuits appear to be in proper order. It does not indicate, however, that all of the tubes are operating properly. There are two ways of determining whether one or more of the tubes are defective: The tubes may be checked on a tube checker, or the incoming signal may be traced through the radio receiver, as described later.

During the inspection to check the tube filaments, power should also be supplied to other parts of the receiver if the power tube and the power supply are operating properly. A check with a voltmeter at the plate and screen connection of each of the tube sockets will verify whether they are receiving B+ voltage.

The checking procedure just described has assumed that the radio has been removed from the cabinet. This has allowed the serviceman to also begin a visual check of the radio by checking all the wiring and parts. Be sure to look for any indication of burned parts, broken wires, loose connections, dirty switches, etc. With the radio chassis removed from the cabinet, normal safety precautions should be observed to avoid electrical shock since high voltage for the plates and screens of the tubes is normally present.

If the radio is turned on, an inspection should be made of the resistors and capacitors for any signs of overheating. Capacitors normally do not get warm, while resistors do become warm and are designed to radiate the heat generated in them. The physical size of the resistor will indicate how much heat it is designed to radiate. In most cases, a defective resistor will be badly burned and will be easy to locate. Some resistors, however, might be only slightly scorched, which might be the result of an intermittent electrical short.

If any overheated or burned out parts are located, they should not be replaced until the cause of the failure has been discovered and corrected. However, some servicing can be done by replacing the parts and making a resistance check with an ohmmeter to eliminate any short circuits that were present to cause the trouble. Remember that a short can occur inside a vacuum tube, and this could easily account for a large current drain and a burned out coil or resistor.

Physical Defects

Trouble in a receiver can be caused by a multitude of defects, either singly or in combination. In addition to the problems caused by defective capacitors and resistors, trouble can be caused by:

Loose wiring. Broken wiring, frayed insulation, poorly soldered joints, and burned or charred power cords are common.

Switches. The contacts on switches can become defective due to normal arcing of the contacts, especially in the switch that controls the 120-volt power. It is also possible that the plug itself has become defective, or the junction of the wires to the prongs in the interior of the molded plug has separated.

The rotary selector switches used in medium grade equipment are usually silver plated and only require proper cleaning to be restored to an operating condition. These contacts, like all other contacts, can become contaminated from dirt particles in the air which act as an insulator. They should never be sandpapered to clean them. An aerosol spray will clean and lubricate them.

Tube sockets. The pins that extend from the base of vacuum tubes make contact with the spring-like fingers of the tube socket that is mounted on the chassis. Some tube sockets have spring contacts that are shaped to fit around the pins of the tube. Other tube sockets have spring contacts that are spread apart when the pins of the tube are inserted. The latter type of socket only makes line contact with the vacuum tube pins. Both kinds of sockets can also collect dirt that eventually forms an oxide on the mating surfaces between the tube pins and the springs of the socket. This oxide acts as an insulator and can cause an inoperative condition in the receiver.

There may be other plug and socket combinations in larger sets, such as the interconnecting wiring between the motor in record players or recorders and the amplifier. Some TV sets have a plug and socket between the yoke wiring on the neck of the picture tube and the chassis. Here the contact made between the plug and the socket can become oxidized and cause problems.

Coils. The wires that connect the coil wire to the terminal on the coil form can sometimes break. There might be no apparent reason for any break to occur, but the short lead wire might have had too much of the insulation removed for soldering. The thin wire would then have been overheated in soldering; or the solder covered the thin wire, which stiffened it and made it less resistive to vibration and movement.

The two broken leads could act as a very low value of series capacity and be the cause for a decrease in volume.

SIGNAL TRACING IN THE RF CIRCUIT

Signal tracing is a technique used to troubleshoot either a weak or a dead radio. This technique provides a quick method of locating a defect in an electronic circuit that is not operating properly. A signal tracer is actually a simplified version of a radio receiver. It has input connections that will accept either a signal from the RF portion of the radio or a signal from the AF portion of the radio.

Signal tracing may or may not use an additional instrument known as a *signal generator.* The signal from a signal generator is fed into different parts of the radio until the defective stage is located. The signal from the generator provides a signal that is the equivalent of a signal received at the antenna input connections of the radio. It is a controllable signal that may be substituted for the signal voltage induced into the input of the radio receiver.

Checking the RF Sections in Tube Radios

Searching for the trouble in a defective radio with a signal tracer is a straight-forward method of locating a defect. The search should be started at the antenna end of the radio with the leads from the RF terminals of the signal tracer connected to the antenna input terminals (Fig. 4).

The illustration shows the leads from the signal tracer connected to the input terminals of a radio circuit. The basic portion of the RF section is all that is shown, as this is the portion of the circuit that both controls and contains the radio signal. The remainder of the circuit is important also, as this portion supplies the proper voltages to the filaments, plates, and screens of the tubes, plus developing any bias voltages that are required. It is assumed that these voltages have all been checked and are available at each plate and screen.

The common or ground side of the signal tracer has been connected to the chassis ground, and the RF lead is shown connected to the antenna, identified as 1 on Figure 4. The antenna may be an external one or it may be one of the loop-stick types as part of the radio itself. If the radio signal is heard in the signal tracer from test point 1, the test lead should be moved to test point 2. Again the signal should be heard and the test lead moved to test point 3.

This procedure of placing the test probe in a step-by-step sequence, beginning at the antenna, is a logical method of localizing the trouble. As each stage of amplification is expected to increase the signal strength, it is apparent that a decrease in signal strength or a complete loss of a signal is a clue that the trouble is probably in that stage. If the signal is present at point 7 but is lacking at point 8, it is apparent that the trouble must lie in the wiring or the components associated with that stage. The trouble might be very simple to find, however, since it could be a bad contact between one of the pins of the tube and the spring contacts of the socket. Rocking the tube in its socket or pulling it out and reinserting it might be all that is needed to clean off the oxide that formed and acted as an insulator. Remember, voltage that is present at the tube socket is no indication that the voltage actually is present inside the tube at one of the elements.

Checking for Oscillation

If no signal is present at test points 5 or 6, the trouble might be

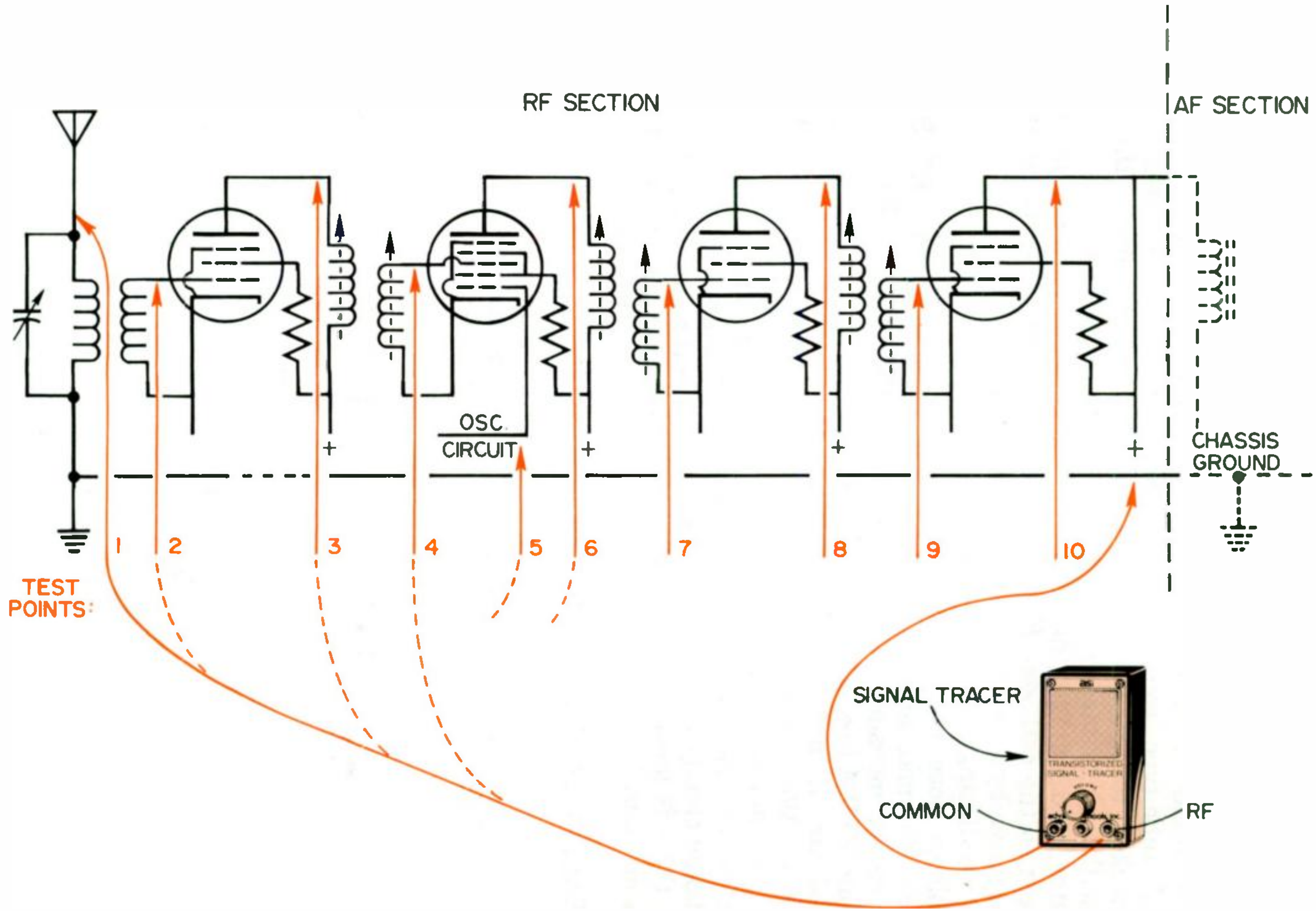


Figure 4 — Step-by-step method of searching for trouble in the RF section of a tube-type radio.

in the oscillator circuit. The circuit of Figure 5 is almost standard for the converter stage. The screen (or shield) grid of the converter tube acts as the oscillator "plate," and the cathode of the tube is grounded. All tube-type converters can be checked to see whether they are oscillating by measuring the oscillator, grid voltage (this is the grid next to the cathode). If the grid is negative by a few volts, the circuit is oscillating. In some tubes this voltage does not always exceed –1 volt. To make sure the oscillator is working, measure the voltage with your VTVM (use a 1-meg, isolation resistor, if not provided in the probe). While reading the voltage, move the dial from one end to the other on the radio. The voltage should change as the radio is tuned; if there is no change, the oscillator is not working.

Finding Oscillator Troubles

Once you have determined that the oscillator is not working, check each individual component for a defect. Remember, also, that an oscillator will sometimes be working but not at the correct frequency. Check for open coils, broken wires, open capacitors, and open resistors. In tube circuits or in transistor circuits if the oscillator cuts off at one end of the dial or the other, check the tube or transistor. In tube circuits, an open oscillator grid capacitor can cause the radio to cut off at the low end.

Checking the RF Sections in Transistor Radios

The method of locating defects in tube-type radios should be followed when repairing transistor radios (Fig. 6). Remember that we are following a high frequency radio signal beginning at the input of the receiver and tracing it step by step through the RF section. This procedure should not be started until all the necessary voltage checks have been made to be sure that the proper values from the DC supply are available at the transistors.

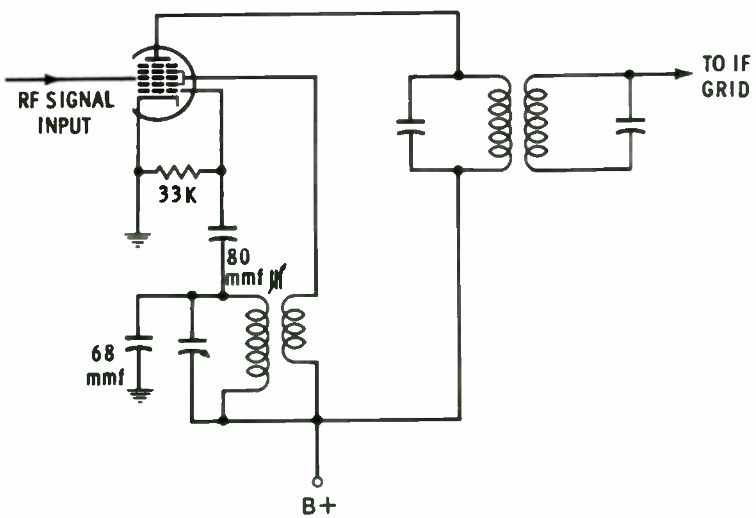


Figure 5 — Tube type of mixer-oscillator circuit.

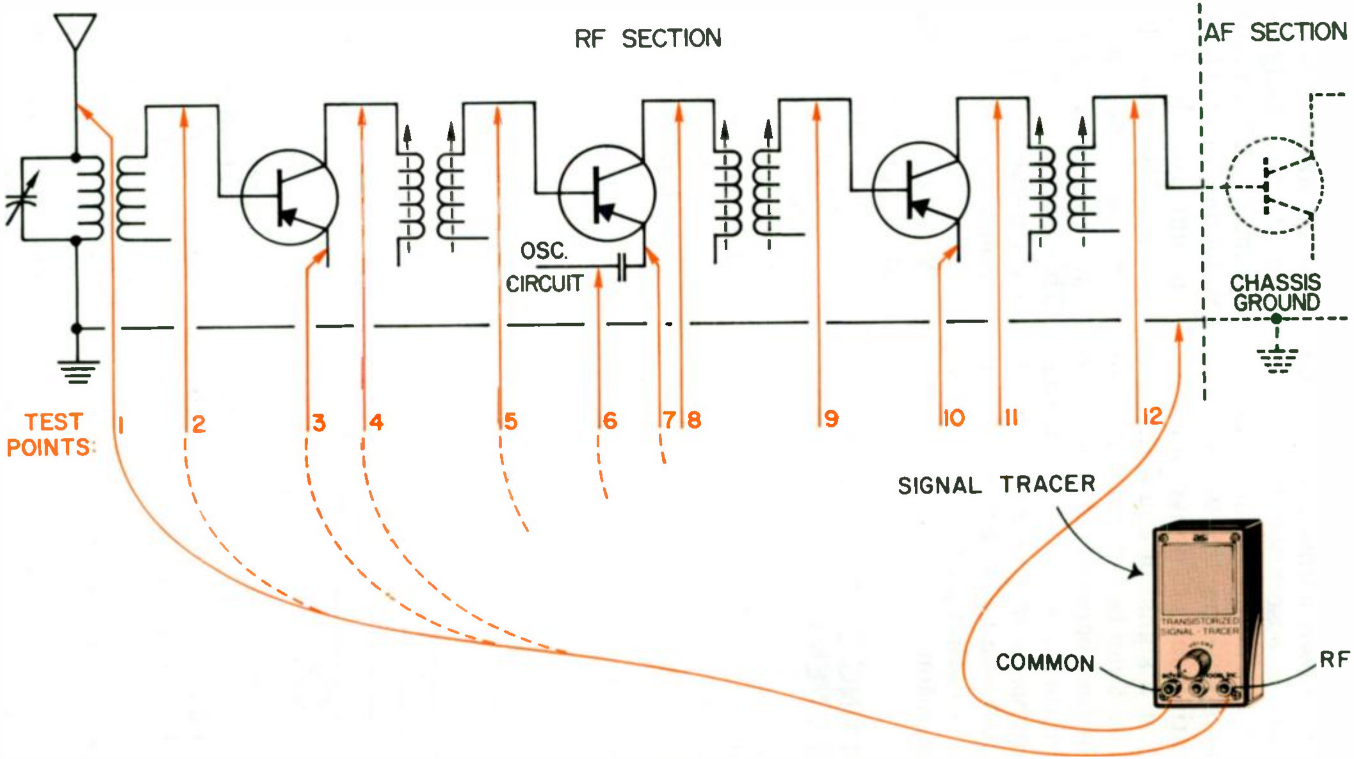


Figure 6 — Searching for RF defects in a transistorized radio.

The basic transistor receiver circuit is all that is shown in Figure 6. The successive stages of amplification are shown without any of the components associated with each transistor. The signal should be followed step-by-step through the circuit until it fails to deliver a louder signal or a signal of equal intensity. Then it can be assumed that the trouble lies between the last two test points. It will not mean that the trouble is in the transistor located between these test points, but that it is in that particular stage of amplification.

LOCATING DEFECTIVE RF COMPONENTS

When a trouble spot has been identified, it becomes necessary to determine the exact defective component. If every component were to be replaced in the trouble area, the defective component would probably be one of those replaced, but this procedure would not be followed in actual repair work.

An experienced serviceman would search for the defect in an orderly manner and replace only that one defective part. In addition to analyzing the problem, he would review the probable causes in an orderly and logical manner. Locating a defective resistor is usually easy to do, but defective capacitors are not as simple to locate.

Service Problems In Tube Circuits

One of the common RF circuit problems, outside of defective tubes, is a leaky coupling capacitor C_3 in Figure 7. This almost always produces noise in the output of the radio, since it is usually an unstable breaking down of the dielectric. If the leakage is steady, the symptom will usually be a drastic reduction in sensitivity. This may account for the customer's complaint: "My radio plays fine while I'm close to the station, but it fades out as soon as I get out of town." This sort of complaint is almost always due to a fault in the RF or antenna circuit.

You can isolate the noise problem if you merely short out the converter grid to see whether the noise stops. If it does, your trouble is in the RF circuit. One good way to check for leakage in C3 (Fig. 7) is to pull out the converter tube and measure the voltage on the signal grid with your VTVM. If there is a positive voltage, then look for trouble in C3. There is not much use making the test with the tube in the circuit, unless the leakage happens to be severe; the grid circuit rectification will not allow the grid to go positive.

Capacitor C_r can also cause low sensitivity if it grows weak; however, it cannot cause noise unless it has B + across it in the circuit. If you cannot adjust C_r for a peak (or at best a broad peak), then you may suspect it of a defect, but don't overlook the possibility of other parts of the resonant circuit being defective. An open RF coil or one of the capacitors connected to it are possibilities. The usual reason for trouble in C_r is moisture and dirt accumulation to a point where there is leakage across it. Try a

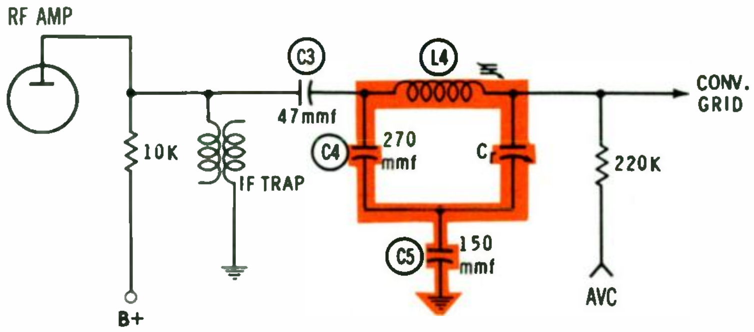


Figure 7 — A pi-coupled RF circuit with an IF wavetrap.

good TV tuner-cleaner in a spray can to see if there is an improvement. If you use carbon tet, be sure you let it dry for some time after application. Carbon tet causes drifting of the circuit and may mean that a radio you repair will continually grow weaker as the circuits drift out of tune.

Replacing C_r

C_r can be replaced in an emergency with a different capacity trimmer from the original. If you can find only a 3-30-mmf capacitor, for example, and the schematic calls for 10-80 mmf, use the 3-30-mmf unit and place a 47-mmf mica fixed capacitor across the trimmer and see if the circuit will peak up. If it won't, drop the size of the parallel capacitor to about 33 mmf and try again, etc.

Intermittent Fading

When you have intermittent fading, it is a good idea to check the RF and converter grid circuits for continuity. An open resistor in the grid return circuit can cause no end of unusual symptoms, depending on the condition of the tube affected. You may find, for example, that an old, weak gassy tube will work fairly well in the circuit while a fresh new tube may not work at all. If this is the problem, check the grid circuit.

Repairing RF Coils

It is not toc unusual in older radios to find that coil L_4 may have opened up for one reason or another (Fig. 7). Often by careful removal and inspection the break can be found and repaired. Figure 8 demonstrates easier repair when the original lead from the coil is not long enough to reach the terminal. Take a piece of stranded hookup wire and remove one strand. Take this strand of bare wire and solder it to the terminal. Make it long enough to reach the broken lead with a little slack. Scrape the broken lead very gently, because these leads are easily broken. Lay the lead on your finger and gently scrape with a knife or razor blade. You do not have to break through the enamel, except on one side. Now take the lead and wrap it around the bare wire strand once or

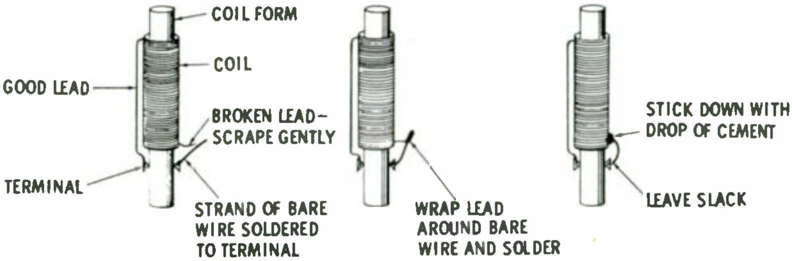


Figure 8 — Repairing antenna or RF coil.

twice and solder the two together. Gently push the wires against the side of the coil and apply a drop of speaker cement on them to protect the splice from damage. Caution: Always leave a little slack in the wires so there may never be any mechanical strain to the connection.

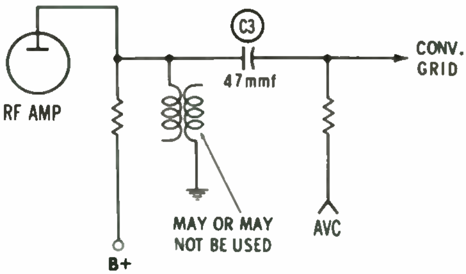


Figure 9 — Modification for bypassing defective RF coil.

Bypassing the Coil

There are times when it will be impossible to repair the coil and a new coil may not be available. If the radio is used where image rejection is not a serious problem, the circuit can be modified to bypass the coil without noticeable detriment to the performance of the radio. This is done by elimination of L_4, C_4, C_5, and C_T of Figure 7 and reconnecting the circuit as shown in Figure 9. When an antenna coil is irreparably open, you can often switch the RF coil into the antenna circuit. You don't have to make a mechanical change, just switch the leads and use the resistance-coupled circuit of Figure 9 to eliminate the RF coil from the circuit.

Repairing Oscillator Coils

It is usually more difficult to repair a slug-tuned oscillator coil than to repair either the RF or antenna coils, but it can be done often if you are careful. (Information on the repair of RF, antenna and oscillator coils is given later in this lesson.) If the cathode or screen winding is open and you are unable to repair it, you can usually wind another coil in its place; this coil is almost invariably on the outside around the grid coil. Try to determine the approximate number of turns on the original coil and wind this many on the new coil. The wire size is not too critical, as long as it is small enough not to hinder the remounting. If you cannot tell how many turns the old coil had, try about 20 turns for a cathode circuit and about 50 turns for a screen-grid circuit. If the circuit will not oscillate after the new winding is added, reverse the leads on the new coil. It is usually better to have too few turns than too many. If the circuit will oscillate over the whole band, the injection is usually fine. Too many turns will increase the oscillator grid bias and reduce the gain of the converter stage.

Quick Checks In the RF Circuit

How can you tell if the trouble is really in the RF circuit? If the radio is weak, for instance, how would you isolate the trouble to the right stage? Here's one way: Grasp the metallic blade of a screwdriver and touch it to the grid of the RF stage; does the radio play better than it did with the antenna connected? If it does, the trouble is in the antenna circuit. If it doesn't play better, touch the blade to the plate circuit of the RF amplifier; now does the radio play better than when you touched the grid circuit? If it does, you have trouble in the RF amplifier; if it doesn't, touch the blade of the screwdriver to the grid of the converter circuit. If the radio plays better than when you touched the plate of the RF amplifier, then you have trouble between the plate of the RF amplifier and the grid of the converter.

In transistor circuits you will likely get an apparent loss between the collector of the RF amplifier and the base of the converter. This is due to the differences in impedances of the circuits and does not necessarily indicate trouble. In any transistor circuit you will usually have better luck injecting a signal into a high-impedance circuit. (Signal injection is presented later in this lesson.) A high-impedance signal injected into the base of a transistor may actually give less output from the radio than the same signal injected into the collector or output circuit of the same transistor. This doesn't occur when you are using a signal generator with a low-impedance output (which fortunately most generators have), but it does occur when you are injecting signals with your body as a pickup antenna—this is a high-impedance signal.

The gain of both tubes and transistors varies widely with design. Often the designer is more interested in selectivity or isolation than in gain. On the other hand, almost any RF stage is expected to have some gain to make up for losses in low-selectivity circuits and to provide a better signal to noise ratio into the converter. Gain figures of 1.5 to 5 are common, though gains of up to 10 are possible.

SIGNAL TRACING IN THE AF SECTION

The application of the signal tracer to locate defects in the audio portion of a receiver is similar to its use when searching for defects in the RF section. The only difference is the use of the audio amplifier part of the signal tracer instead of the RF and detector part.

Checking the AF Section in Tube Radios

The audio section of a tube-type radio is designed to amplify the audio signal that has been demodulated by the detector. The detector portion of the radio circuit has an RF signal going into it and produces an AF signal coming out. This action of *RF in and AF out* makes the detector circuit part of both the RF and the AF sections of the receiver. The detector has been included under the AF section, as it is assumed that an RF signal is present at the output of the last RF stage and is available at the input to the detector.

A representative AF section of a tube-type receiver is shown in Figure 10. The probe is connected to the signal tracer at the AF tip jack, and the tracing of the signal starts in the area around the detector circuit. Test points 1 and 2 would be checks of the signal that exists in the AVC circuit (Automatic Volume Control circuit). The signal is weakest at these points and becomes increasingly stronger as the test probe is placed at succeeding test points. A low value of DC voltage is available at the output of the AVC circuit and should be measured with a DC voltmeter.

Checking the AF Section in Transistor Radios

Searching for AF trouble in a transitorized radio requires that the same general procedure be followed when attempting to locate the defect (Fig. 11). With the probe lead in the audio tip jack, attempts are made to pick up an audio signal at different points in the detector portion of the circuit. Whenever an acceptable audio signal is heard it proves that this portion of the circuit is operating properly.

The next step is to proceed toward the speaker end of the radio in orderly fashion, moving the probe from test point to test point. If audio voltage exists at these points and produces a reasonable signal level, the voltage will be further amplified in the signal tracer. This audio signal will be heard in the speaker of the signal tracer and may be controlled in intensity by the volume control on the tracer. It should be remembered that at these numbered test points, it is the variation in audio voltage that produces an input to the signal tracer.

Figure 11 has four test points identified by letters. These four test points all point to the base connection of the transistors. The variations of the signal at these four points are a variation in the amount of current, and are not a variation in voltage. There is an extremely small amount of voltage variation present at the bases. Sometimes it is not strong enough to be picked up by a medium sized tracer. There will be a voltage variation at the numbered test points in a proper operating receiver, but there is only a current variation at the bases of the transistors. These bases are the inputs to the transistors in the circuit. This action points out again that the transistor is a current operated device, while a vacuum tube is a voltage operated device.

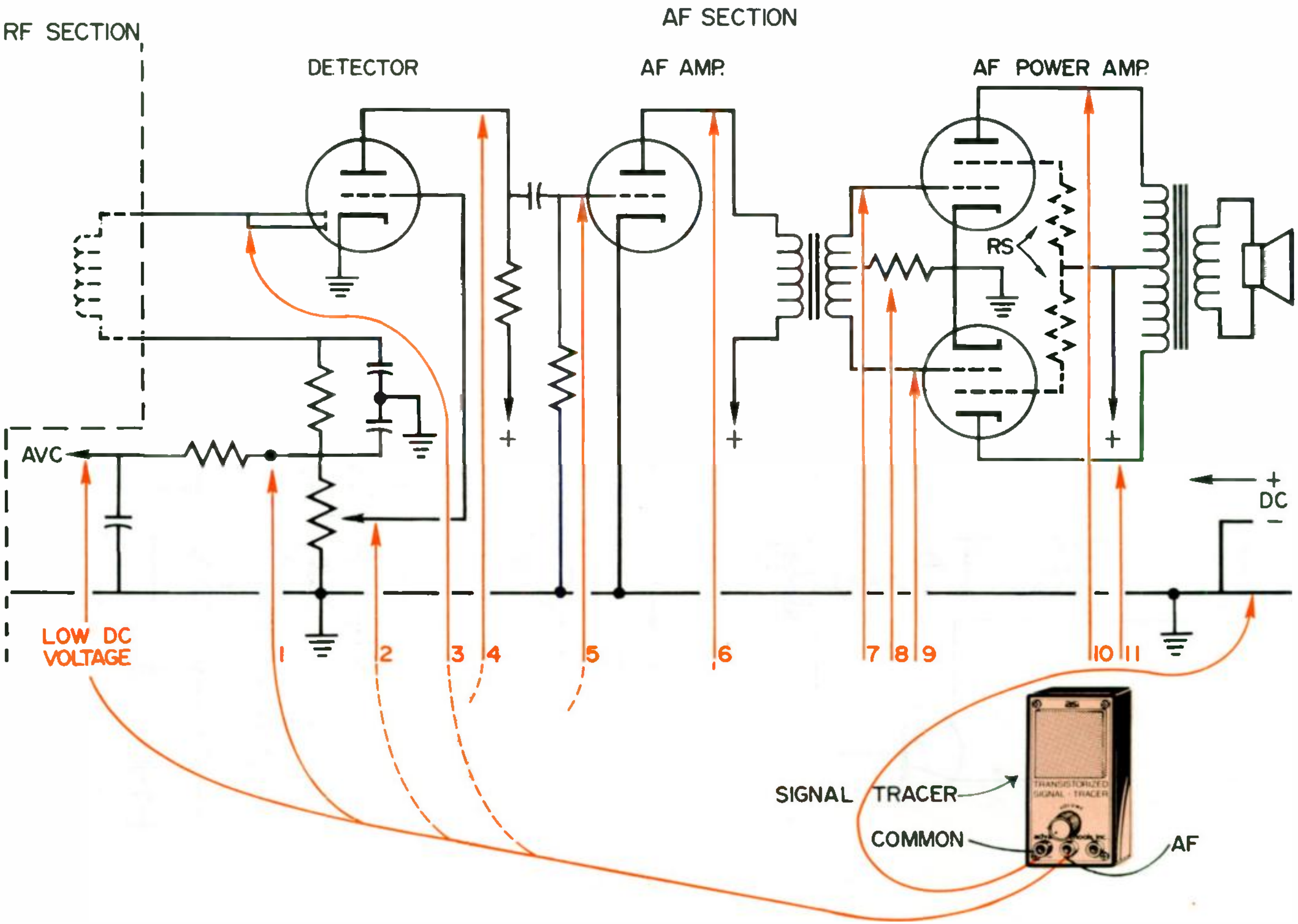


Figure 10 — Suggested test points in the AF section of a tube-type radio.

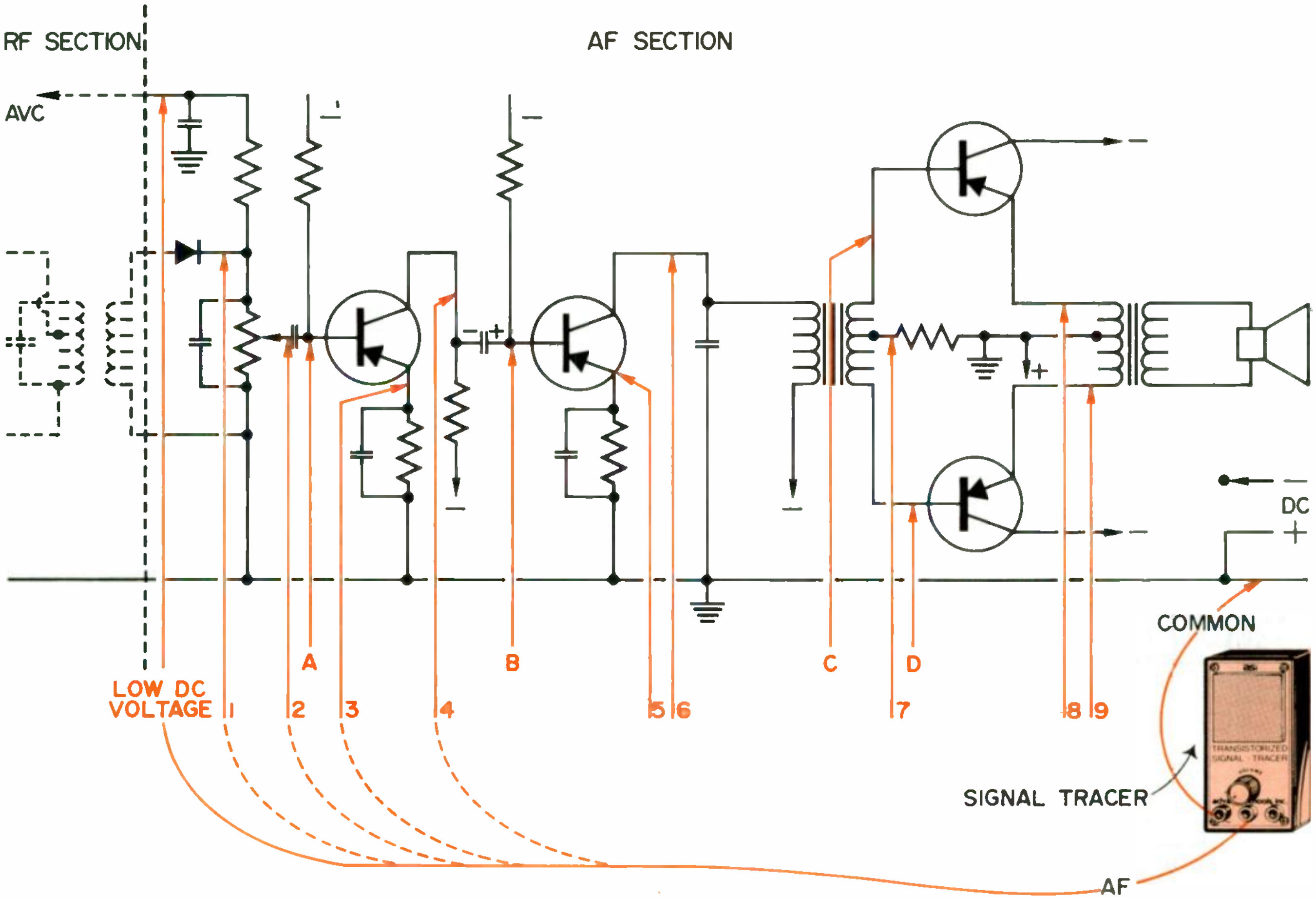


Figure 11 — Some test points in a transistorized radio.

The signal in the audio portion of a receiver is controlled by the volume control. As the probe is moved from test point to test point in a properly operating receiver, the volume control will usually have to be rotated toward the low-volume end of the control to decrease the sound level in the signal tracer. There is a limit to the amount of audio voltage that may be injected into the signal tracer without overloading it and causing distortion.

SIGNAL GENERATOR

As the name implies, a Signal Generator is a test instrument that can produce either an RF signal or an AF signal. In combination it applies the internally generated AF signal to modulate the RF signal. A combination unit of this type is usually the handiest to use in service work. Separate generators for AF and RF are usually used in laboratory design and test work. No matter what type or kind of generator is used, its use in troubleshooting is the same.

Signal Injection

Signal injection is a technique used to troubleshoot weak or dead electronic devices (radio and TV receivers, Hi-Fi amplifiers, etc.) to find the circuit that is not operating properly. In this method, a signal is coupled into the stages of the defective equipment, one stage at a time, until the defective stage is located.

Tracing RF Troubles with a Signal Generator

The output of a signal generator is used as a substitute for either an RF or an AF signal. If there is no RF signal at the input of the first RF amplifier, the signal from the RF generator can be injected into the radio at an appropriate point in the circuit. It is not good practice to connect the output from a generator directly into the circuit, since the generator might load the radio circuit and detune it, or the signals may be noisy or distorted. The output impedance of the generator may not have the proper value of impedance to match the input impedance of the circuit under inspection. There is a simple way to overcome this mismatch.

Impedance Matching

The impedance matching circuits shown in Figure 12 are called "Matching Pads." They can be constructed using standard values of composition resistors when you want to match a 50-ohm generator to a 300-ohm or 72-ohm load. When these pads are used, each circuit will be connected to the proper impedance. Some of the signal will be lost in these pads due to their resistive nature. Impedance matching with these pads, while not theoretically perfect, will usually be adequate.

RF generators usually have a low output impedance, such as 600 ohms or 50 ohms. Figure 13 shows three ways an RF signal can be connected to a high impedance circuit so the generator does not load down the circuit. If a large capacitor is connected to the grid of the tube, as shown in Part A, the low impedance of the generator will tend to short out any signals from previous circuits, and only the sig-

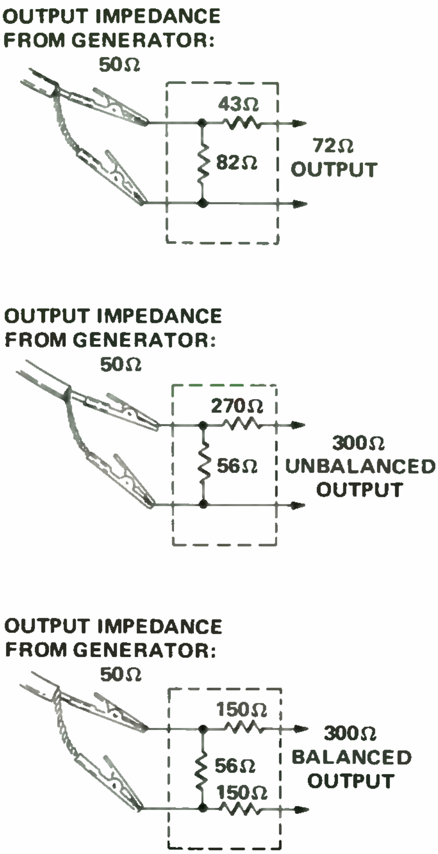


Figure 12 — Three types of matching pads used to match different values of impedance. (Reproduced with the permission of Heath Co., Benton Harbor, Michigan).

nal from the generator will be present at the grid of the tube. Often the hot lead to the signal generator can be clipped to an insulated lead connected to the grid of the tube, thus producing capacitive coupling through the insulation. Then the signal is added to the other signals that are already present.

In part B of Figure 13, the signal is injected into the tube by wrapping a loop of wire around it. The signal is then coupled to the tube by both inductive and capacitive coupling.

In Part C, the signal is capacity-coupled to the tube through the tube shield which is propped up on the tube so that it is not grounded. Figure 14 shows a dummy antenna circuit that can be used to connect the output of an RF generator to the antenna circuit of a radio. This circuit is used so the input circuit of the radio is connected to the same amount of impedance as with its own antenna.

The dummy antenna circuit shown is for use with AM receivers at all frequencies from 550 kHz to30 mHz. It offers an impedance to the radio that simulates the average impedance for most AM receiver antennas such as a 30-foot wire from a rooftop to a tree). The pads in Figure 12 can also be used as dummy antennas. The 72-ohm pad simulates a dipole antenna and the 300-ohm balanced pad simulates a folded dipole antenna.

A small coupling capacitor (.01 to .1 μ fd) should always be used with the hot generator lead to keep large DC voltages from being connected to the generator. Also, care should be used so the test signal does not overdrive the stage it is connected to.

Tracing AF Troubles with a Signal Generator

Figure 15 shows a block diagram of an audio amplifier. If the signal injection process were to be used to troubleshoot this amplifier, you would begin by connecting an audio signal to the grids of the output stages. If the sound heard from the speaker seems normal, with the

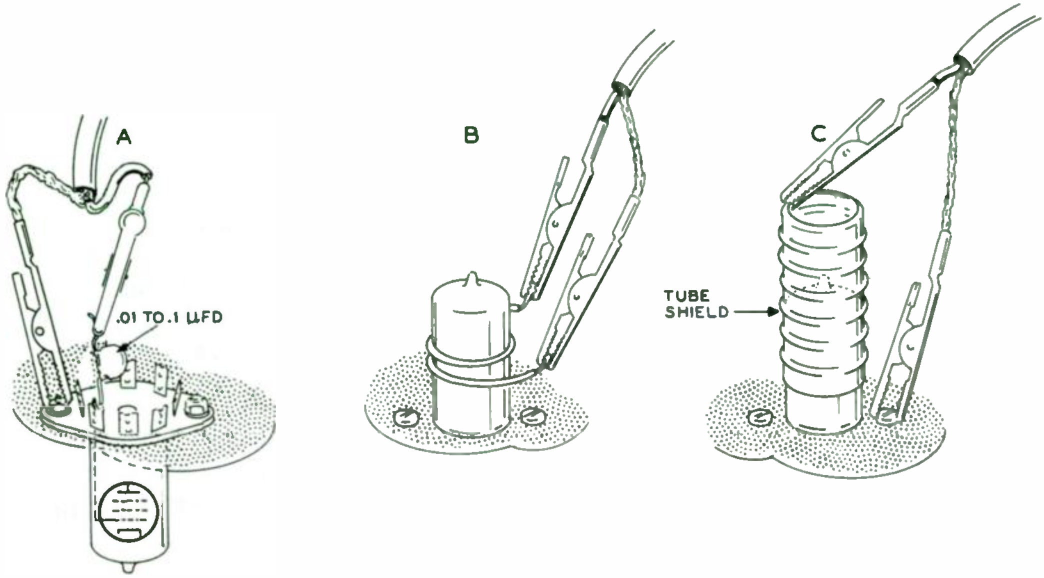


Figure 13 — Methods that can be used to couple a generator signal into an high impedance circuit. (Reproduced with the permission of Heath Company, Benton Harbor, Michigan).

signal connected to the grid of each output tube, the audio signal would be moved back to the grid of the inverter tube.

If the audio signal at the grid of the inverter produces a normal sound from the speaker, the lead from the generator would be moved back to the grid of the audio amplifier.

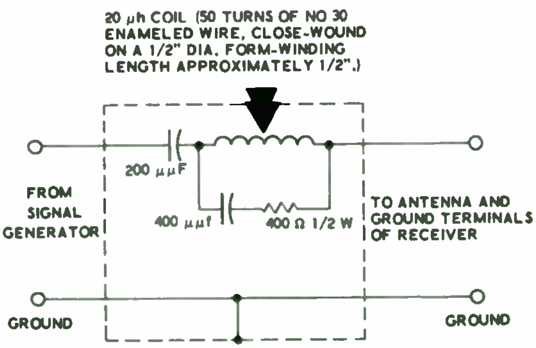


Figure 14 — An impedance match from a signal generator to the antenna input of the radio. (Reproduced with the permission of Heath Company, Benton Harbor, Michigan).

As the signal is connected to the grid of each amplifier stage, a clear tone should be heard in the speaker. Each time the generator lead is moved back one amplifier stage, a definite increase in volume should be noted. It may even be necessary to reduce the volume control or generator output level setting. When the signal is connected to the grid of the weak or faulty stage, little or no increase in volume will be heard.

This method can also be used to find an open coupling capacitor between two amplifier tubes. In this case, the signal would be heard when connected to the grid of the second tube, but would not be heard when connected to the plate of the first tube.

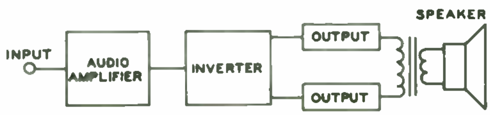


Figure 15 — Block diagram of an audio amplifier. (Reproduced with the permission of Heath Company, Benton Harbor, Michigan).

Typical Troubleshooting Methods

Figure 16 shows how signal injection can be used to find the faulty stage of a small radio receiver. First, the signal from an AF generator (or the 400 hertz AF signal from an RF generator)is connected to the grids of the output and the audio amplifier stages. If a normal sound is heard from the speaker in both of these cases, a modulated RF signal would be used to check the remaining stages of the radio.

First, the modulated RF signal is connected to the input of the detector stage. This signal must be at the IF frequency of the receiver, usually 455 kHz in home radios. If a loud, clear tone is heard from the speaker, the generator lead is moved to the grid of the IF amplifier. Now, a much louder signal should be heard.

If the signal is still normal, the generator lead is connected to the grid of the mixer stage; a loud, clear tone should again be heard from the speaker. Weak sound, or no sound at all will be heard from the speaker if a weak or dead stage is discovered during these tests.

An unmodulated RF signal can be used as a substitute for the local oscillator signal when that circuit is not operating properly. Tune the generator to a frequency that is 455 kHz (if that is the IF frequency) higher than the frequency the radio is tuned to. Connect this signal to the grid of the converter tube. Adjust the attenuator of the signal generator to give the normal amount of voltage for this grid, as shown in the receiver schematic.

To test the RF stage, use the dummy antenna circuit shown in Figure 14 between the generator and the antenna input of the radio.

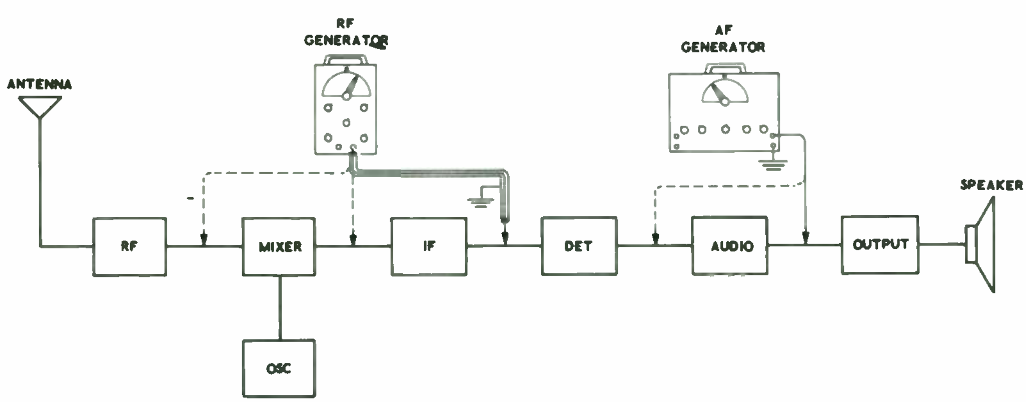


Figure 16 — Using signal injection to locate defective components. (Reproduced with the permission of Heath Company, Benton Harbor, Michigan).

Signal injection can also be used to troubleshoot TV receivers. For tests in the audio and video amplifier sections of the receiver, use the audio signal from an AF generator or from the AF output jack of an RF generator. When checking in the audio stages, this signal will be heard as a tone in the loudspeaker. When checking in the video stages, the signal may be observed as a series of horizontal bars on the screen of the receiver.

A modulated RF signal that is within the frequency range of the video IF of the set will generally suffice for signal injection tests in the video IF stages. Again, the output indication will be horizontal bars across the TV screen.

Be sure to use a small DC blocking capacitor in series with the "hot" signal generator lead when making signal injection tests.

In some TV receivers, it may be impossible to obtain the horizontal bar pattern when checking the last video IF stage. This is generally due either to the low gain of the IF stage or to detuning caused by the signal generator lead. In such cases, the signal may be injected into preceding stages to obtain the additional gain necessary.

SUMMARY

Signal tracers are test instruments that can pick up either an RF or an AF signal in a radio, record player, or a TV. When a signal is present at a test point, it indicates that the radio is operating properly up to that point.

Before signal tracers are used in tracing a signal through an electronic device, an inspection should be made to locate obvious defects. These defects may be charred resistors, burned wiring, or other obvious physical defects. Then an inspection should be made of coils, tube sockets, and tubes. The same inspection of transistorized radios should be followed as used in tube-type radios.

A quick check should then be made to determine if the trouble exists in the AF or RF portions of the radio. Once the trouble area is localized, a systematic procedure should be followed in following the signal through the defective circuit.

A signal generator is sometimes used to inject a signal into a portion of a radio circuit. This injected signal must be of the proper frequency, and when it is properly used, it can substitute for any of the signals that should be present at specific test points.

TEST

Lesson Number 54

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-054-1.

1. Signal tracers are

A. mostly used in tracing AF signals.
B. mostly used in tracing RF signals.
C. only used on radio receivers.
D. used in tracing a signal through a commercial electronic device.

2. In Figure 4, when the signal tracer is connected to test point number 1 no signal is heard, the problem is in the

A. antenna circuit.
B. oscillator circuit.
6 C. mixer circuit.
D. IF amplifier circuit.

3. When searching for a circuit defect, the quickest plan to follow is

A. to skip around the circuit with the probe.
B. an orderly inspection from one end of the circuit to the other.
10 C. to check all of the tubes on a tube tester first.
D. to realign the IF transformer first.

4. Signal tracers consist of

A. a tracer circuit and a signal generator.
B. an electronic circuit that can accept either an RF signal or an AF
1 signal.
C. a simple RF receiver circuit.
D. a simple AF amplifier circuit.

5. A signal tracer can only be used to locate trouble in
A. radio receivers.
4 B. TV sets.
C. record players and recorders.
D. all of the above.

6. Signal tracers assist a serviceman in locating defects only after
A. it is determined that the tubes or transistors are supplied with the proper voltages.
4 B. a visual inspection shows that no resistors are charred.
C. it appears that no electrical shorts are present.
D. all of the above.

7. The principal test instruments that are used in conjunction with the signal tracer are
A. an ohmmeter and a voltmeter.
3 B. a power supply for the tubes and a signal generator.
C. a voltmeter and a signal generator.
D. none of the above.

8. The apparent loss in signal strength between the collector of the RF amplifier and the base of the transistor in the converter stage is due to
13 A. a change in base bias.
B. the selectivity of the RF stage.
C. the difference in circuit impedances.
D. none of the above.

9. Impedance matching devices
A. match circuits having different values of impedance.
B. can only match circuits from 50 ohms to 72 ohms.
C. can only use resistors in the matching device.
D. can only be used at the antenna input terminals of the receiver.

10. In using the AF output from a signal generator, a defective coupling capacitor used between stages would be located if
A. the signal is present at the plate of the first tube and is not present at the grid of the succeeding tube.
B. the signal is not present on either side of the coupling capacitor.
C. no DC or AC voltage is present at the output side of the coupling capacitor.
D. the filament voltage is low.

Notes

Notes

Notes

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Portions of this lesson from
Auto Radio Servicing Made Easy
by Wayne Lemons
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STICK-TO-IT-IVE-NESS

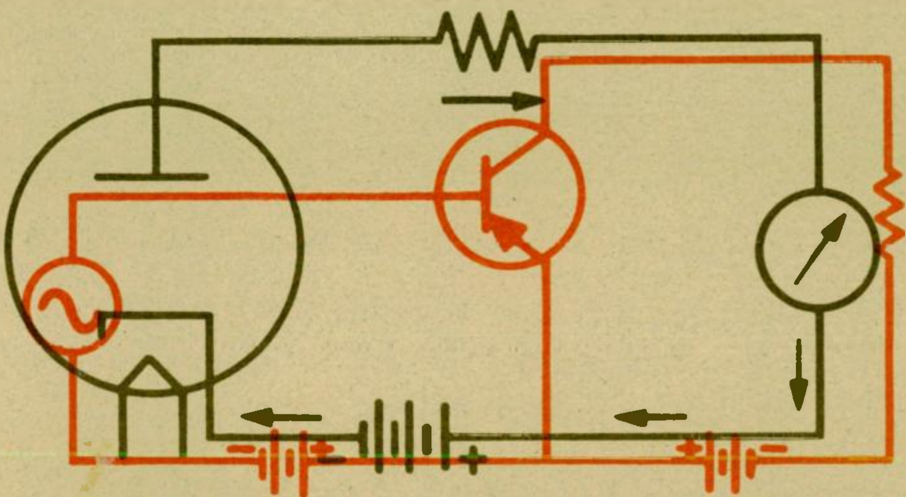
Does this word look real to you? Well, according to Webster's, it is a real word and it means "dogged perseverance, tenacity." In other words, you don't give up.

ASI wants you to "hang in there"—study your lesson material, use your time productively, and practice what you learn. With such an attitude, you can't help but be successful.

S. T. Christensen

LESSON NO. 55

SIGNAL GENERATORS



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-055

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ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

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CONTENTS

Advance Schools, Inc.

52-055

SIGNAL GENERATORS

INTRODUCTION

There are many types of RF signal generators in common use. The most familiar instrument is the amplitude-modulated (AM) generator which has a multitude of applications, such as alignment of radio receivers, stage-gain measurements, resonant-frequency determination, calibration of auxiliary equipment, signal-substitution tests in troubleshooting procedures, and measuring the Q of tuned circuits. Sweep generators are a somewhat more elaborate type of signal generator. The chief distinction between a sweep generator and an ordinary AM generator is that a sweep generator has an output signal which is repeatedly swept across a selected frequency range. Quartz-crystal oscillators are commonly built into sweep generators; this feature permits pips or markers to be displayed on an oscilloscope with the sweep signal trace.

DESCRIPTION OF GENERATORS

The AM and sweep generators are comparatively simple instruments which provide known frequencies within rated accuracy limits; however, they do not supply a known output voltage. The output voltage is adjustable over the necessary range, but no indication is provided concerning the number of microvolts or millivolts that are applied to the receiver or circuit under test. Hence, you cannot use an AM generator or a sweep generator to measure the sensitivity of a receiver. Sensitivity is defined as the number of microvolts that must be applied to a radio or TV receiver to obtain a standard output. Similarly, you cannot use an AM generator or a sweep generator to calibrate a field-strength meter. The purpose of a field-strength meter is to indicate the number of microvolts that are applied to its input terminals.

As the state of the art developed, the standards for test-signal sources became higher. During World War II, technicians at military bases gained valuable experience with precise signal sources. Military technicians were required to align receivers so that the tuning dials accurately indicated the incoming frequency. The receivers had to be carefully serviced to provide rated sensitivity. Moreover, it was the responsibility of the technician to check out selectivity, AVC characteristics, and image rejection.

Land/Mobile radio technicians have much the same responsibility. These receivers are not useful unless they have a sensitivity of 1 microvolt or less. Selectivity must be optimized to pass an FM signal without objectionable distortion, and also to reject adjacent signals. Four known accurate frequencies are necessary to align a triple-conversion superheterodyne. Only a high-quality standard signal generator will suffice for front-end alignment. Evidently a suitable generator must provide both FM and AM carrier modulation. Hence, a generator that is quite satisfactory for application in one service area may be utterly useless in another application area.

Communications equipment is multiplexed in some cases. Signal generators used in maintenance and troubleshooting of multiplex receivers must provide comparatively elaborate carrier modulation. Various forms of pulse-amplitude modulation are most common, although specialized types of frequency modulation are also encountered. Single-sideband output may be required from a signal generator in testing other types of receiving systems. In any case, your selection of a signal generator must be made on the basis of its intended application. Technically, a basic standard signal generator is a source of sinewave voltage of known frequency and amplitude. The frequency might range between 10 Hz and 10,000 MHz. The output amplitude is usually adjustable to one microvolt or less. Most generators supply an output up to two or three volts. On the other hand, a test oscillator is commonly defined as a source of sine-wave voltage that has a known accurate frequency, but an amplitude which is not known. However, test oscillators are often loosely termed *signal generators*. In an attempt to avoid confusion between the two basic types of instruments, complete and highly accurate generators have become known as standard-signal generators. Test oscillators should never be referred to as standard-signal generators. An RF signal generator can be compared to a small portable radio transmitter whose frequency output level and modulation are adjustable.

STANDARD SIGNAL GENERATORS

The plan of a typical standard signal generator is depicted in Figure 1. It comprises a sine-wave oscillator, a tuning capacitor calibrated in frequency, an output meter calibrated in volts, a precision attenuator calibrated in microvolts, and a shielding system to prevent objectionable leakage of high-frequency energy into surrounding space. True signal generators provide a good sine-wave output and they also minimize harmonics to the lowest percentage possible. On the other hand, test oscillators often have a highly distorted sine-wave output. The distortion components consist of even and odd harmonics. Higher frequency bands of a test oscillator often use the same output as lower

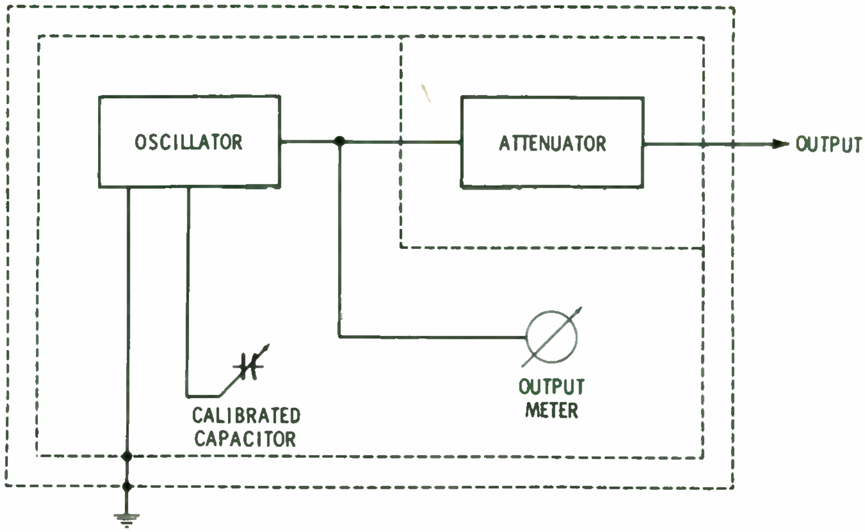


Figure 1 — Plan of a typical standard signal generator.

frequency bands—the high-frequency bands are merely calibrated in terms of harmonic frequencies.

Oscillators used in conventional generators are tunable over various bands of frequencies. It is not practical to design LC oscillators that provide a band-tuning range greater than about 3.16 to 1. Hence, band switching is required to select different coils for each band. Oscillator circuits are designed to generate as pure a sine wave as possible. The output amplitude on each band is also maintained as uniformly as possible to minimize resetting of the level control for the output meter. Some generators employ a form of AGC control to achieve maximum uniformity of output.

2

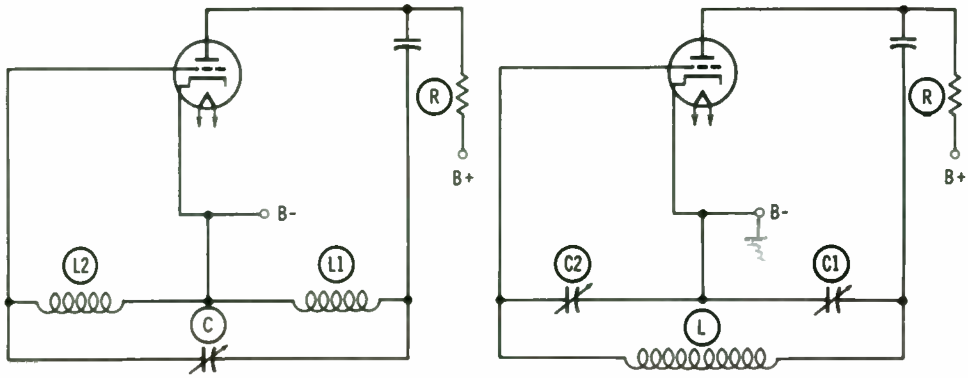
Oscillators with RF output frequencies up to 470 MHz generally utilize a carefully designed version of the Hartley or Colpitts circuits (Fig. 2). Frequency stability is an important consideration, inasmuch as it determines the accuracy rating of the generator, with respect to frequency. Stability is dependent on the effect of temperature, with respect to the resonant frequency.

3

Warmup drift is unavoidable, but a well-designed generator quickly achieves its equilibrium condition and remains reasonably free from frequency drift with changes in ambient temperature. Temperature-compensating capacitors are often used in the oscillator circuitry for this reason.

ATTENUATORS

All generators are provided with some type of attenuator so that the output voltage may be set at a desired level. Simple test oscillators often use a conventional potentiometer. To reduce feed-



A - Hartley.

B - Colpitts.

Figure 2 — Basic oscillator circuits.

through voltage at the minimum setting, two potentiometers may be utilized, as shown in Figure 3. On the other hand, an attenuator for a standard signal generator (Fig. 1) is designed to provide accurately-known output voltages over a typical range from 1 microvolt to 100,000 microvolts, or perhaps higher. The output meter may be calibrated with a "set carrier" mark; when the carrier-level control is adjusted to bring the pointer to this reference level, the number of microvolts output is indicated by the attenuator setting. The output meter may also be calibrated in volts, 0-1 or 0-3.

Attenuators have a low impedance, such as 50 ohms. There are two basic reasons for using low-impedance attenuator systems. First, stray capacitances have less serious effects in low-impedance circuits. A good attenuator system has an accuracy of ±1%. This accuracy can be achieved only by minimizing the bypassing action of stray capacitances. For example, at 100 MHz, 5 pf has a reactance of about 300 ohms. Unless the attenuator resistance is in the order of 50 ohms, it is obviously impossible to achieve high accuracy. The second reason for employing a low-impedance attenuator is to feed a

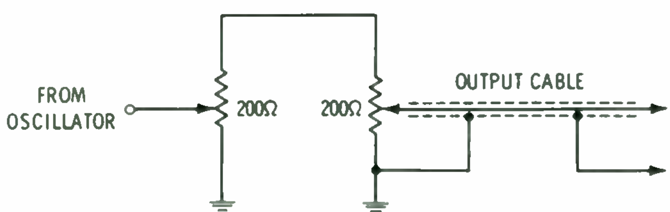


Figure 3 — Two potentiometers used as an attenuator.

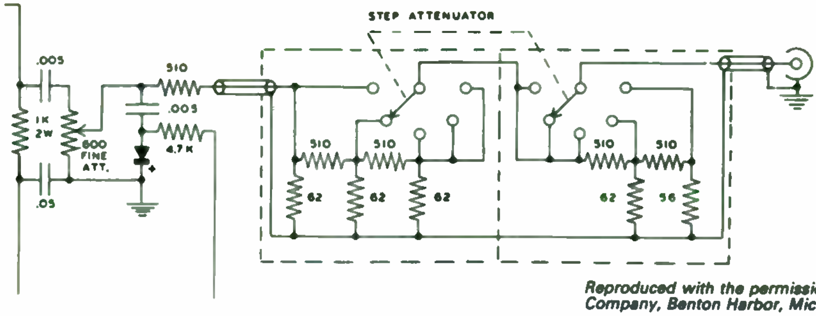


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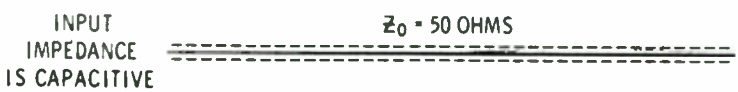
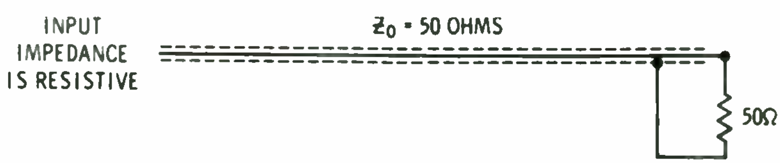
Figure 4 — Example of a step attenuator used in a signal generator.

coaxial transmission line having 50 ohm surge impedance.

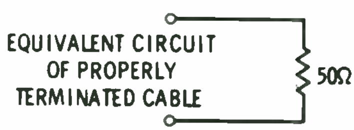
The step attenuator is a ladder configuration, comprising 62-ohm and 56-ohm shunt resistors with 510-ohm series resistors (refer to Figure 4). When the fine attenuator is adjusted for full-scale indication on the meter, each step on the calibrated attenuator provides a known number of microvolts output. The output voltage is fed to a coaxial cable. It is impractical to use ordinary test leads, because the leads would radiate high-frequency energy. The attenuator calibration would be meaningless unless a coaxial output cable were used. It is also essential to terminate the output cable with a resistor which has a value equal to the characteristic impedance of the coax cable. The terminating resistor eliminates standing waves and makes the input impedance of the cable purely resistive (Fig. 5).



A - Unterminated cable has standing waves; input impedance is capacitive.



B - Properly terminated cable has no standing waves; input impedance is resistive.



C - Input impedance of a properly terminated cable "looks like" the terminating resistor.

Figure 5 — Terminating resistor has no standing waves.

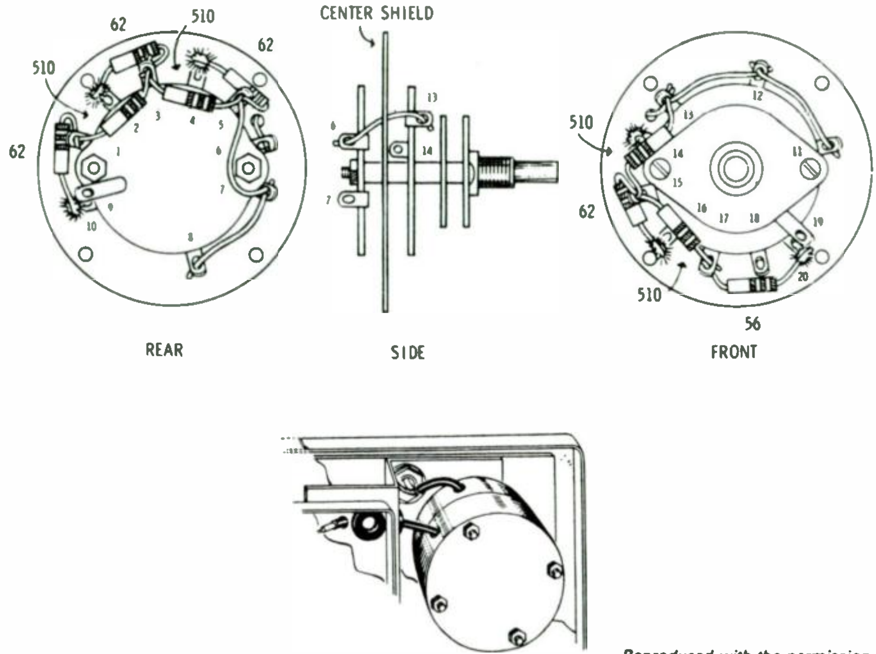


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Figure 6 — Construction of a simple step attenuator.

Attenuators must be well shielded. A simple arrangement is depicted in Figure 6. An important consideration in any shield design is make all high-frequency grounds at the same point in the shield structure. A single grounding point minimizes circulating RF currents in the shield metal. Obviously, circulating ground currents cause radiation (leakage from the generator), and can cause feedthrough of high-frequency energy from input to output of the attenuator system. Feedthrough not only impairs attenuator calibration, but it also increases the minimum attainable signal level. Alignment of sensitive receivers may require that the attenuator reduce the available output to less than 1 microvolt.

Figure 7 depicts the same basic ladder configuration as in Figure 4, but with additional sections for greater attenuation and more elaborate shielding than shown in Figure 6. Attenuator shielding is provided in addition to oscillator shielding as depicted in Figure 4. In turn, both of these shield systems are supplemented by the generator case. The shielding provided in a standard signal generator is one of the basic features which distinguishes this type of instrument from a test oscillator. Without effective shielding, it is impossible to achieve accurate calibration of a step attenuator.

When double-shielding is utilized, such as for oscillator coils, the

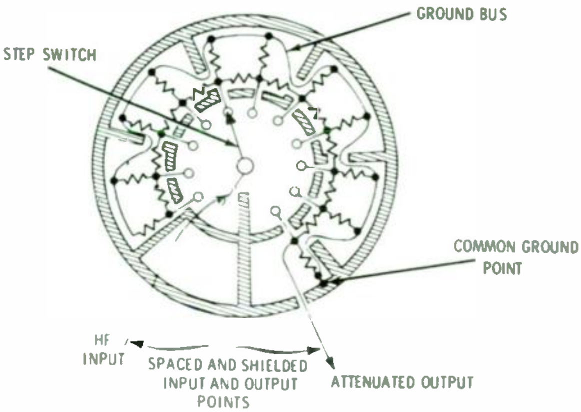


Figure 7 — A more elaborately shielded attenuator.

inner shield box is connected to the outer shield box at only one point. This single high-frequency ground point minimizes the flow of circulating ground currents.

Control shafts for tuning capacitors, switches, or potentiometers present another problem. Test oscillators may provide only a sliding spring contact against the shaft for high-frequency grounding. On the other hand, the residual leakage from this simple arrangement cannot be tolerated in calibrated standard signal generators. Two general methods are utilized to minimize leakage. In some cases, a metal control shaft is used. A specially designed collar is used where the shaft passes through the shield wall. The collar provides a very tight metal seal, while permitting shaft rotation. However, it is not always desirable to use a metal control shaft. If double-shielding is employed, it may not be practical to bring the shaft out near the common-grounding point. In such a case, the shaft is very likely to set up circulating high-frequency ground currents. This problem is overcome by using control shafts that are made of insulating material.

MODULATION OF GENERATORS

The most common types of generator signal modulation are sine-wave amplitude modulation and sine-wave frequency modulation. Pulse modulation is utilized in most color signal generators. An example of sine-wave amplitude modulation is depicted in Figure 8A. The most common modulating frequency is 400 Hz; however, some generators utilize a 1-kHz modulating frequency. An example of frequency modulation is seen in Figure 8B. Many generators employ a 60-Hz sinewave modulating signal for frequency modulation. A sawtooth waveform is used instead of a sine wave for sweep frequency modulation. It has been noted that a few generators provide a choice of frequency modulation or amplitude modulation. An

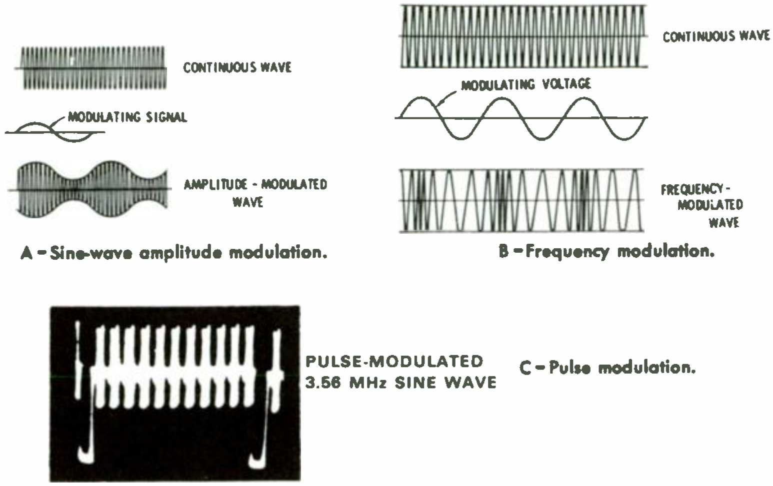


Figure 8 — Basic examples of Generator signal modulation.

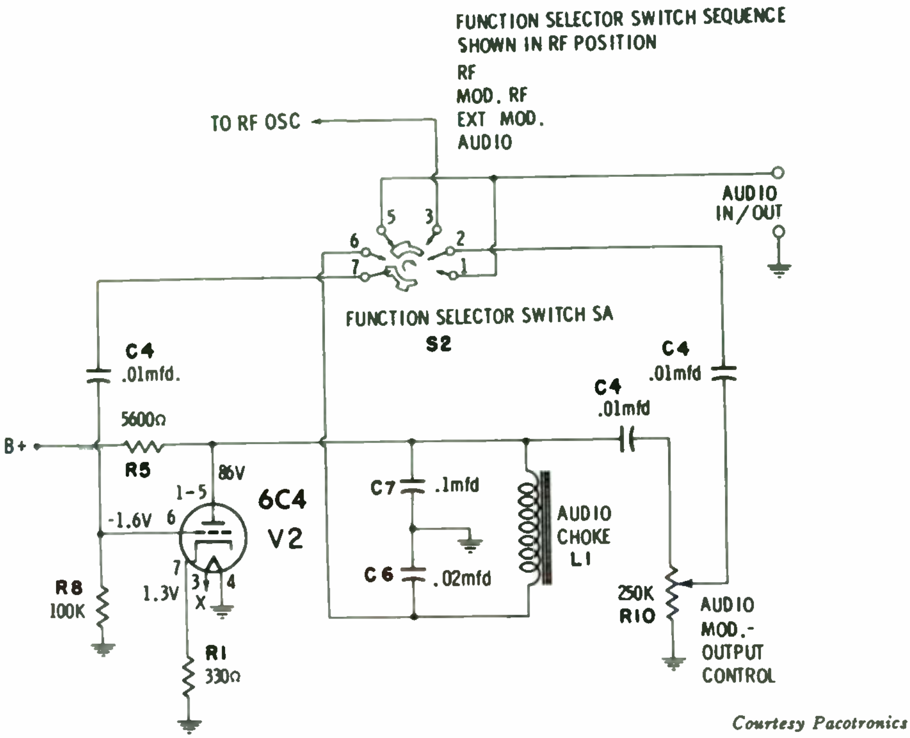
example of pulse modulation is shown in Figure 8C. A color signal generator may have a single output waveform. On the other hand, it may provide a choice of several pulse-modulated outputs, plus a 3.56-MHz c-w output.

SINE-WAVE AMPLITUDE MODULATION

The percentage of modulation is fixed in some generators but is adjustable in others. When the modulation percentage is adjustable, a front-panel control is provided. Nearly all AM generators have the modulating signal accessible externally for use in audio-frequency tests.

The modulating signal is obtained from an audio oscillator. A basic requirement is the generation of a good sine wave. In the past, tickler-feedback audio oscillators were used extensively. The oscillator transformer carried grid, plate and output windings. The present-day trend is to other oscillator configurations, such as the Colpitts circuit. A typical arrangement is shown in Figure 9. The oscillating frequency is determined by the inductance of L1 and the capacitance values of C_6 and C_7. These values are chosen for a nominal resonant frequency of 400 Hz.

The percentage of modulation or the amplitude of audio-output voltage is varied by R_{10}. The output from the oscillator is coupled to the RF oscillator (or to the audio-output connector) by C_4. If the oscillator is lightly loaded, adjustment of R_{10} does not change the oscillator frequency appreciably. Even under heavy-load applications, a small change in oscillator frequency can usually be disregarded. Note that iron core inductors operate as nonlinear components unless the magnetic flux variation is kept well below the



Courtesy Pacotronics

Figure 9 — Colpitts audio oscillator.

saturation region. The Colpitts circuit is advantageous in this regard, because the DC plate current does not flow through the coil. Furthermore, by operating the oscillator at a comparatively low-power level, the AC current flow through the coil is kept well below the core-saturation region. In turn, a good sine wave is generated.

The amount of feedback voltage (and hence the oscillator power level) is determined by the capacitance ratio of C_6 and C_7. In other words, the two capacitors form an AC voltage divider. Thus, the AC voltage drop across C_6 is applied to the grid of V_2. Since L_1 is not a pure inductance but also has resistance, the ratio of C_6 to C_7 also affects the phase of the AC voltage fed to the grid. Oscillation cannot occur unless there is sufficient in-phase voltage fed back to cancel out the losses in the circuit. Hence, the oscillation level depends on both the amplitude of the feedback voltage and also on its phase.

A good amplitude-modulated waveform Figure 8A requires not only that the audio oscillator produce good sine waves, but also that the RF oscillator produce good sine waves. In other words, if the RF oscillator generates a highly distorted waveform, it is impossible to symmetrically modulate the distorted waveform with a sine-wave signal. This principle is often confusing to the beginner—he finds it difficult to understand why the modulated RF output might have a poor waveform although the modulating voltage has a good sine wave. It is easy to check both the RF waveform and the AF waveform with a wide-band scope. However, it is not always easy to pinpoint the circuit defect which is causing distortion.

VARIABLE MODULATION FREQUENCY

Technicians who work with hi-fi systems need to check frequency response over the entire audio-frequency range. Hence, an audio frequency oscillator is used for external modulation of the signal generator, as shown in Figure 10. When external modulation is used, the signal generator is switched to "Ext. Mod." Figure 9. In turn, fixed-frequency oscillator V2 is disabled; the audio-oscillator signal is fed to the RF oscillator for modulation of the carrier. Adjust the output level of the audio oscillator to provide 30% modulation, in accordance with receiver test standards. This is done by connecting a wide-band scope at the output of the RF signal generator. The pattern on the scope screen appears as seen in Figure 11, and the percentage of modulation is calculated as noted in the diagram.

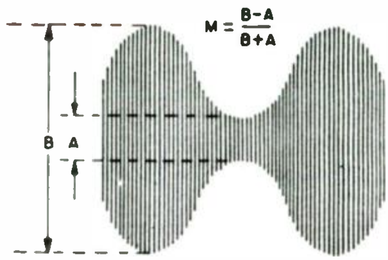
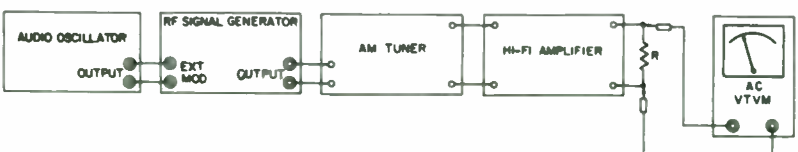
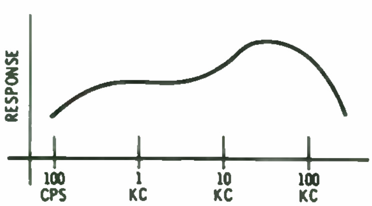


Figure 11 — Percent modulation.

The frequency response of the system (Fig. 10) is then plotted over the entire audio-frequency range. If the frequency response is not flat, as exemplified in Figure 10B, the trouble may be localized to the AM tuner, to the Hi-Fi amplifier, or possibly to both. Note load resistor R in Figure 10A; unless the amplifier is correctly loaded, its frequency response will be impaired. Most of the better quality Hi-Fi



A – External modulation of signal generator.



B – Scope pattern indicated subnormal low-frequency and abnormal high-frequency response.

Figure 10 — Audio oscillator used for external modulation.

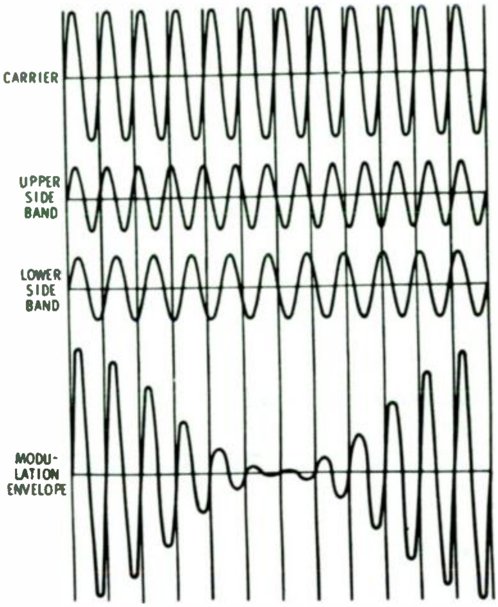
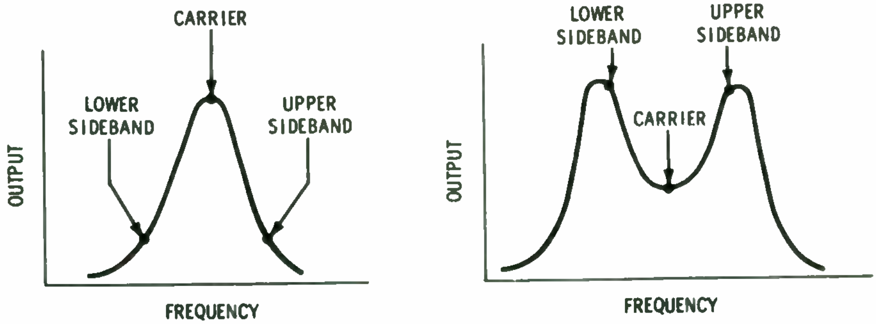


Figure 12 — Modulation of signal-generator carrier produces sidebands.

systems will have an essentially flat response curve from 50 to 15, 000 Hz while lower cost AM receivers will be flat only over a frequency range of 150 to 4000 Hz.

External modulation, as depicted in Figure 10, requires uniform output from the audio oscillator over the entire audio-frequency range. Only high-quality audio oscillators provide a satisfactorily flat output. However, you can use an ordinary audio oscillator if you monitor the output and adjust the level control when you change frequency. To check the uniformity of output, connect a scope across the audio-oscillator output terminals. Choose a convenient reference level and then maintain this value of vertical deflection at each audio-frequency setting in the test procedure.

8 Why does the alignment of the AM tuner in Figure 10 affect the audio-frequency response of the system? It is because modulation of the RF carrier in the signal generator produces sidebands, as shown in Figure 12. The upper sideband has a higher frequency than the carrier, and the lower sideband has a lower frequency than the carrier. If the AM tuner is misaligned, the sideband signals are distorted with respect to the carrier. In turn, the test waveform at the second detector in the AM tuner is also distorted. Subnormal sideband response causes poor high-frequency response. On the other hand, abnormal sideband response (excessive double-humped curve) causes poor low-frequency response. These relations are shown in Figure 13.



A - Subnormal sideband response. **B - Abnormal sideband response.**

Figure 13 — Effects of sideband response.

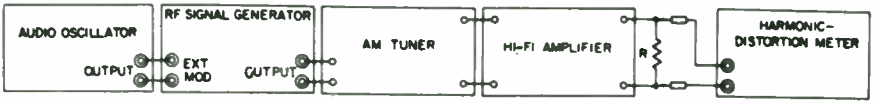


Figure 14 — Signal generator externally modulated by an audio oscillator.

HARMONIC DISTORTION

Technicians who work with Hi-Fi systems are also concerned with harmonic distortion. Harmonic distortion is rated in percent at a specific power output. Most small AM and TV receivers will produce about 5 to 10% distortion at one-watt output. Elaborate Hi-Fi units may have distortion levels down to .05%. A basic test setup is shown in Figure 14. The total percentage of harmonic distortion is read on the harmonic-distortion meter. This test requires that the signal generator provide a good, modulated waveshape. Otherwise, a deficiency in the signal generator would be falsely charged to the AM tuner or to the amplifier. A rough test of the generator waveform can be made by applying the 400 Hz output from the signal generator directly to the harmonic-distortion meter. If a low reading is obtained, you know that the modulating waveform of the signal generator is satisfactory. A wide-band scope can be used next to check the modulated RF waveform. If visible distortion does not appear in the scope pattern, the signal generator can be used with reasonable confidence in harmonic-distortion tests.

SQUARE-WAVE MODULATION OF SIGNAL GENERATORS

Square-wave tests of Hi-Fi systems have become increasingly popular. Square-wave tests will disclose transient distortion, which is not disclosed in sine-wave tests. A suitable test setup is depicted in Figure 15. Note that square-wave modulation of a signal generator is comparatively free from difficulties. The reason for this is that the modulation is simply an off/on sequence. However, there are certain practical points to consider:

1. The Square-wave generator must have good waveform, and a sufficiently fast rise time.
2. The oscilloscope used as an indicator must have good square-wave response.
3. Neither the AM tuner nor the amplifier should be overloaded.

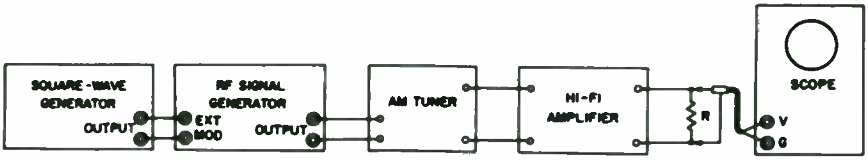
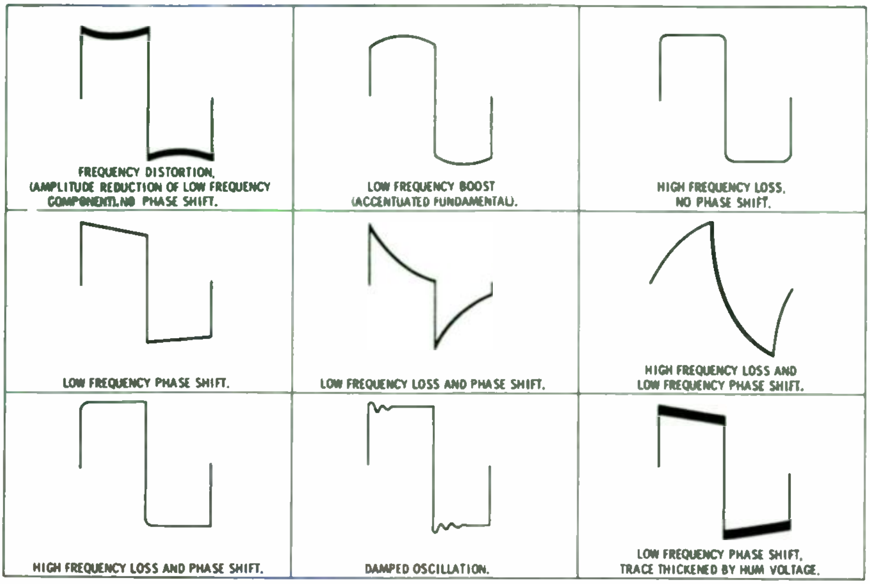


Figure 15 — Square-wave modulation of the signal generator.



Courtesy Precision Apparatus Co.

Figure 16 — Typical square-wave distortions.

You can connect the output from the square-wave generator directly to the scope to determine whether the generator and the scope have satisfactory characteristics. Next, connect the output from the square-wave generator to the external-modulation terminals of the signal generator, and check the modulated RF waveform with the scope. Advance the level of the square-wave signal for 100% modulation of the carrier. You are now prepared to make a test of transient response with the signal generator, as shown in Figure 15. Typical square-wave distortions are illustrated in Figure 16. Some photos of serious system distortion are seen in Figure 17.

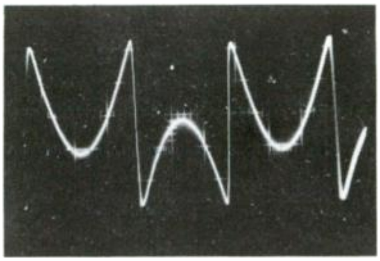
Square-wave modulation is a special case of pulse modulation in which the "off" time is equal to the "on" time.

Color signal generators have built-in pulse-modulation facilities. Since this type of signal is used only to check the performance of color-TV receivers, a detailed explanation of color signal generators is not included in this lesson.

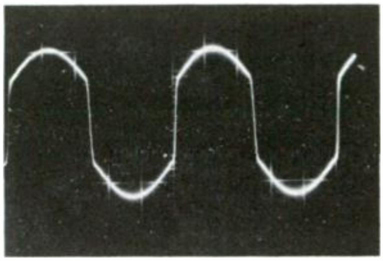
SWEEP SIGNAL GENERATORS

RF Sweep generators are in wide use when designed for TV application, such generators provide frequency coverage only from 4 MHz to 250 MHz in most cases.

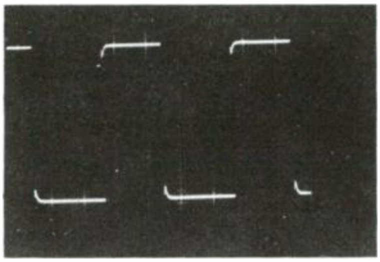
The chief requirement for a sweep generator is that it provide a uniform output over the swept band. You can easily check this characteristic by feeding the output from the sweep generator to a scope via an ordinary demodulator probe. If the generator has a flat output,



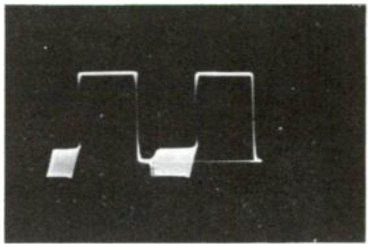
A - Attenuation of square-wave fundamental.



B - Boost of square-wave fundamental.



C - Diagonal corner distortion.



D - Parasitic oscillation.

Figure 17 — Examples of serious system distortion.

the response shown in Figure 18 will be displayed on the scope screen. Why is a flat output important? If the generator has "hills" and "valley" in its frequency output, generator deficiencies will be falsely charged to the receiver under test.

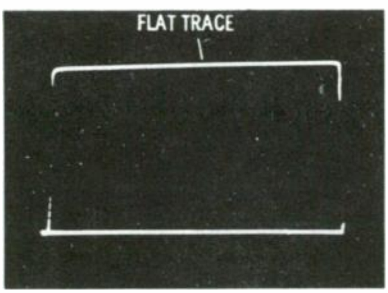


Figure 18 — A good uniform output response from a sweep generator.

Figure 19 shows the circuit configuration for a typical sweep generator. The tank circuit of the sweep oscillator contains coils with ferrous cores. The curve for the core characteristic shows that the magnetic flux is nonlinear with respect to substantial permeability. This is just another way of saying that the inductance of the coil becomes less when the magnetic field is at maximum. Or, the resonant frequency of the sweep oscillator in Figure 19 can be varied by changing the total magnetic field. This change occurs at a 60-hertz rate, and the amount of frequency sweep is determined by the setting of R_3, which is called the sweepwidth control.

Note that the swept trace appears above a baseline in Figure 18.

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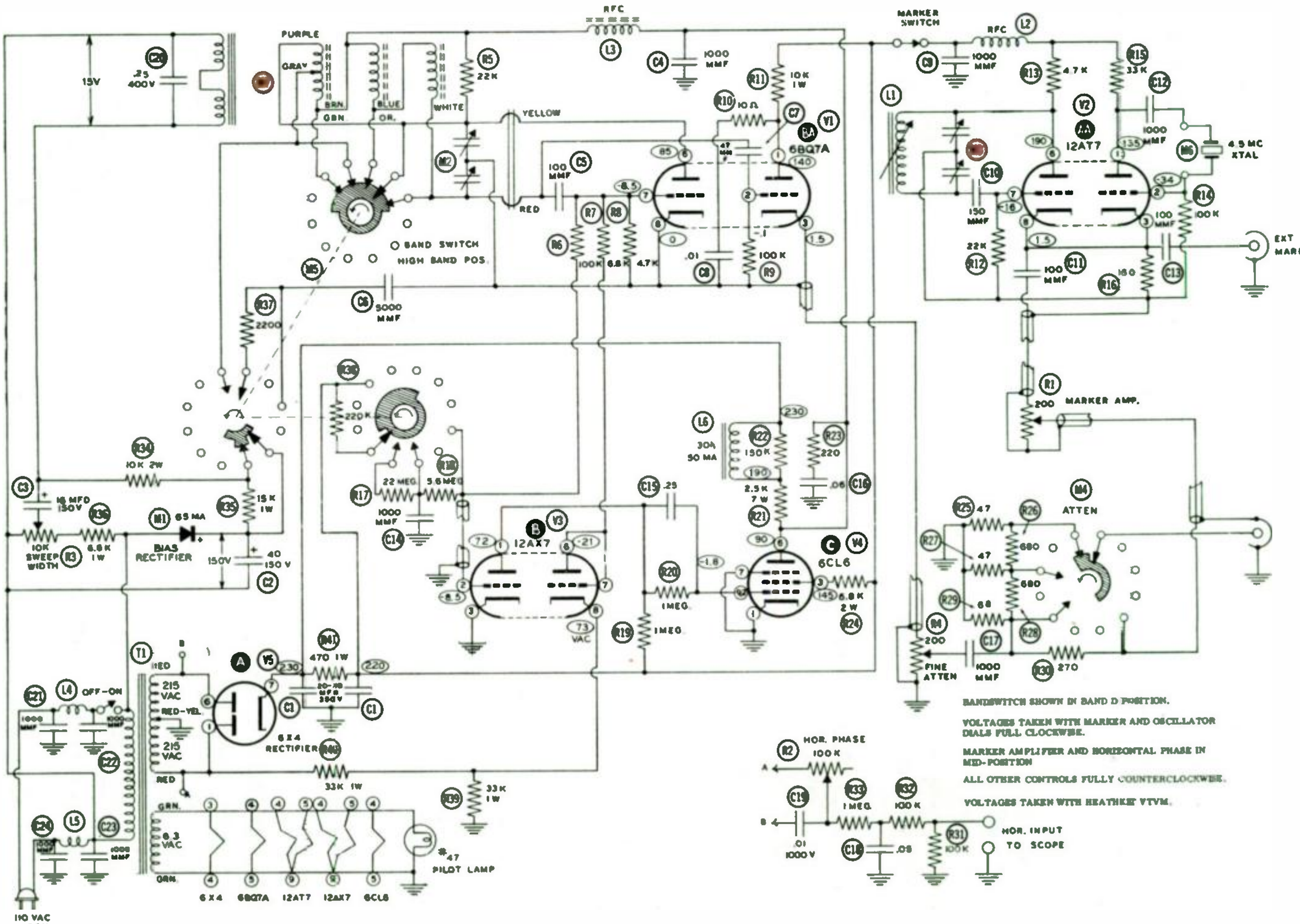


Figure 19 — Typical sweep generator.

The baseline represents zero signal output from the sweep generator. In other words, the oscillator is "on" for 1/120 second, and is "off" during the next 1/120 second. This keying of the oscillator is accomplished by means of a 60-Hz square wave. A clipper tube (V_3) is used to change the 60-Hz supply voltage into a 60-Hz square wave. This square-wave voltage is applied as grid bias to the oscillator tube (V_1). In turn, the tube is keyed off and on at 1/120-cycle intervals.

As in an AM generator, several oscillator coils are used in a sweep generator to cover the total frequency range (3.6 to 220 MHz) in several bands. Thus, the permeability-swept unit, M_7 in Figure 19, comprises three oscillator coils. On the other hand, marker generator V2 has only one oscillator coil. Tuning capacitor M_3 provides a fundamental marker range from 19 to 60 MHz. Second and third harmonics are used to mark frequencies from 60 to 180 MHz. The 4.5-MHz crystal oscillator serves to calibrate the marker generator; its output can also be used to mark intercarrier sound curves.

FREQUENCY CALIBRATION AND ACCURACY RATINGS

The accuracy rating on frequency is commonly specified in terms of the dial reading. For example, if the rated accuracy is ±1% and the tuning dial is set to 40 MHz, the generated frequency is between 39.6 and 40.4 MHz. It is often desired to calibrate a generator to a much higher accuracy than its rating. There are two principal methods in common use for highly accurate calibration. One method, which incidentally provides maximum accuracy, is to beat the generator output against the standard frequencies transmitted by the National Bureau of Standards, located at Boulder, Colorado. Station WWV transmits on 2.5, 5, 10, 15, 20, and 25 MHz twenty-four hours a day. These standard-frequency and time-of-day transmissions can be heard on any good short-wave radio receiver. During daylight hours the strongest frequencies are 10, 15 and 20 MHz. Late afternoon and evening, 2.5 and 5 MHz are generally best.

First, tune in the WWV transmission. If the signal happens to be modulated at 440 cycles or 600 cycles, or the station announcement is being made, wait until the continuous-wave (CW) transmission interval starts. Then, place the signal-generator output cable near the antenna of the receiver. Adjust the tuning dial of the generator until the modulated signal of the generator is heard on the receiver. Turn off the 400 Hz modulation and carefully and slowly tune back and forth across the WWV signal. The signal from the generator will beat or hetrodyne with the WWV signal, and an audible tone will be heard in the radio. The pitch of the tone will go from high to low as the generator's frequency approaches that of WWV. If the generator frequency (or its harmonic) is exactly equal to WWV, there will be no audible sound from the speaker. Thus, the generator is said to be at zero beat. When a zero beat is obtained, the generator is operating at the WWV frequency. Of course, this is a spot-frequency check, which provides calibration only at 2.5, 5, 10, 15, 20 or 25 MHz. However, you can take advantage of the fact that most signal generators have at least a small percentage of harmonic output.

For example, even a standard signal generator may be rated for 7% carrier distortion. This rating refers to total harmonic distortion. If you tune the generator to 1.25 MHz and advance the output level, you will hear a beat between the second harmonic of the generator frequency and the 2.5-MHz WWV signal. Hence, you can easily calibrate the generator to extremely high accuracy at 1.25 MHz. Again, suppose you wish to calibrate the generator at 3 MHz. Tune in the 15-MHz WWV signal on the receiver and set the generator dial to 3 MHz. In many cases, the fifth harmonic of the generator will produce an audible beat. It is sometimes necessary to couple the generator output to the antenna-input terminal of the receiver through a small capacitor.

Harmonic calibration increases the available number of spot-frequency checks. Nevertheless, many practical situations arise which require calibration at arbitrary frequencies that are not harmonically related to WWV signals. Hence, quartz crystal oscillators are commonly used as secondary frequency standards. Note that WWV signals are primary frequency standards. In other words, WWV signals have the highest attainable accuracy, and, therefore, they are the standard of comparison. The National Bureau of Standards states that their atomic standards are accurate to two parts in 100 billion. Any oscillator or generator which is zero-beat against a WWV signal is called a secondary frequency standard, which implies that there is a probable experimental error. Nevertheless, the secondary standard can be adjusted to very high accuracy. A suitable secondary standard will provide spot-check frequencies at 100-kHz intervals, for example.

Hence, quartz-crystal oscillators are the second principle method used for highly accurate calibration of signal generators. Sweep generators often have built-in crystal oscillators. Some signal generators have crystal oscillators.

Only an exceptional signal generator has a tuning dial whose frequency has a constant and equal change in relationship to the rotation of the control knob (true straight line frequency vs rotation). Hence, it is best to calibrate a generator at three or four different frequencies on each tuning range.

Standard AM broadcast stations provide an excellent source of numerous frequencies for calibration. Standard AM broadcast stations are required to maintain their carrier frequencies to ±10Hz of their assigned channels; these channels are spaced 10kHz apart.

AUDIO FREQUENCY GENERATORS

Many variable frequency audio generators utilize the Wien-bridge oscillator depicted in Figure 20. It is a two-tube RC oscillator which is tuned by a resistance-capacitance bridge. V_1 serves as an oscillator and amplifier; V_2 is an inverter. The circuit would oscillate even without the RC bridge, because of the 180° phase shift produced by V_1 and V_2. However, this arrangement would not generate a specific frequency, nor would it generate a sine wave. Therefore, the bridge circuit is utilized to insure the elimination of all feedback frequencies except one. This one frequency is determined by the values of R and C in the bridge.

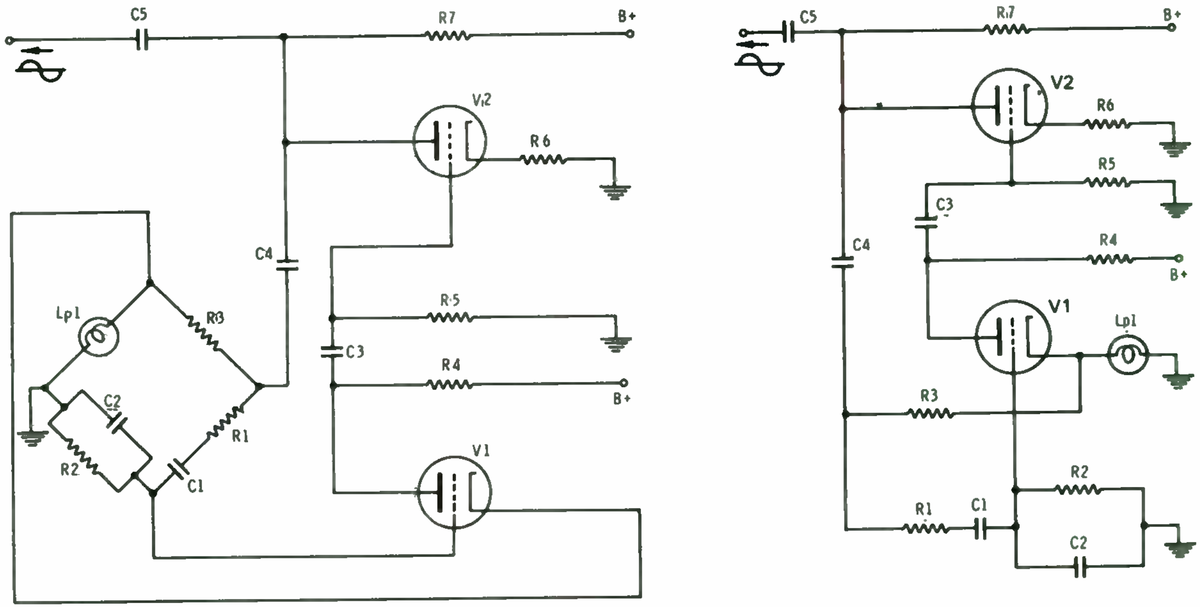
The bridge oscillator in Figure 20B facilitates circuit analysis. A degenerative feedback voltage is provided by R_3 and lamp LP_1. The amplitude of this feedback voltage remains nearly constant for all frequencies, since the resistances are practically constant for all frequencies, and there is no phase shift across the voltage divider. Inverter tube V_2 shifts the output of V_1 by 180°. Thus, the voltage appearing across R_2 in the bridge is in the correct phase to sustain oscillation. This action occurs when $R_1C_1 = R_2C_2$. The frequency at which the circuit oscillates Is:

$$f = 1 \div (2\pi R_1C_1)$$

Lamp LP_1 is a nonlinear resistance. Figure 21 shows how filament resistance increases when the applied voltage is increased. When more current flows, the filament becomes hotter, and this causes an increase in its resistance. It follows from Figure 20 that the lamp compensates automatically for variation in circuit action, so that sufficient feedback voltage will always be applied to V_2. When the current in the circuit increases, the lamp drops a greater voltage. This represents more degeneration, which reduces the gain of V_1 and holds the output signal at a nearly constant amplitude.

Tuning the generator to different operating frequencies tends to change the circuit current. In typical generators, C_1 and C_2 in Figure 20 consist of a ganged variable capacitor. When it is tuned, the capacitive reactances change, which tends to change the AC signal levels. However, the lamp resistance largely compensates for this change, so that the output signal voltage remains about the same. Band-switching is accomplished in typical generators by use of different values of R_1 and R_2 in Figure 20. This results in a different voltage-divider action, which tends to change the circuit current. Again, a compensating change in lamp resistance maintains the output signal voltage at about the same level.

Note the typical Wien-bridge generator configuration shown in Figure 22. You will observe that this is the same basic configuration as in Figure 20. Tuning is accomplished by variable capacitors C_2 and C_3, which are ganged. Trimmer capacitor C_1 is provided for dial calibration. Band switching is provided by S_2, which switches different values of resistance into the bridge circuit. Good sine waves require that the feedback be limited to a value which does not drive V_1 and V_2 past their region of linear operation. Accordingly, R_9 is provided as a maintenance adjust-



A - Circuit diagram.

B - Redrawn oscillator circuit.

Figure 20 — Wien-bridge oscillator.

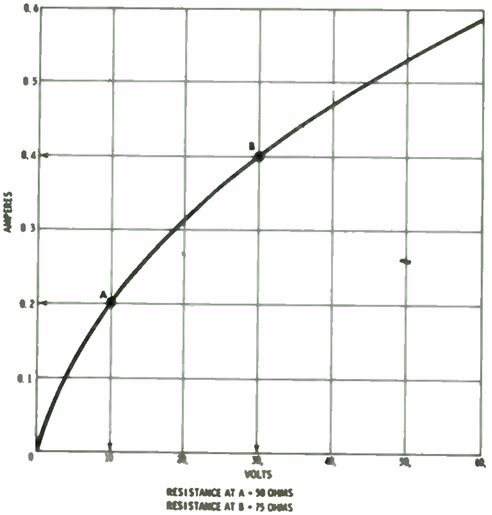


Figure 21 — Curve for positive temperature coefficient of resistance.

ment to set the feedback level correctly for a good waveform output.

Output is taken from the plate of V_2 fed to a cathode follower, shown in Figure 23. A 50K potentiometer is used in the grid circuit as an attenuator. A maximum of 10 volts rms is available from the cathode. Rated distortion is less than 1% and the output level does not vary more than ±1.5 db from one band to the next. The hum level is less than 0.4% of the signal-output level. You will find that the hum level in simple Wien-bridge generators does not come from the power supply, as might be supposed. Instead, it is

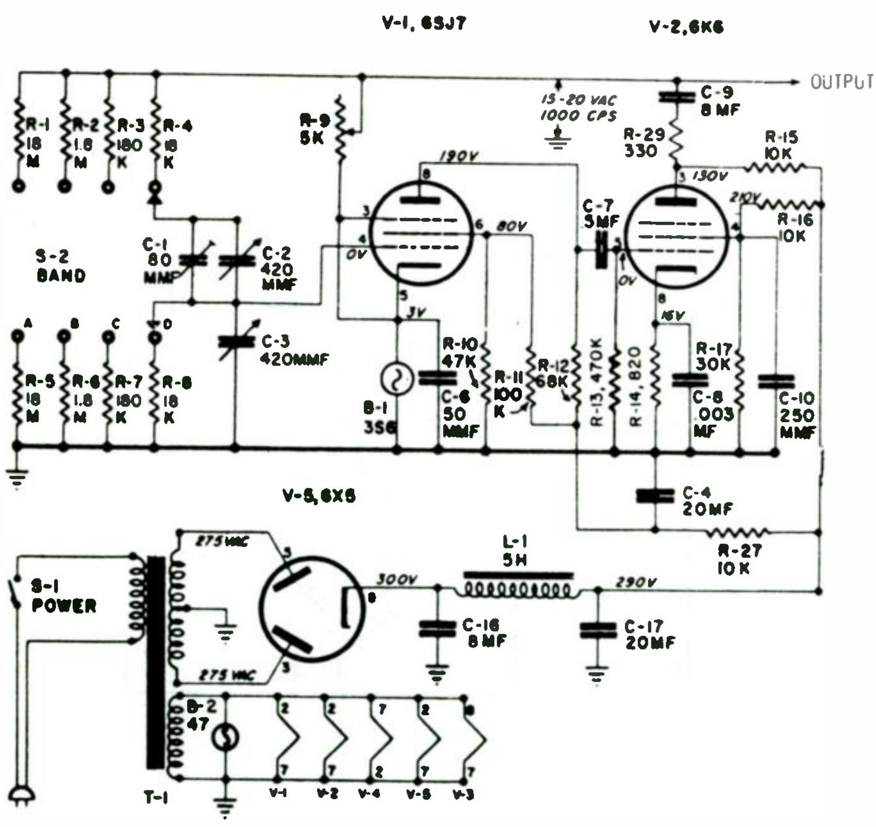


Figure 22 — Typical Wien-bridge oscillator.

due to stray-field pickup by the high-resistance bridge circuit. Ample shielding is required to minimize the hum level.

In this type of RC oscillator, the frequency ratio of each range can be as high as 15:1, but is generally chosen to provide decade ranges (10:1).

The generator illustrated in Figure 22 has the following frequency ranges: 20-200, 200-2000, 2000-20,000 and 20,000-200,000 Hz.

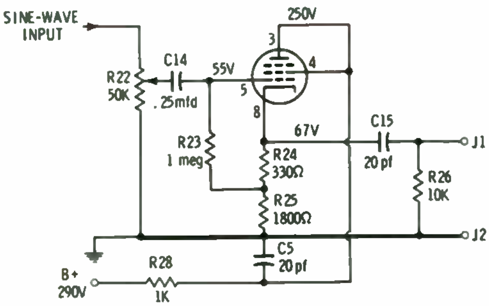


Figure 23 — Cathode follower output.

SUMMARY

You have learned that an RF signal generator is essentially a small radio transmitter. You should be able to define a standard signal generator as well as a sweep generator. You should also know the important application of each of these two types of instruments. The principle of modulation of a carrier frequency was restated in this lesson as it is an important element, not only in generators, but also in frequency conversion in superheterodyne receivers.

You have also learned a basic principle of frequency measurement by the "Zero Beat" Method. Further, you have learned that the proper circuit arrangement of R, C and gain is capable of generating sine-wave AC power.

TEST

Lesson Number 55

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-055-1.

1. An AM signal generator is a device that
- A. is used for TV tests.
- B. provides a sweep signal.
- C. provides a modulated RF signal.
- D. is used to provide a "pip."

2. Some standard signal generators employ a form of AGC to provide a
- A. square wave output.
- B. uniform level of output voltage.
- C. sweep frequency.
- D. sawtooth wave output.

3

3. The Hartley circuit is used in
- A. audio amplifiers.
- B. RF generators.
- C. distortion meters.
- D. square wave generators.

3

4. An attenuator is similar to
- A. an inductor.
- B. an LC circuit.
- C. a capacitor.
- D. a voltage divider.

Mod Sig
Not Relat
Freq.

5. A transmission line when terminated with the correct resistance
A. has standing waves.
B. is reactive.
5 C. will radiate a signal.
—D. is resistive.

6. The RF sweep generator is employed primarily in servicing
A. AM radios.
13 —B. television receivers.
C. phonographs.
D. tape recorders.

7. A variable frequency audio generator is used to
A. evaluate generator shielding.
B. measure a transmission line.
10 —C. plot the AF response of a receiver or amplifier.
D. modulate a sweep generator.

8. The alignment of a receiver
A. does not effect the audio response.
B. reduces audio power output.
11 —C. affects the audio response.
D. increases hum level.

9. Harmonic distortion is rated in
A. volts.
12 B. power.
—C. percent.
D. watts.

10. Most variable frequency audio generators use
A. an L/C oscillator circuit.
B. a Colpitts circuit.
17 C. a quartz crystal.
—D. a Wien-bridge circuit.

Notes

Notes

Notes

Portions of this lesson from
Know Your Signal Generators
by Robert G. Middleton
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"School Without Walls"
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BRAIN CAPACITY

Albert Einstein, a great scientist and mathematician, estimated that he only used about 18% of his brain capacity. That being the case, what then could man accomplish by using the total capacity of his brain . . . or even 50% of the brain's capacity!

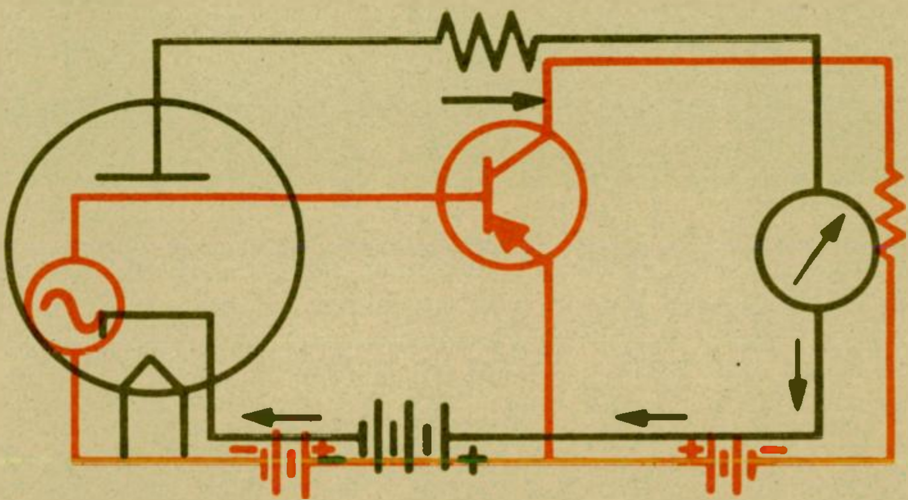
One thing is certain, the more effort you put into learning your ASI lesson material, the closer you come to knowing the answer . . . and the more successful you will be in your job.

You owe it to yourself to make the most of your spare time. Work hard, apply brain power, and you will be successful!

S. T. Christensen

LESSON NO. 60

INTEGRATED CIRCUITS



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CONTENTS

52-065

INTEGRATED CIRCUITS

INTRODUCTION

In 1957, a revolutionary incident occurred in the world of electronics: the invention of the integrated circuit (abbreviated IC) by Jack S. Kilby at Texas Instruments, Inc. (In 1969, Mr. Kilby received the National Medal of Science.) The IC ushered in the present age of microelectronics by offering on a single, tiny, semiconductor wafer an entire circuit including diodes, transistors, resistors, capacitors, and internal "wiring." In the decade that followed its relatively quiet introduction, the IC found application in all kinds of electronic equipment, from space vehicles to TV receivers. An entire circuit can now be plugged in and out of a system in the same way that a single transistor formerly was. Sometimes, an external component or two will be needed, but often only a DC supply is required to make an IC work.

This lesson describes the IC and explains the highlights of IC fabrication and operation.

SEMICONDUCTOR REVIEW

Before proceeding with our discussion of integrated circuitry, we will review semiconductor materials and junctions. The semiconductor material used in most transistors for radio and audio equipment is either germanium or silicon. Semiconductors, as the term implies, fall in a category between good conductors and good insulators. The semiconductor material is not used in its pure state. Controlled amounts of certain impurities are added and, by imparting certain conduction properties to the material, they produce what is known as a doped semiconductor.

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

1. Donor impurity—donates electrons to the semiconductor. Donor impurities produce N-type semiconductors.
2. Acceptor impurity—accepts electrons from the semiconductor material. Acceptor impurities produce P-type semiconductors.

The primary difference between P and N material is the type of charge movement. In N-type material, current is produced by a movement of electrons or negative charges; in P-type material current is produced by a movement of holes or positive charges.

Electrons and Holes

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

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

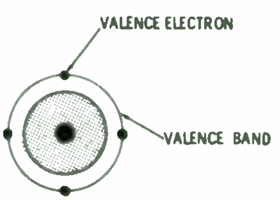


Figure 1 — Exaggerated sketch of an atom, showing the various parts.

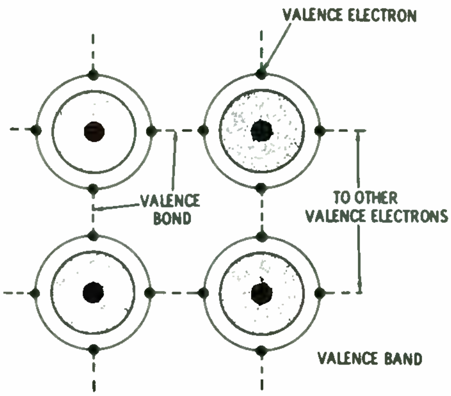


Figure 2 — Composition of crystal structure from atoms.

If atoms with five valence electrons (Fig. 3A) are added to the structure shown in Figure 2, the material would then contain free electrons that would not be held by a valence bond. This addition can be performed in semiconductors by adding a donor impurity that produces an N-type semiconductor. The electrons (negative charges) not bound in the crystal structure can now be used as charge carriers. In N-type material, the electrons are called majority carriers because the majority of the current will be composed of electrons. This statement presupposes that current can be composed of holes, and this supposition is correct. The holes are minority carriers in N-type semiconductors.

In the same manner that a donor impurity donates electrons to the semiconductor material, an acceptor impurity (Fig. 3B) causes the semiconductor material to accept electrons. Adding acceptor atoms (Fig. 3B) produces a P-type semiconductor. In the P-type semiconductor, there are atoms that lack an

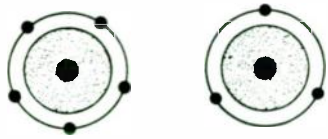


Figure 3 — Donor and acceptor atoms at a junction.

electron in the valence band. This lack of an electron is termed a hole, or positive charge. The hole, being the lack of an electron in the valence band of an atom, does not move out of this band; therefore, conduction takes place in the valence band. This action can occur in solids only (such as P-type semiconductors); it does not apply to vacuum-tube theory. Because the majority of electric current in P-type semiconductors is composed of holes, the holes are the majority carriers and the electrons are the minority carriers.

To understand this theory, the reader should think in terms of positive and negative charges.

1. An electron is a negative charge that will be attracted by and will move toward a positive charge.
2. The hole is a positive charge that will be attracted by and will move toward a negative charge.

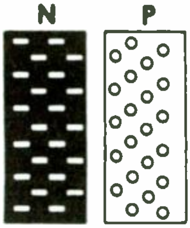
An electron leaving the valence band will leave a hole in the valence band, and an electron-hole pair will be formed. The electron and the hole will have equal charges but opposite polarities. If an electron fills a hole in the valence band, the charges will be cancelled.

The main points to remember are that electrons are negative charges, and that holes are positive charges. Both can move and, as such, can be current carriers. In N-type semiconductors, the electrons are the majority carriers; in P-type semiconductors, the holes are the majority carriers. Current in a semiconductor is composed of negative or positive charge movement, or both negative and positive charge movement.

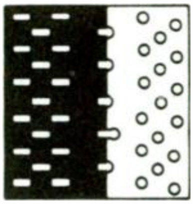
Junction of P and N Semiconductors

Transistor operation is normally based upon the action of the carriers at the junction of P and N materials. A pictorial method of describing the action of the carriers at a junction will probably be the easiest to follow. For this purpose, the blocks labeled N and P in Figure 4A will represent the doped semiconductor materials. The N material is shown as having electrons as majority carriers, and the P material is shown as having holes as majority carriers.

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



A - Two types of semiconductor materials and their associated carriers.



B - Action that takes place when junction is produced.

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

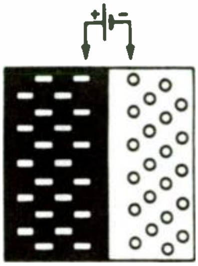


Figure 4 — Action of the carriers at a junction.

level by a process such as fusion or melting.

When P and N semiconductors are formed together to produce a junction, the majority carriers near the junction move toward each other and cancel out (Fig. 4B). Because of this cancelling action at the junction, a charge has now been established between the semiconductor materials. Since some of the majority carriers (electrons in N-type holes in the P-type) have been effectively cancelled, the material at the junction assumes a positive charge in the N semiconductor material and a negative charge in the P semiconductor material. Remember, as we previously noted, the majority carriers were bound in the crystal structure and, before the junction was formed, there was an even distribution of these carriers in the individual semiconductor materials. Therefore, the material by itself had a zero net charge.

The electrons in the N material now are repelled by the negative charge in the P material, and the holes (positive charges) are repelled by the positive charge in the N material. These majority carriers therefore maintain positions back from the junction. The charge and its polarity at the junction are represented by the battery in Figure 4C. This charge, or potential, is extremely small—in tenths of a volt—but does produce an effective potential hill or barrier to the passage of the current carriers. To pass from one side of the junction to the other, the electron or hole must gain energy equal to this potential hill.

The sources of external energy that can move the carriers across a junction may be radiation in the form of heat, light, or X rays; or the source may be a more usual one, like a battery or power supply.

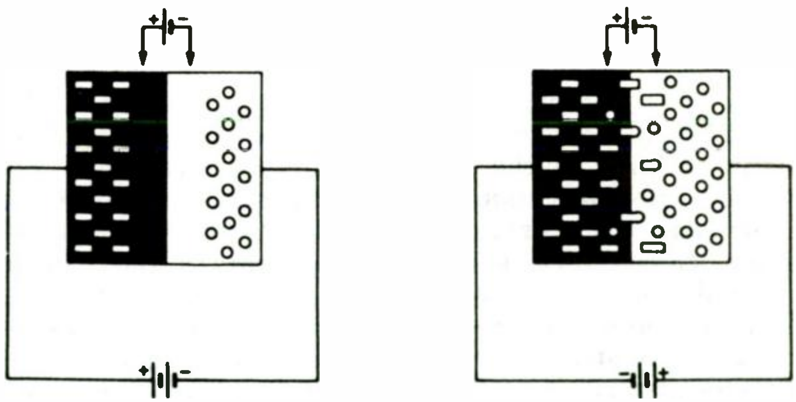
Forward and Reverse Bias

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

The potential hill at the PN or NP junction, represented by the battery at the junction in Figure 4C, must be overcome before the carriers can move. When a battery is connected so that it aids or increases the potential hill at the junction, the carriers are pulled farther away from the junction (Fig. 5A). The minus charge of the battery attracts the holes to the right, and the positive terminal of the battery attracts the electrons to the left. Such a reverse-biased junction can have a DC resistance reading in the megohm region.

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

The resistance of a reverse-biased junction depends upon the applied voltage. The current in a reverse-biased junction is relatively constant. As the voltage across a resistance is changed, the current changes. With a junction diode, however, the reverse-bias voltage produces a resistance change, but the current remains nearly the same. This condition can be shown by the Ohms Law formula $I = E/R$. Thus, if E (voltage) increases across a resistor and if



A - Result of connecting a battery to aid, or increase, the potential hill (reversed biasing).

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

Figure 5 — Relation between the applied voltage and the potential hill.

the resistance is constant, I (current) will increase. If E increases and if the resistance increases proportionately (as it does in the junction diode), then "I" will remain constant.

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

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

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

Junction Transistor

The junction transistor is made by forming two PN junctions within a small block of germanium or silicon. This is done by alternately adding acceptor and donor atoms to sections of the block. The three sections formed within the crystal block have alternately opposite polarities. This results in a transistor that is either PNP or NPN in material arrangement. The arrangement of charges designates the external bias polarities that must be applied for it to function in a circuit.

Figure 6A illustrates the junction charges of an unbiased PNP transistor. Notice in particular the charge potentials and wide depletion layers at the junctions. The existing potential hill prevents majority current flow through any portion of a transistor under *no bias* conditions.

In Figure 6B, a collector bias battery has been connected between the emitter and collector. This in itself does not cause significant current to flow. The addition of the base bias battery between the base and emitter, however, does affect current flow. The small base-emitter potential shown in Figure 6B sweeps some of the junction charges from the base region and narrows the depletion layers. This reduces the junction resistance and allows some current to flow from the emitter across the base-emitter junction and then across the base-collector junction into the collector area. The amount of current flowing from emitter to collector is actually much larger than the current flow between the emitter and base. This effect is called *amplification* or current *gain.*

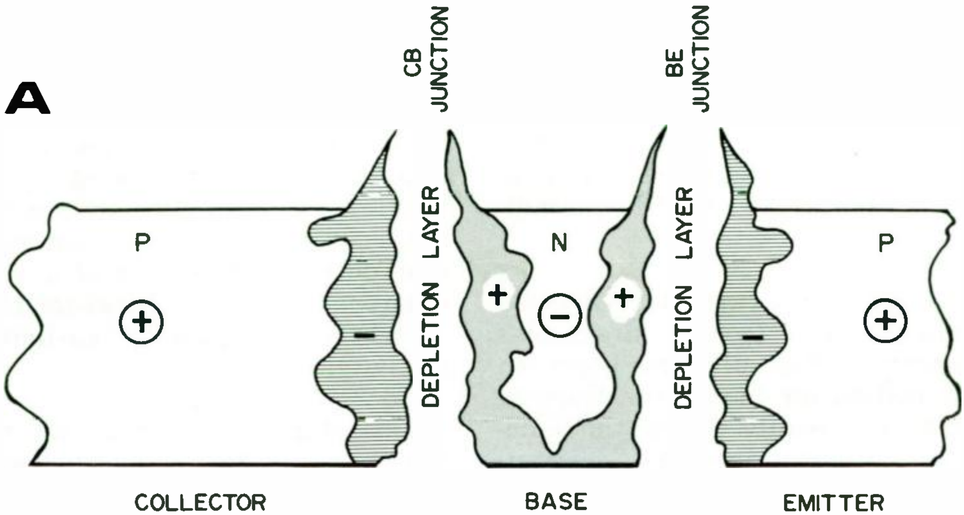


Figure 6A — No forward bias conditions.

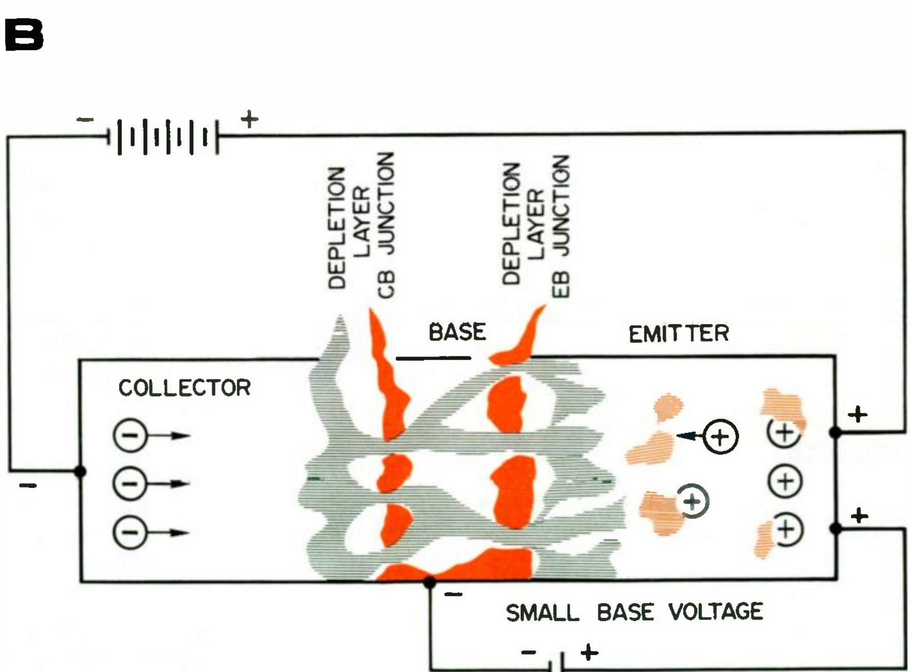


Figure 6B — Small forward bias conditions.

In Figure 6C, we show a larger base potential. This acts to further reduce charges at the junctions and to further narrow the depletion areas. Even more collector-emitter current now flows across the junctions than under small bias conditions.

When more current is injected into the base from a larger bias potential (Fig. 6D), we approach saturation for the device. Current streams steadily across the junctions, almost unimpeded. The transistor under saturated conditions due to high bias is conducting as much collector current as it possibly can.

The three bias conditions shown, small bias (Fig. 6B), medium bias (Fig. 6C), and large bias (Fig. 6D), represent small signal, large signal, and saturated operating conditions for transistors. Small signal conditions are used for many amplifier functions, such as RF, AF preamps, and IF. Large signal conditions are observed for audio power amps. Saturated operation applies to switches and multivibrators as used in solid state TV sweep circuits.

Germanium and Silicon Transistors

Two basic types of transistors are presently being produced. They receive their name from the semiconductor material from which they are produced—germanium and silicon.

The primary differences between these two types are the maximum allowable operating temperature and the voltage required to overcome the potential hill.

The bias voltage applied to the emitter-to-base junction of a germanium transistor to produce forward current will be approximately one-tenth to two-tenths of a volt, whereas the silicon transistor bias will be approximately four-tenths to six-tenths of a volt.

Operating temperature for the silicon transistor is nearly twice that of the germanium. The maximum junction temperature for a germanium transistor is about 110°C. The silicon transistor can be operated as high as 200°C. Therefore, the silicon transistor is generally preferred over the germanium type.

Amplification and Gain

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

The input circuit of a transistor is associated with the injection of carriers into the base region. The output circuit is associated with the flow of carriers from the emitter to the collector. The larger portion of the current is between the emitter and the collector, and only a small current will exist between emitter and base.

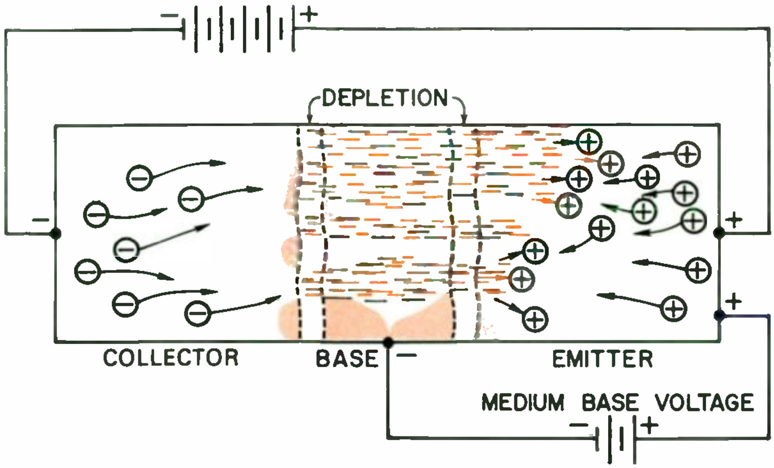


Figure 6C — Large forward bias conditions.

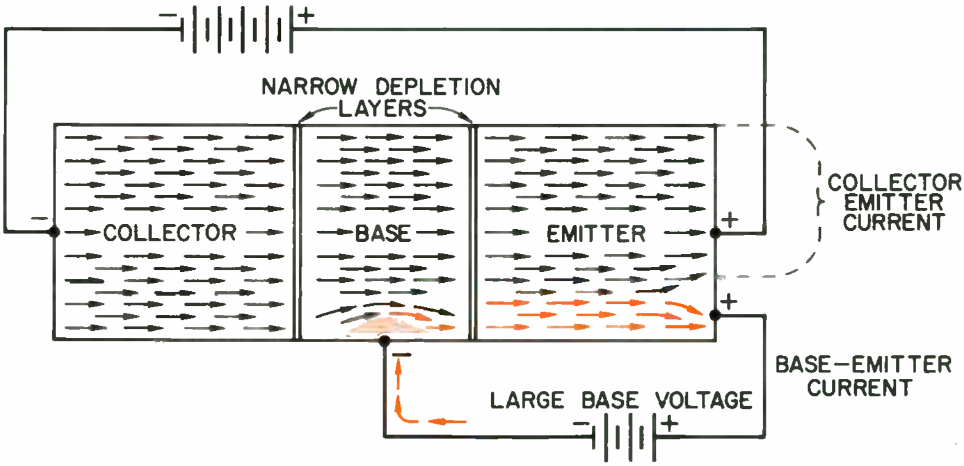


Figure 6D — Saturated forward bias conditions.

Figure 7 shows the material charge arrangements for both PNP and NPN transistors. Also shown are their associated schematic symbols and a bottom view of the lead arrangement for popular T05 cased transistors and several other small sizes. In Figure 8, we show forward bias conditions for both the PNP (8A) and NPN (8B) transistor. Individual collector-emitter and base-emitter bias batteries are shown in this illustration. In practice, however, the base-emitter battery is usually replaced with voltage dividing resistive networks.

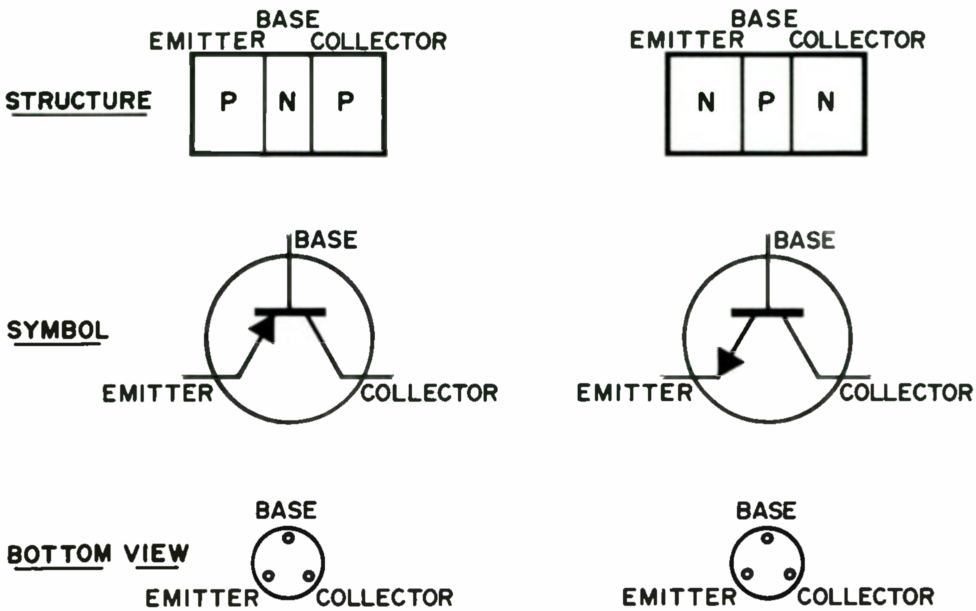


Figure 7 — Material arrangement with symbol and lead locations of the PNP and NPN transitor.

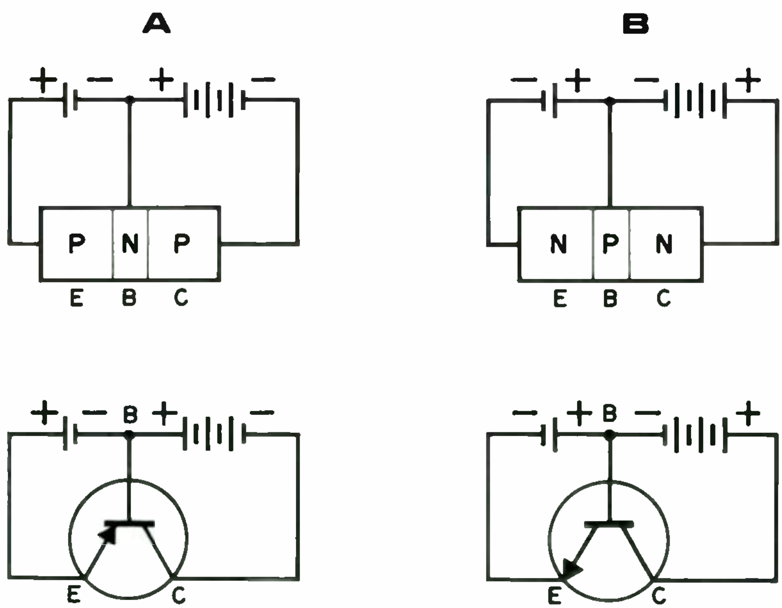


Figure 8 — Forward bias polarities.

TRANSISTOR CONFIGURATIONS

A signal may be inserted into either the base or the emitter of a transistor. The amplified output can be taken from either the emitter or the collector. The position of a transistor relative to input and output signals is called the configuration of a transistor.

The configuration adapted to perform a function with transistors is frequently determined by one of two important requirements: the amount of current gain required, or the amount of voltage gain required. A combination of the two results in a power gain that may also be a prime consideration.

The most common arrangement for amplifiers is the common emitter configuration. It is also referred to as a grounded emitter circuit. The output load is in the collector's circuit (Fig. 9), and the input signal is injected into the base.

Common emitter amplifiers owe their popularity to their desirable gain features. These features are relatively high current, voltage and power gain in one circuit. Common emitter amplifiers also have a relatively high input impedance and absorb only a moderate amount of power from the signal source.

A common collector configuration (also known as an emitter follower) is shown schematically in Figure 10. Like the common emitter circuit, the input signal is also injected into the base. The output, however, is taken across a load resistor R_L that appears in the emitter's current path.

Common collector amplifiers have exceptionally high current gain. This means that a current input signal will be boosted many times. The output voltage, however, will be less than that of the input signal; therefore, the voltage gain will be less than one to one or

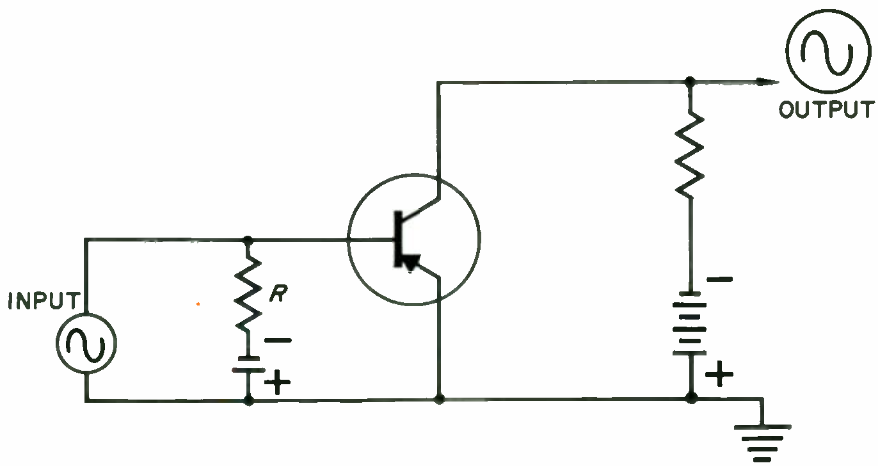


Figure 9 — Common emitter amp.

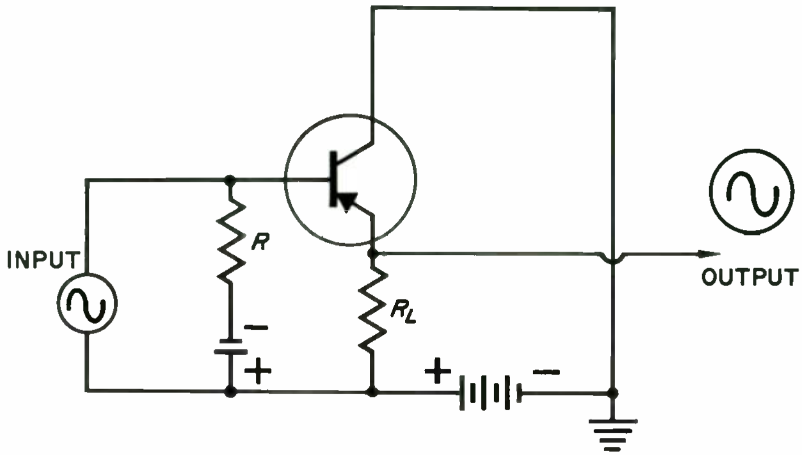


Figure 10 — Common collector (emitter follower) amp.

unity voltage. The common collector amplifier has the highest input impedance of all configurations.

Common base configurations were the earliest used arrangements for amplifiers (Fig. 11). The input signal is injected into the emitter instead of the base, and the output is taken across R_L in the collector circuit. Common base amplifiers have phenomenal voltage gains, but their current gains are less than unity. They also have very low input impedances.

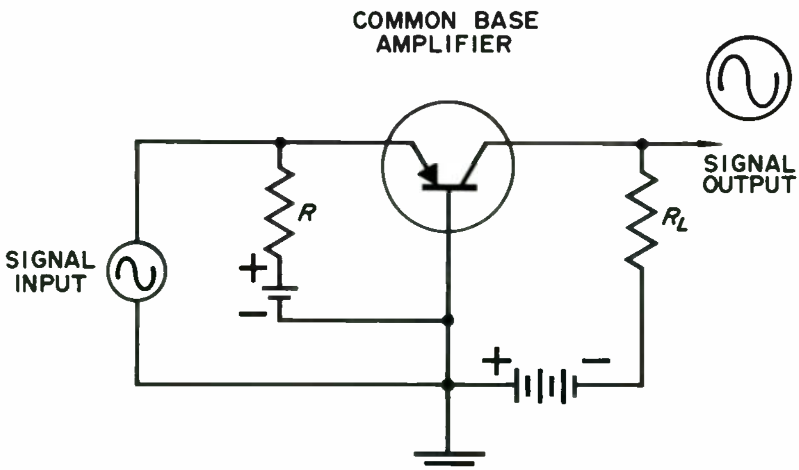


Figure 11 — Common base (grounded base) amp.

FIELD EFFECT TRANSISTOR

A conventional transistor is known as bipolar, because it makes use of both positive and negative current carriers. The field effect 3 transistor (FET) is unipolar; it uses only one polarity of current. Whether the current is positive or negative depends upon whether the device is of P-channel construction or N-channel construction.

Unlike bipolar transistors, FETs use a controlling voltage instead of a controlling current. FETs are available in two types, as determined by their gate construction. These are the JFET and the IGFET. Each of these is available with either N-material (N-channel) or P-material (P-channel). In addition, they may have only one gate or dual gates. Figure 12 shows a pictorial view of both the N-channel and P-channel JFET with a single gate.

The JFET is a small, thin wafer of silicon, doped with either an N or a P impurity. A contact is provided at each end. One end is called the source (S) and the other is the drain (D). A gate (G) is formed by doping a thin strip on each face with an impurity that is opposite in polarity

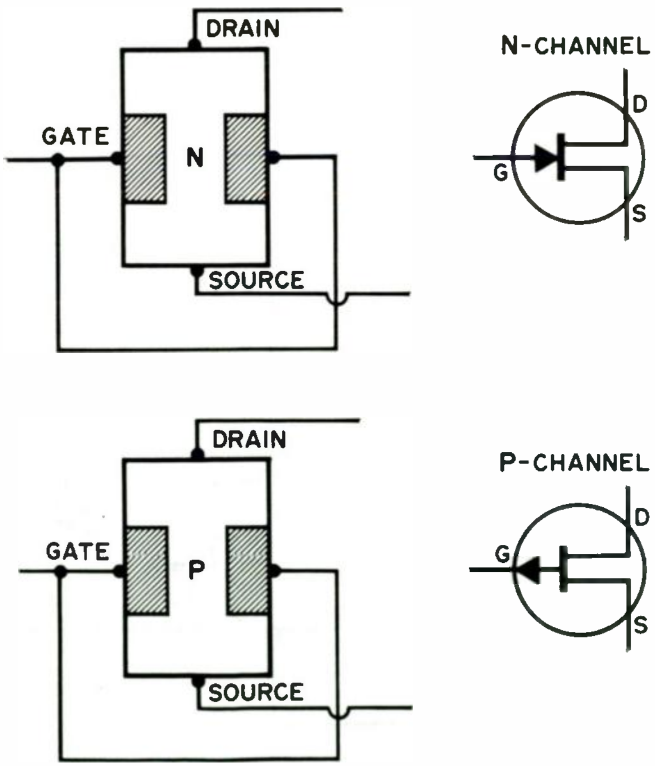


Figure 12 — Element arrangements of JFETs.

to that of the material. Gate contacts are attached to each of these strips and then tied together.

Figure 13 illustrates an N-channel JFET with a bias battery attached between the drain and source in series with R_L. Current flows freely through the device from the source to the drain.

In Figure 14 we have added a gate bias battery between the gate and the source with its negative

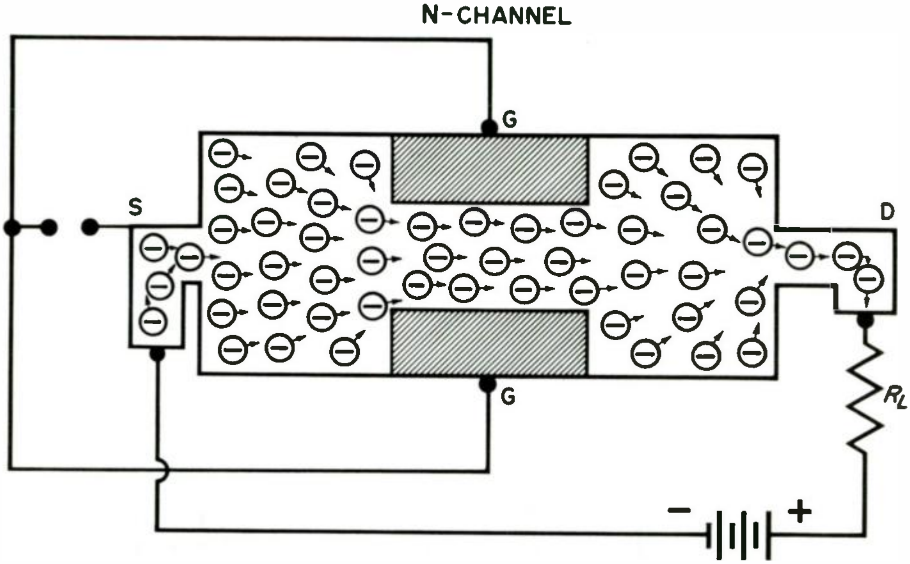


Figure 13 — Channel current in a JFET without gate bias.

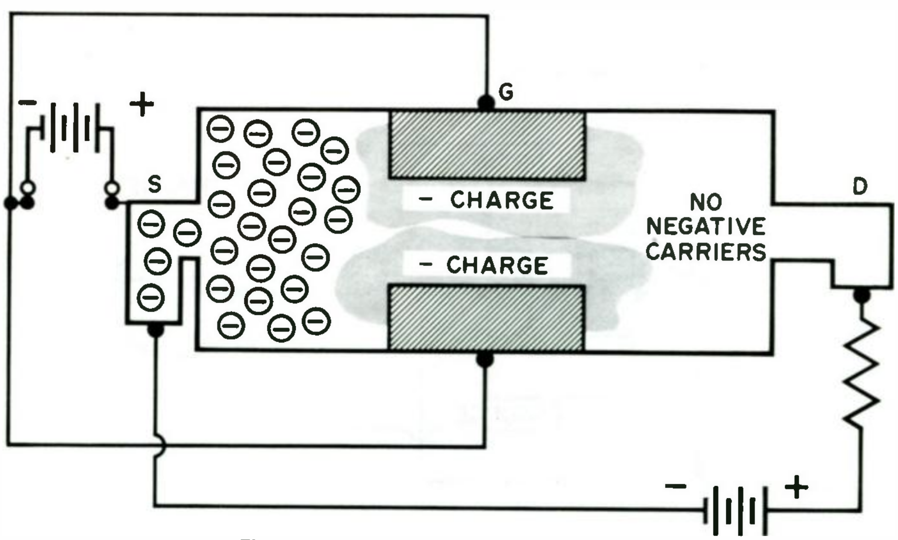


Figure 14 — Pinch-off condition of a FET.

terminal to the gate. A powerful negative charge extends into the N-material and prevents electrons from flowing through the material between the gate elements. If this charge is great enough, current will cease to flow between the source and the drain; the device is then said to be in a "pinch-off" condition. The gate potential required to accomplish this is called the pinch-off voltage.

Figure 15 illustrates two JFET amplifiers. One uses an N-channel JFET and the other a P-channel JFET. A steady drain-source current flows in each of these circuits, even with no signal applied. The amount of source-drain current flowing in this static or no-signal state is established by the value of R_2 in series with the source due to the voltage drop that occurs across R_2. The source is, therefore, either more positive (in the N-channel circuit) or more negative (in the P-channel circuit) than the gate. Effectively, the gate is reverse biased and its field potential will somewhat impede drain-source current flow.

This mode of operation is called the depletion mode, because the gate-source potential is polarized to

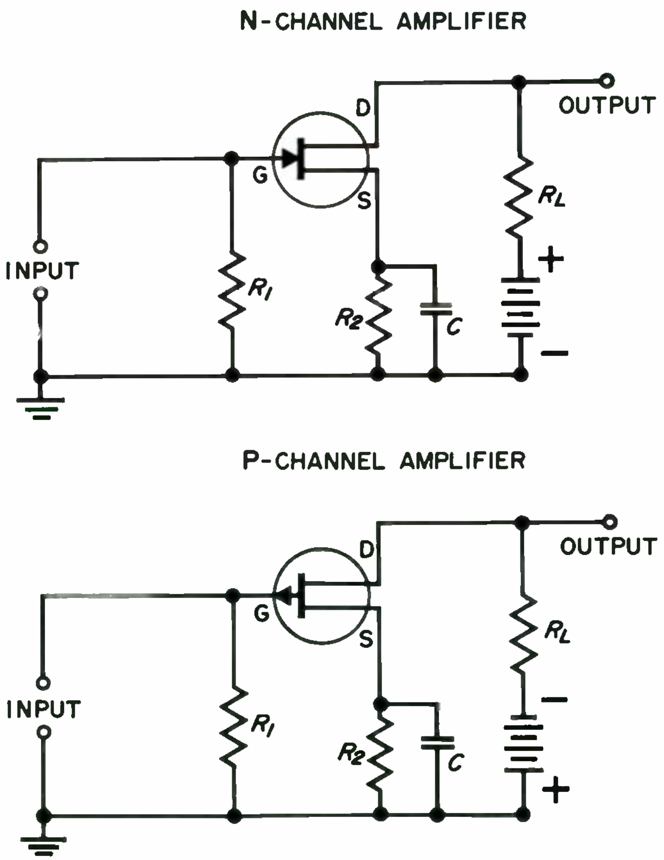


Figure 15 — Common source JFET amplifiers.

restrict or deplete the devices charge carriers. Nearly all JFETs operate in the depletion mode.

If a changing voltage is applied to the inputs of the amplifiers in Figure 15, its changes will affect the depletion charges of the gate area. These charges will become either more or less negative and will permit more or less drain-source current to flow. The drain-source current, therefore, reflects the change (direction and amplitude) of the input signal. The drain-source change is much greater in magnitude than the input signal. The output signal will be an amplified duplicate of the input.

Thus far we have discussed only the JFET. Another type of field effect device is now available that has numerous advantages over the JFET. This is the MOSFET or insulated gate field effect transistor, sometimes abbreviated IGFET. It is called an insulated gate device, because the gate is a metal strip insulated from the source and drain. MOS is interpreted as metal-oxide-semiconductor.

4

MOSFETs are available as either a P-channel or an N-channel device. They are also available as depletion or enhancement devices. The depletion MOSFET operates with a reverse bias voltage on its gate, like the JFET. The enhancement type, unlike the JFET, needs a forward bias voltage on its gate to conduct drain-source current.

Since the gate in MOSFETs is insulated from the other elements, for all practical purposes it draws no current from the signal source. MOSFETs have the highest input impedances of any amplifying device. Since they require no current from the signal source and their input requirements are strictly voltage, they absorb no power in the input.

Figure 16 shows the construction of both the enhancement MOSFET and the depletion MOSFET. Notice that the drain-source areas are in a substrate of opposite polarity material. The depletion MOSFET contains a channel for the drain-source current, while the enhancement MOSFET uses the substrate for drain-source current.

The schematic symbols for MOSFETs are shown in Figure 17. Study them carefully, so that you will be able to identify them whenever they are encountered on drawings.

WHAT IS THE IC

In many respects, the IC is a refined and subminiaturized version of the early electronic module. A module is a complete circuit (such as an amplifier, flip-flop, oscillator, or detector stage) made as small as possible and provided with a plug-in base so that it may quickly be inserted into or removed from a larger circuit or system (receiver, transmitter, test instrument, computer, etc.).

The first modules used tubes and were monstrous by present-day standards of size. Then came transistorized modules, which were

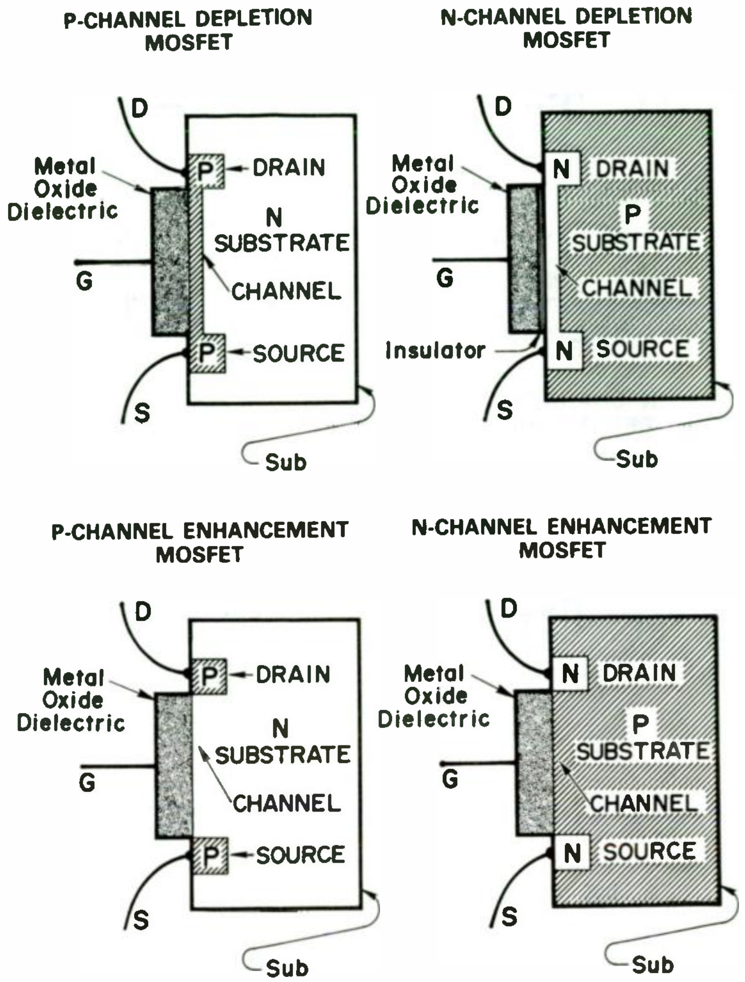


Figure 16 — Structure of MOSFETs (IGFETs).

much smaller. Next, printed-circuit techniques resulted in further size reduction and improved uniformity. Finally, the IC took the stage as a microminiature module. An IC no
5 larger than a small-signal transistor, and even resembling the latter in size and shape, can contain a number of diodes, transistors, capacitors, and resistors, plus all of the interconnections between these components needed to provide a complete circuit. Various input, output, DC-power, and auxiliary connections are made to appropriate points in the tiny circuit and are run to pigtails or lugs for external connection. In the design of the early tube- or transistor-type modules, the goal was to make components as small as possible, wiring as compact and simple as practicable (even fastening the terminals of some components together to avoid interconnecting leads), and packaging of the components as

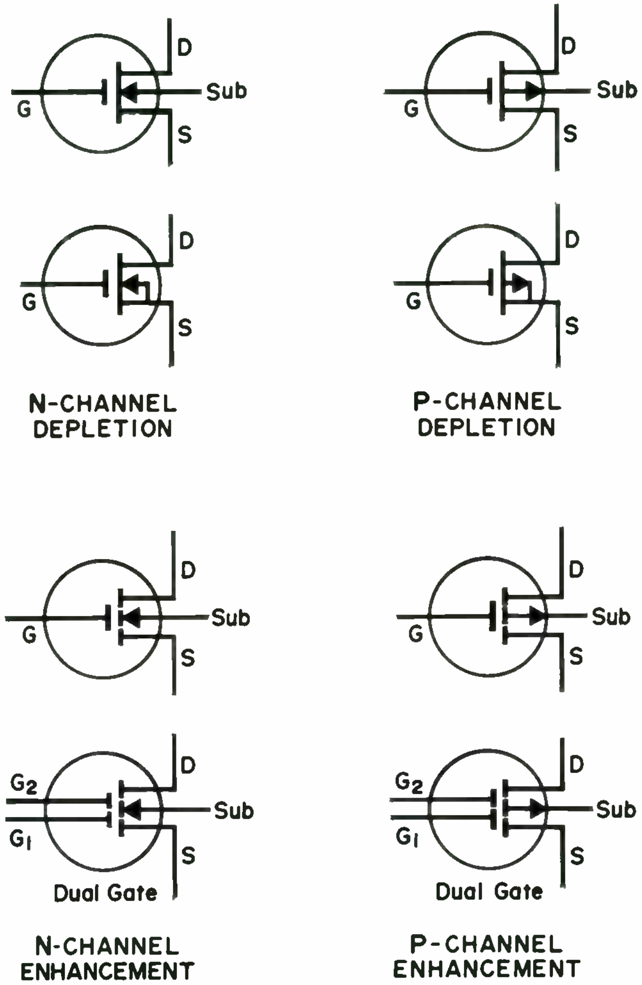
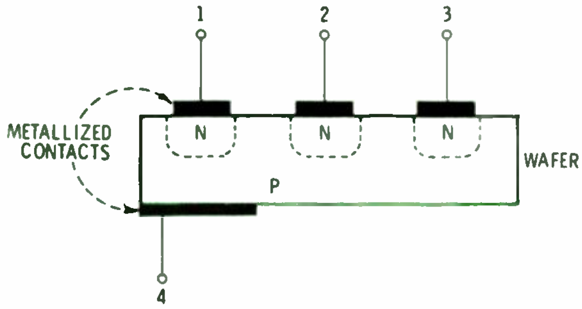


Figure 17 — MOSFET symbols.

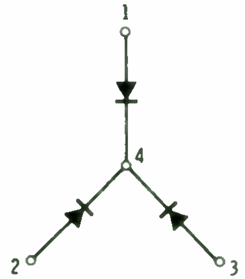
tight as practicable. In the IC, however, all of the components and interconnections are fabricated by processing appropriate areas of a single-crystal semiconductor chip or wafer, the whole being kept to microminiature size.

Integrated Diodes

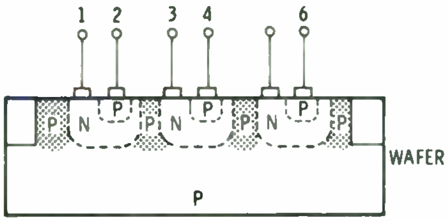
6 In Figure 18A, the wafer contains three diodes. Each of these consists of a small diffused N-type region forming a junction with the P material of the wafer. Each of the N regions thus makes a diode with the common P region supplied by the substrate. Thus, the P-type wafer not only supplies the substrate which supports the diodes, but also acts as a common cathode for all three diodes (see the equivalent circuit in Fig. 18B). Although, for easy illustration here, the



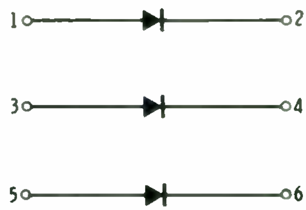
A - 3-diode IC (common cathode).



B - Equivalent circuit.



C - 3-diode IC (isolated sections).



D - Equivalent circuit.

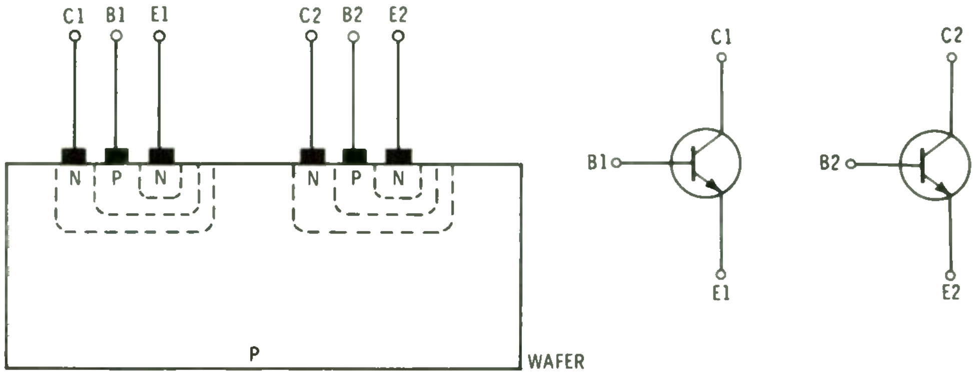
Figure 18 — Basic integration: diodes.

metallized contacts are shown as having simply been deposited on the surface of the wafer over the proper areas, the arrangement usually is not this simple. Instead, a thin oxide layer or film is formed over the diffused areas to protect them; then this film is properly etched to allow contact with the specific areas, and finally the metal is deposited on top of the oxide.

Unlike the common-cathode arrangement of Figure 18A, the three diodes in Figure 18C have individual, separated cathodes. For each diode, an N region (for the anode) first is diffused into the wafer, and then a P region (for the cathode) is diffused into the N region. The three diodes (see equivalent circuit in Fig. 18D) then may be connected in any way the user desires.

Integrated Transistors

Figure 19A shows how the technique just described is extended to produce transistors in the substrate. Here, an N region first is diffused (for the collector electrode of the transistor) into the substrate. Next, a P region (for the base) is diffused into this N region. And finally, an N region (for the emitter) is diffused into this base P region. The result is an NPN transistor.



A - 2-transistor IC.

B - Equivalent circuit.

Figure 19 — Basic integration: transistors.

A number of transistors might be processed into the wafer, consistent with the size of the wafer, but for simplicity only two isolated ones are shown in Figure 19A. The equivalent circuit is given in Figure 19B.

Although simple bipolar transistors are shown here, FETs and MOSFETs also are found in integrated circuits, and power transistors are found as well as small-signal ones.

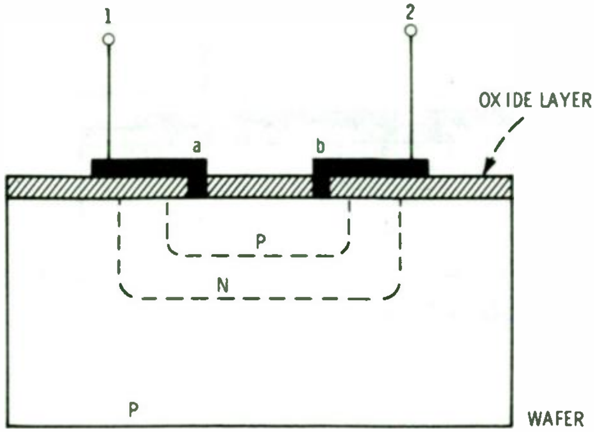
Integrated Passive Components

Resistors and capacitors also may be processed into the IC wafer. Figure 20A shows the formation of a resistor. Here, the metallic electrodes (a, b) make contact with the diffused P region that constitutes the resistor "material." (Suitable control of the chemical composition of this P region determines the amount of resistance.) The surrounding diffused N region forms a diode with the resistive P region to isolate the integrated resistor from other components integrated into the same substrate. Figure 20B shows the equivalent circuit.

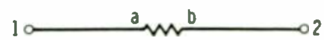
Figure 20C shows the formation of a capacitor. Here, one metallic electrode (a) makes contact with the diffused N region, which acts as one plate of the capacitor. The other metallic electrode (b) is deposited on top of the oxide layer, directly over and facing most of the N-region area, but now extending through to that area, and forms the second plate of the capacitor. The oxide layer between electrode b and the N region serves as the dielectric separator of the capacitor.

Integrated Complete Circuit

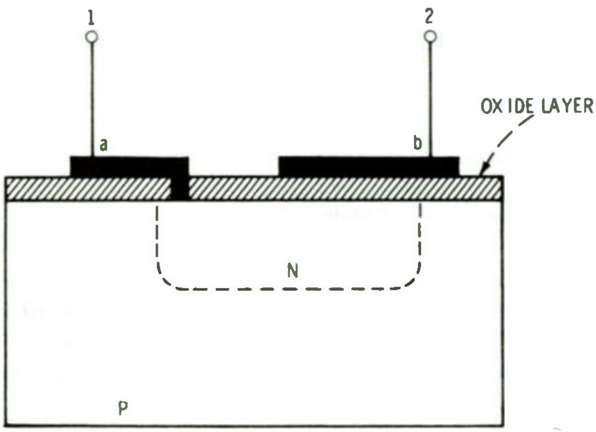
Figure 21 shows a full circuit containing both active and passive components integrated into a single P-type wafer. While this circuit is not necessarily functional, consisting as it does of three components connected in series, it is illustrative of the method and configuration of the integrated circuit.



A - Resistor.



B - Equivalent circuit.



C - Capacitor.

D - Equivalent circuit.

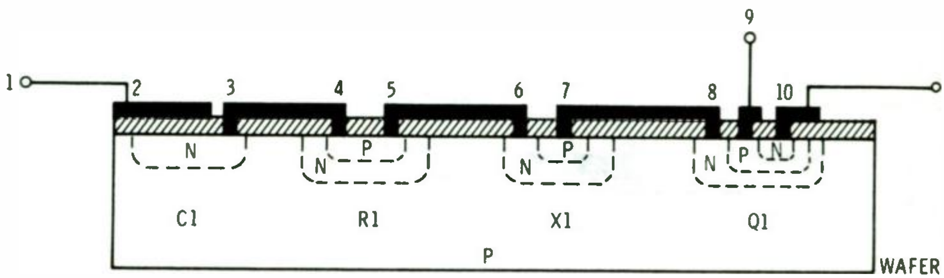
Figure 20 — Basic integration: passive components.

The individual components (from left to right in Fig. 21A: 1 capacitor, 1 resistor, 1 diode, and 1 transistor) were separately described in the preceding discussion. The components are "wired" in series by having the deposited metallic electrodes run between and make contact with the individual components. Figure 21B shows the equivalent circuit, with the identifying numbers matching those in Figure 21A.

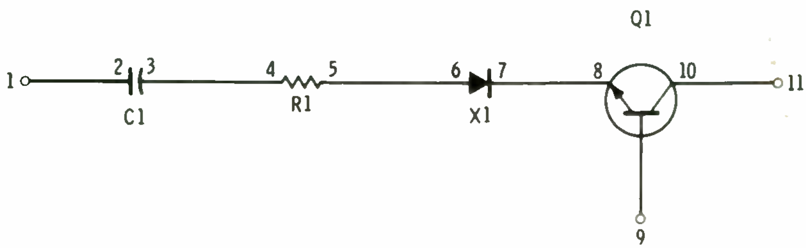
From this rudimentary illustration, it should be easy to visualize a multistage amplifier circuit consisting of several properly connected transistors, bias resistors, coupling capacitors, load resistors, and voltage-stabilizing diodes, all integrated into a single wafer.

Typical ICs

For some idea as to the component content of a typical in-



A Structure.



B - Equivalent circuit.

Figure 21 — Basic integration: complete circuit.

tegrated circuit, see Figure 22. This is the internal circuit of the RCA Type CA3030 operational amplifier IC. In this unit, there are 10 transistors, 2 diodes, and 18 resistors (30 components and all the internal "wiring" on a chip a few mils square). This IC has two inputs (terminals 3 and 4) and one output (terminal 12). Its frequency range is DC to 50 MHz, and its voltage gain is 70 db. As shown in Figure 22, a number of terminals are provided. This enables the user to use a part of the internal circuit, as well as the entire IC.

For some idea of the appearance of an IC chip, see Figure 23. In this illustration, the chip has been drawn many, many times larger than actual size. Areas of a few of the components are shown along with other notations relative to input, output and power connections.

From the foregoing descriptions in this section, the reader will find the Electronic Industries Association's definition of the integrated circuit a relevant one. "The physical realization of a number of electrical elements inseparably associated on or within a continuous body of semi-conductor material to perform the functions of a circuit."

Integrated circuits are sometimes described in terms of package type. In a few years, the number of IC types has grown tremendously, and these units are mounted in many different kinds of housings

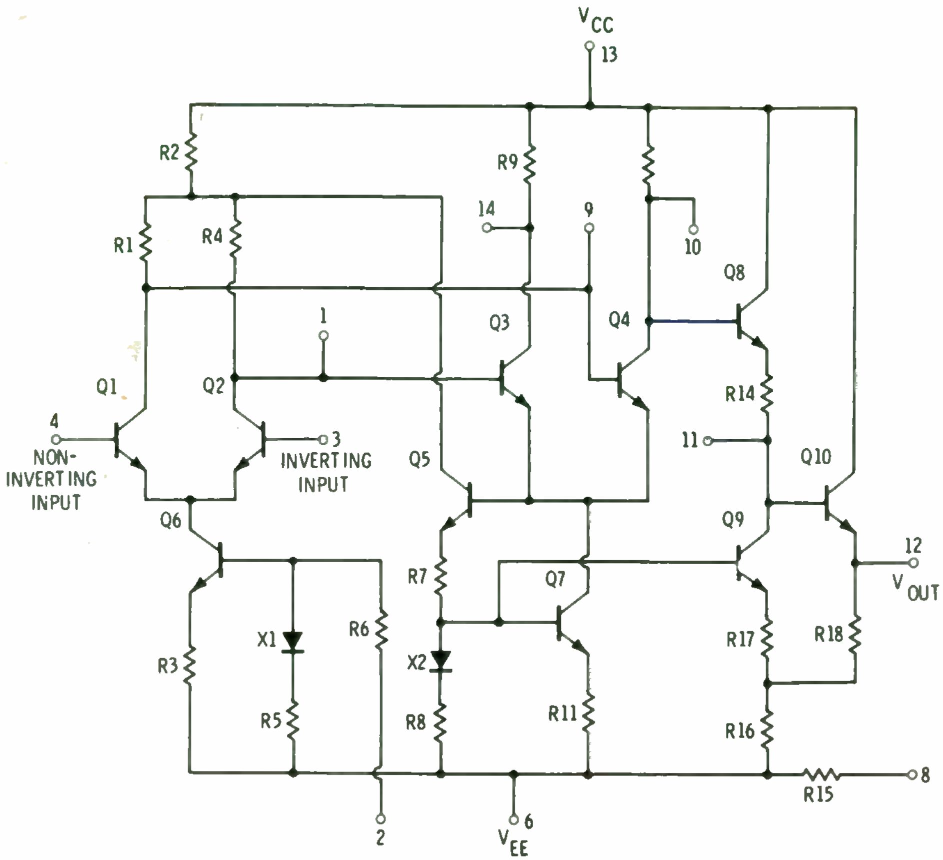


Figure 22 — Typical integrated circuit: RCA type CA3030.

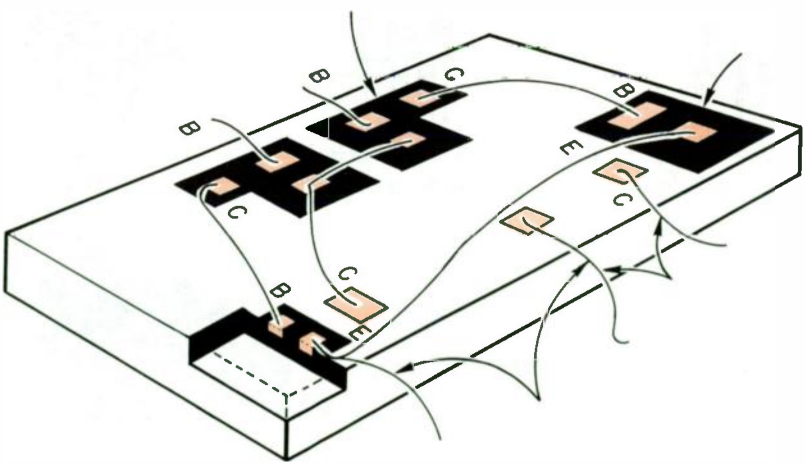


Figure 23 — Drawing of a monolithic block.

(more than 100 styles of case or envelope). There are several common packages, however, and these are shown in Figure 24.

The small T05 type cans (seen in Fig. 24, A, B, C and D) resemble small-signal transistors and are of the same size. The somewhat larger T08 can also is used, as is the T03 "power-transistor-type" package. The flat-pack type (Fig. 24E) resembles somewhat the old plastic-molded resistor-capacitor networks. Figures 24F and 24G show 2 tiny *plastic* "dual inline package" *DIP* ICs.

IC SYMBOLS

It would be tedious to draw most complete IC circuits, especially if several ICs are to appear in a schematic. The symbol shown in Figure 25A is used to represent a complete IC and greatly simplifies the drawing of circuitry. The lines representing leads running to the IC are numbered to agree with the actual terminal numbering of the pack itself.

See, for example, the correspondence between the symbol (Fig. 25A) for the Type CA3034 IC

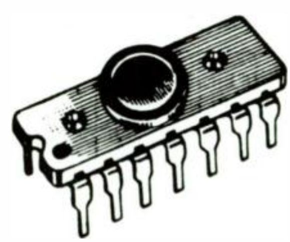
A - TO-5 type, 8 lead.

B - TO-5 type, 10 lead.

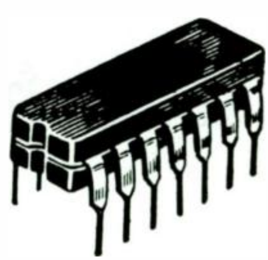
C - TO-5 type, 12 lead.

D - TO-5 type, 10 formed leads.

E - 14-lead *flat-pack.*

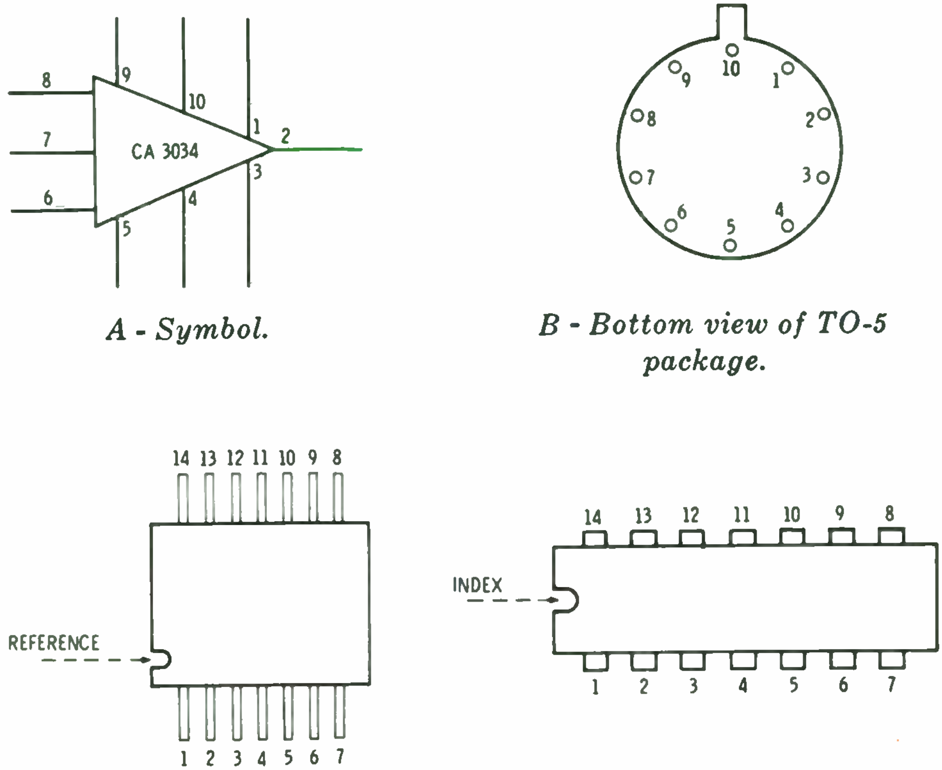


F - TO-116 ceramic dual in-line.



G 14-lead plastic dual in-line.

Figure 24 — Typical IC packages.



A - Symbol.

B - Bottom view of TO-5 package.

C - Top view of 14-lead ceramic flat-pack.

D - Top view of 14-lead dual in-line plastic package.

Figure 25 — Linear IC symbol and terminal layouts.

and the pigtail numbering of this IC. It is not in every schematic that the numbering along the symbol follows the same sequence as the numbering of terminals on the actual IC; the sequence on the symbol is often a matter of drafting convenience. However, the terminals along the left vertical edge of the symbol (e.g., 6, 7 and 8 in Figure 25A) are usually input terminals, and the terminal(s) at the point of the symbol (e.g., 2 in Figure 25A) is usually reserved for the output. (Sometimes, some other terminal near the right end of the symbol, along the top or bottom edge, may be the output. For example, two such terminals, such as 1 and 3 in Figure 25A, may indicate the outputs of an IC having balanced or push-pull output. In Figure 25B correspondence is shown between the conventional triangular symbol and the numbering on the corresponding 10-lead T05 package.

DIGITAL LOGIC

The symbols shown in Figure 26 are digital logic IC stages. They normally operate in the saturated mode and are used to switch information. The important function of digital logic circuits is the production of an output voltage or current when commanded to do so by the presence of an input, voltage or current, or a combination of input voltages or currents.

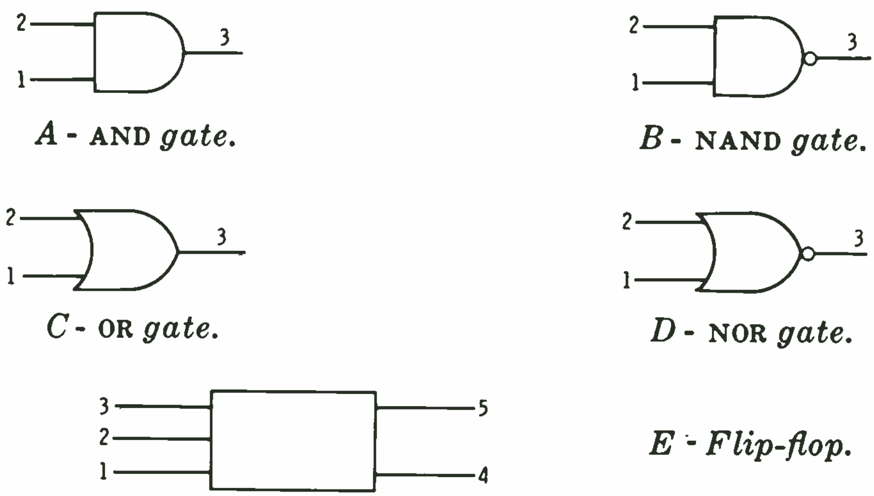
The circuit in Figure 26A is an *AND* gate; it will produce an output from terminal 3 only when both input terminals (1 and 2) are energized. The circuit in Figure 26B represents a *NAND* gate which is an inverting AND gate. It is distinguished from the AND gate by the small circle at terminal 3. Like the AND gate, the NAND gate also produces an output voltage only when all inputs are energized; but the output polarity from a NAND gate is opposite to the input polarities.

An *OR* gate (represented symbolically in Figure 26C) produces an output when either input is energized. A *simple* OR gate will also produce an output when all inputs are energized. Therefore, the circuit in Figure 26C will produce an output voltage from terminal 3 whenever terminal 1, terminal 2, or both are energized. Another OR function used frequently in computers is the *exclusive* OR gate. If Figure 26C represented an exclusive OR instead of a *simple* OR gate, it also would produce an output whenever either terminals 1 or 2 were energized. However, no output could be present if both inputs (1 & 2) were energized.

The *NOR* gate (Fig. 26D) is the inverting version of the OR gate. Its function is the same as an OR, but its output is inverted in polarity from its inputs.

DIFFERENTIAL AMP (Op Amp)

The differential amplifier is now



A - AND *gate.*

B - NAND *gate.*

C - OR *gate.*

D - NOR *gate.*

E - Flip-flop.

Figure 26 — Typical digital-IC symbols.

commonly used in integrated circuit TVs, radio and Hi-Fi amps.

> NOTE: In many of its forms, a differential amplifier is also called an *operational amplifier* or *Op Amp.*

A basic differential amplifier, such as the one shown in Figure 27, has two sets of input terminals. The output signal may be taken from output 1 or output 2, or it may be taken between the two outputs. In the latter case, the output is an amplified difference between the two signals applied to the inputs. This difference signal is also known as a differential signal.

A dual polarity bias supply is often used with differential amplifiers. One polarity (V_{cc}) supplies the collector loads (R_L), and the other polarity (V_{ee}) supplies the emitter load (R_E). The minus of the positive supply and the plus of the negative supply are tied together to form the common.

Differential Amplification

Differential amplifiers owe many of their desirable features to the common emitter resistance (R_E). This resistance assures a proper balance between current through Q_1 and Q_2.

Let us examine the condition in the circuit of Figure 28 when input 1 begins going positive. As input 1 goes positive, it causes additional current to flow through Q_1 and R_E. Because of the increased current through R_E, the voltage across R_E attempts to rise. The emitters of Q_1 and Q_2 attempt to go positive; however, the increased positive potential at the emitter of Q_2 back biases

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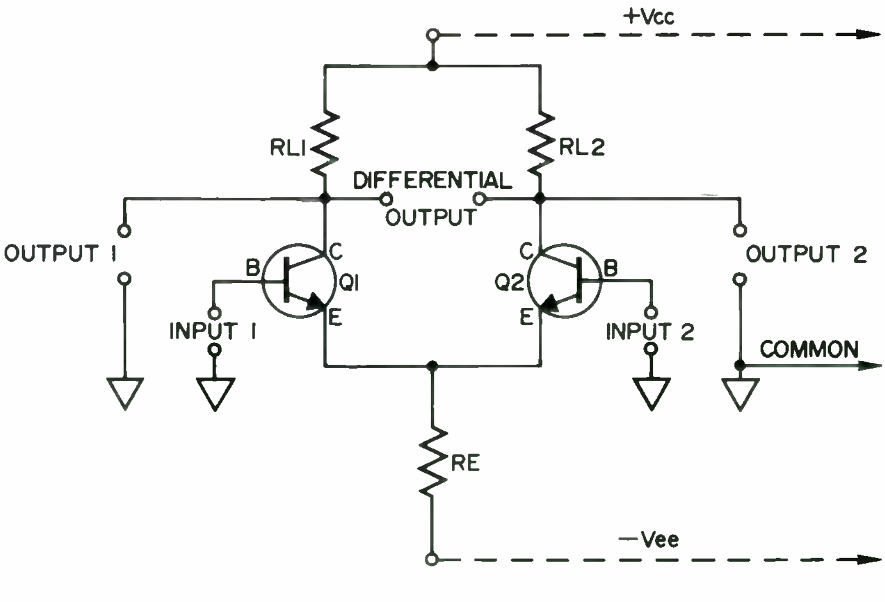


Figure 27 — Basic differential amp.

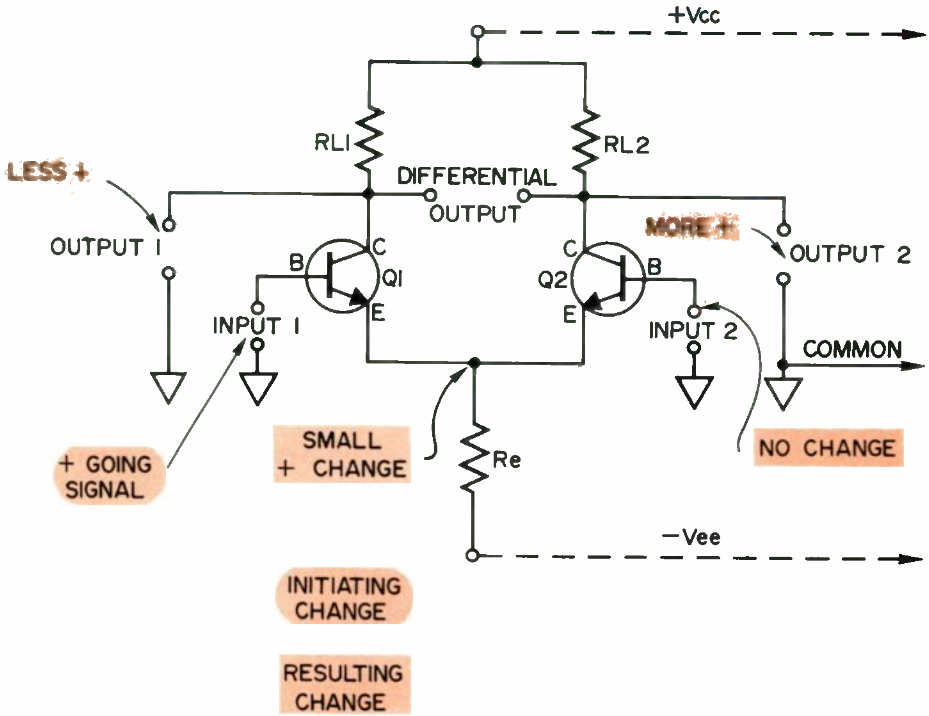


Figure 28 — Single input mode with positive input signal.

this transistor reducing its collector-emitter current. Thus, the current through R_E, the voltage drop across R_E, and the emitter voltage, remain relatively constant. The emitter voltage rises only slightly under this condition.

Because of the increased current through Q_1, the voltage drop across R_{L1} increases and the collector voltage at Q_1 decreases. Because Q_2 is partially back biased at the emitter, it conducts less current through R_{L2} resulting in less voltage being dropped across R_{L2}; the voltage at the collector of Q_2 rises toward V_{cc}. The differential signal is minus at output 1 and positive at output 2.

Figure 29 illustrates the changes that result when the initiating signal or change is in a negative direction. In this case, current through Q_1 and R_E is reduced and less voltage drop occurs across R_E. The emitter voltage attempts to change in a less positive direction. This change at the emitter of Q_2 forward biases Q_2, causing it to conduct additional current through R_E.

As the current through Q_1—R_{L1} decreases, the drop across R_{L1} decreases and the voltage at the collector of Q_1 rises. At the same time the current through Q_2—R_{L2} increases, causing an increased voltage drop across R_{L2}. The voltage at the collector of Q_2 therefore decreases. The differential signal is plus at output 1 and minus at output 2.

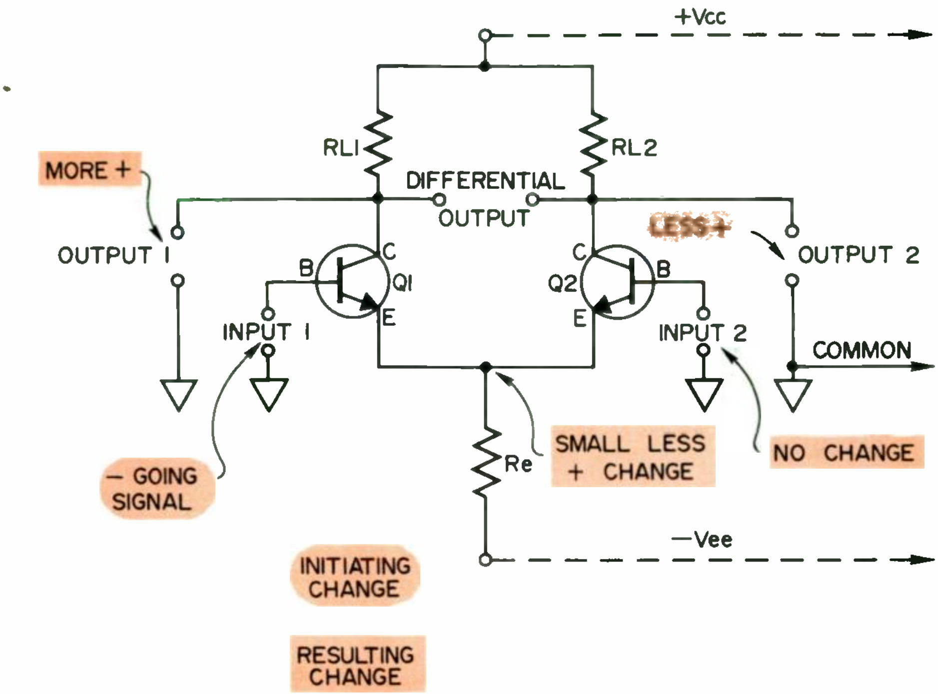


Figure 29 — Single input mode with negative input signal.

In the preceeding examples, the signal is applied to only one input and the stage is operated with a single ended input. When operating a differential amp in the single ended input mode, the unused input is generally connected to a reference point, as shown in Figure 30. Figure 30 shows one of the many schemes used to reference the unused input. In this illustration, input 2 is tied to common through resistor R_B. In other schemes a resistive network supplies the base reference from an output or some other voltage or current source.

In Figures 31 through 34 an amplifier is shown operating in the dual input mode. In this mode both inputs are used with opposite phases of the signal being applied to the two inputs. Thus, as input 1 is driven more positive, the signal at input 2 drives it less positive (in a negative direction). Also when the signal at input 1 is going negative, the signal at input 2 drives this input positive.

Figure 31 illustrates the results of a positive going signal at input 1 and a negative going signal at input 2. An increasing collector current through Q_1 is accompanied by a decreasing collector current through Q_2. The two changes are equal but opposite; therefore, the current through R_E is constant, as is the emitter voltage. Because of the increased drop across R_{L1}, the collector voltage at Q_1 decreases. A decrease in current through R_{L2}

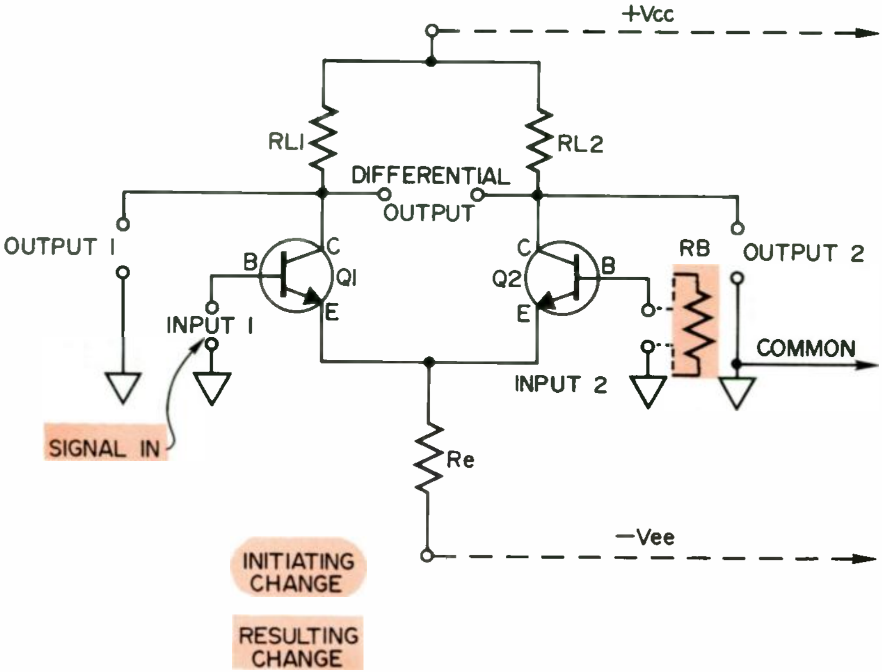


Figure 30 — Referencing the unused input for single input mode operation.

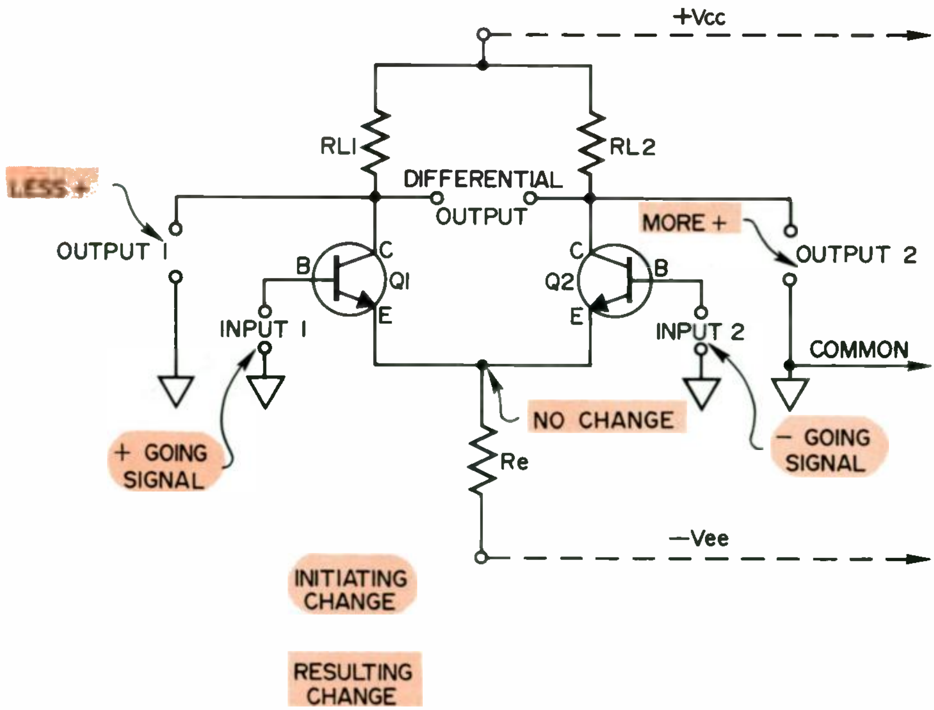


Figure 31 — Dual input mode with positive signal on input 1 and negative signal on input 2.

causes the collector current at Q_2 to rise toward V_{cc}. The differential output is minus at output 1 and plus at output 2.

In Figure 32, a negative going signal is being applied to input 1, while its positive going counterpart is being applied to input 2. Collector current through Q_1 is decreasing while collector current through Q_2 is being increased. With less drop across R_{L1}, the voltage at output 1 rises toward V_{cc}. At the same time, a greater voltage drop occurs across R_{L2} and the voltage at output 2 decreases. There is practically no change in the current through R_E; therefore, the emitter voltage remains almost constant.

Common-Mode Rejection

When properly connected, differ-
10 ential amplifiers have the unique ability to amplify a desired signal when opposite phases are presented to the inputs. They can also reject interference signals that are presented to the two inputs, in phase. This ability is termed common-mode resolution or common-mode rejection and is abbreviated CMR.

Figure 33 shows an interference or *noise field* intercepting both input leads to a differential amplifier. The figure also shows the resulting noise that is either inductively generated or capacitively coupled into each input lead. The resulting signal that appears si-

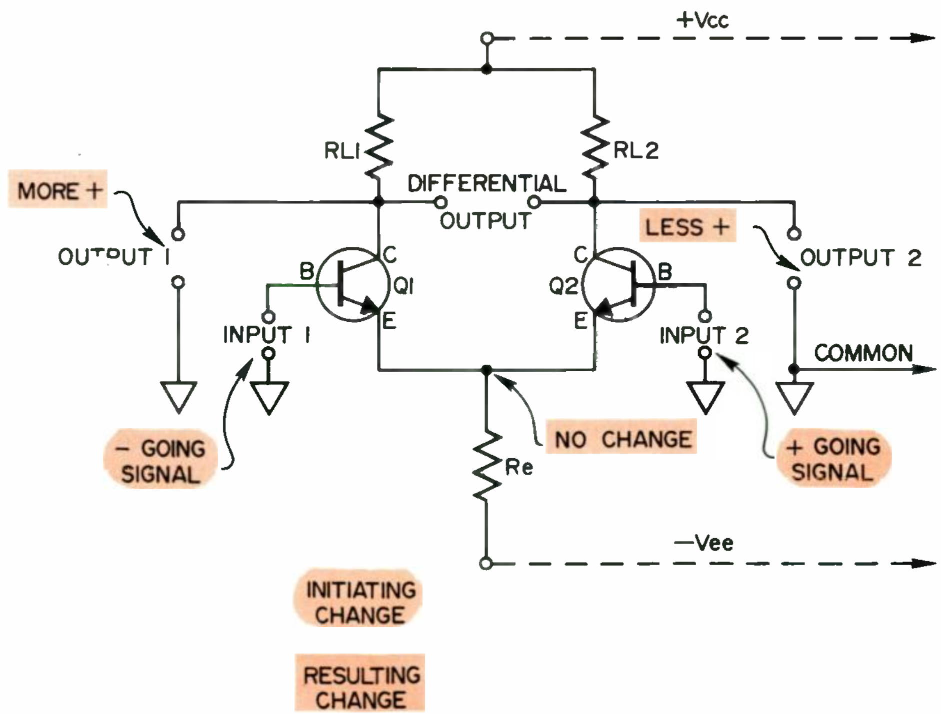


Figure 32 — Dual input mode with negative signal on input 1 and positive signal on input 2.

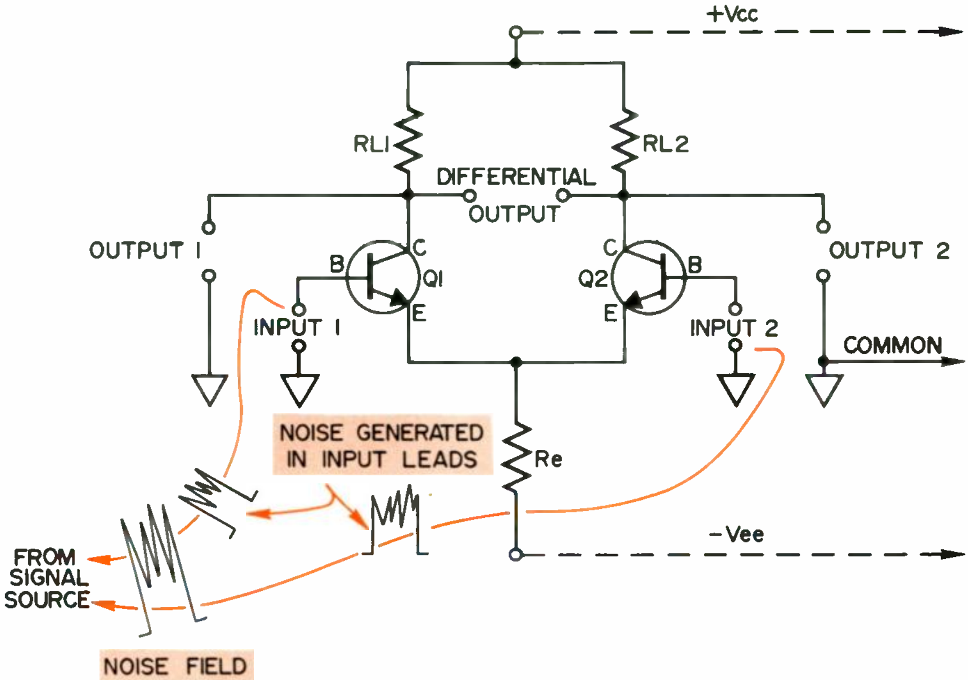


Figure 33 — Illustration of noise field intercepting both input leads, and the resulting noise generated in each input lead.

multaneously and in phase at each input is called the *common-mode signal.* In an ordinary single-ended amplifier having only one input and one output, the noise would be amplified along with the desired signal, with the result that static, hum, or noise would appear at the output.

In the case of a differential amplifier operated in the dual differential mode, this interference would be rejected. The output signal would be nearly interference-free even if the common-mode signal were many times stronger than the desired signal.

Figure 34 illustrates the result of injecting simultaneous positive going signals of equal value into the two inputs. Notice from the illustration that no change occurs at either output, and that there is no differential signal. The only significant changes that occur are:

1. Q_1 and Q_2 both conduct more collector-emitter current;

2. The emitter voltage increases because of the increased current through R_E. The increased emitter voltage proportionately back-biases Q_1 and Q_2.

The result of these two related actions is that the collector voltage at both transistors remains relatively constant. This is because the con-

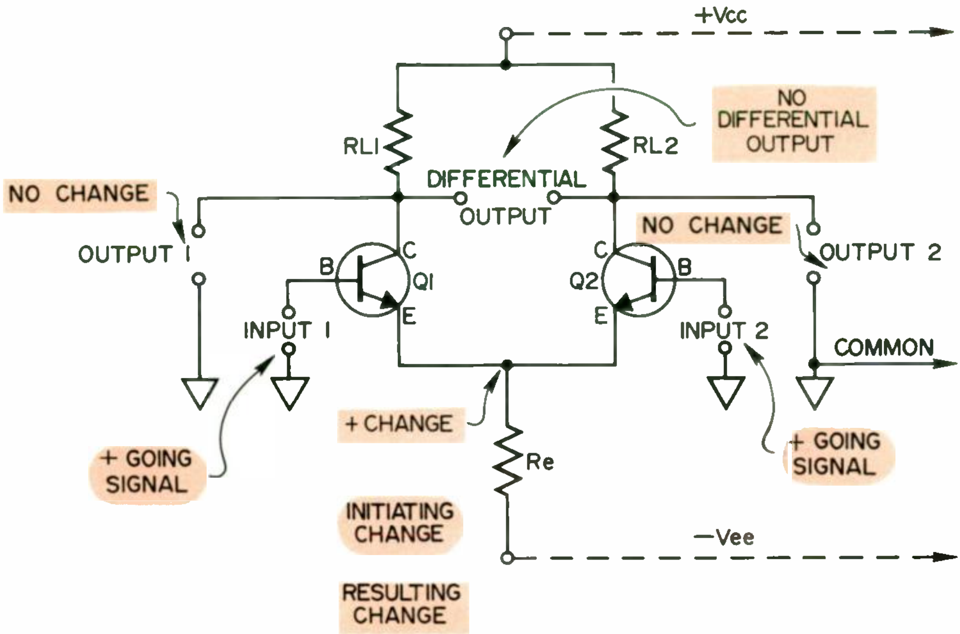


Figure 34 — Dual mode input with equal positive going changes applied to inputs 1 and 2.

duction of each transistor is adjusted automatically by the emitter bias to provide a constant voltage at the collector. The actions illustrated in Figure 35 are the same as in Figure 34, except that they are opposite in polarity.

Two opposite polarity outputs are available from the circuit (shown previously in Figure 27), as well as a differential output.

Functional Differential Amp

Differential amplifiers are seldom as basic as those shown in Figures 27 through 35. Additional stages are usually included to provide more gain and better stability.

The circuit in Figure 36 is more representative of a functional differential amp. Each input has two direct-coupled stages of gain. The output from each side is supplied to terminals and is also fed to a *difference comparator.* The difference comparator produces an output signal that is the mathmatical difference (differential between output 1 and output 2). Since the circuitry involved is quite complex, the difference comparator is shown in block form only.

In Figure 36, a circuit called a constant current source has replaced the common emitter resistor of Q_1 and Q_2. In this stage, (called a constant current stage) the emitter

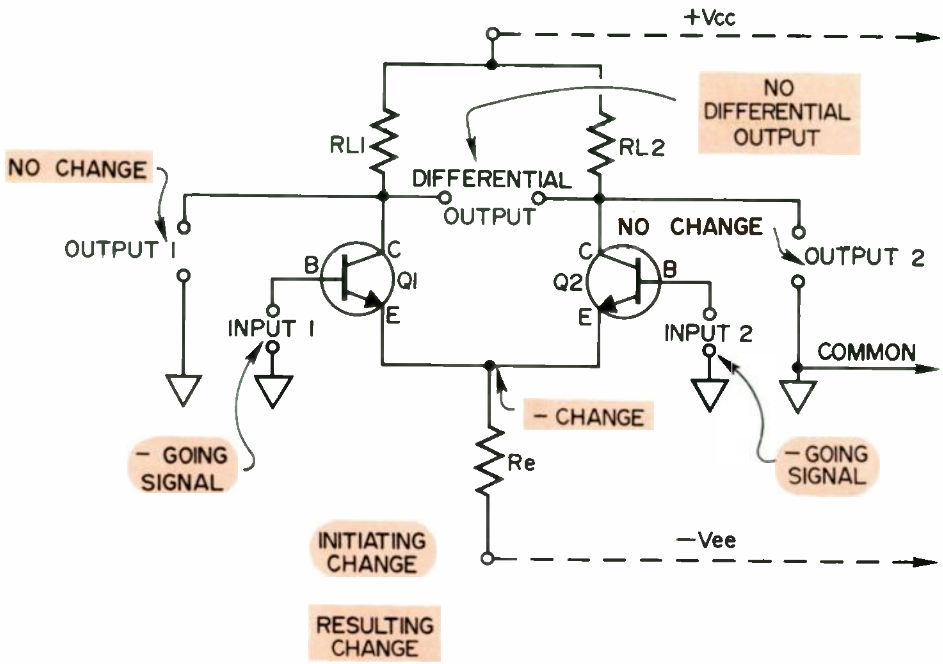


Figure 35 — Dual mode input with equal negative going changes applied to inputs 1 and 2.

is clamped with a zener diode (D_1) and its base is controlled from the emitters of transistors Q_3 and Q_4. Therefore, the emitter bias at the input stage is controlled by the emitter voltage of the output stage. Since voltages in the output stage depend mostly on conditions in the input stage, the circuitry acts like a closed loop compensating network. It compensates for conditions that would otherwise alter the gain of the amp, cause distortion of the signal, or permit interference with the signal.

TROUBLESHOOTING IC BLOCKS

Today the trend in IC circuit drawing is to present it as a series of interconnected blocks rather than as symbolic circuitry. As long as the inputs, outputs, and power connections to a block are shown, that is all the information a technician needs in order to troubleshoot a circuit.

The OP Amp in Figure 36 can be more easily presented in block form, as shown in Figure 37. In this illustration, all the inputs, outputs and power connections are shown. When troubleshooting a stage using this kind of block illustration, a technician would check inputs (terminals 6 and 8) for the presence of a signal and then check the output to be sure that the stage is functioning. If an input signal is present, but the output is missing or distorted, he would then check the voltages applied to terminals 4

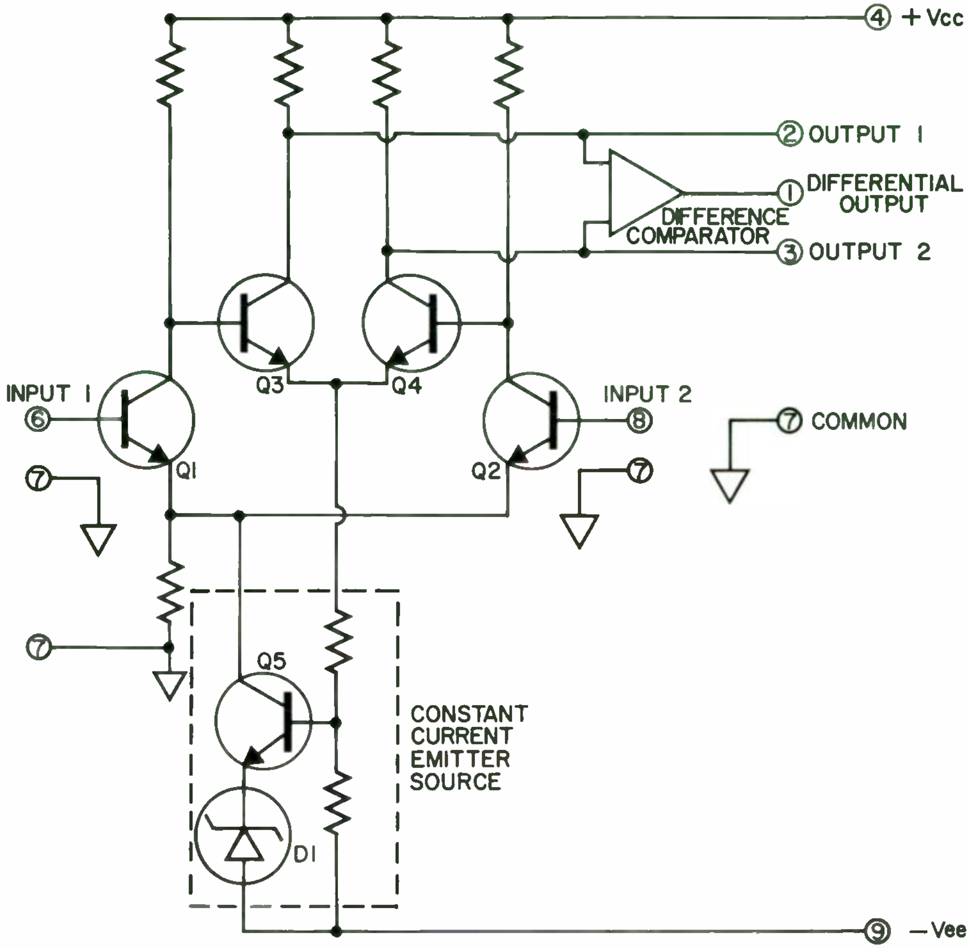


Figure 36 — Multistage differential or Op Amp.

and 9. He would check these voltages for both value and power supply ripple. If the voltages are okay and if there are no externally attached components that could be defective, it is evident that the fault lies within the IC.

An IC circuit is shown in Figure 38 along with the external components necessary for it to function as an amplifier. The troubleshooting procedure for this circuit is the same as for the block in Figure 37, with one note-worthy exception. In addition to verifying input signals, output signals and supply voltages, the technician must also verify the condition of all externally connected components before assigning fault to the IC.

NOTE: This particular amplifier uses a single polarity supply instead of the dual polarity supply of previous illustrations.

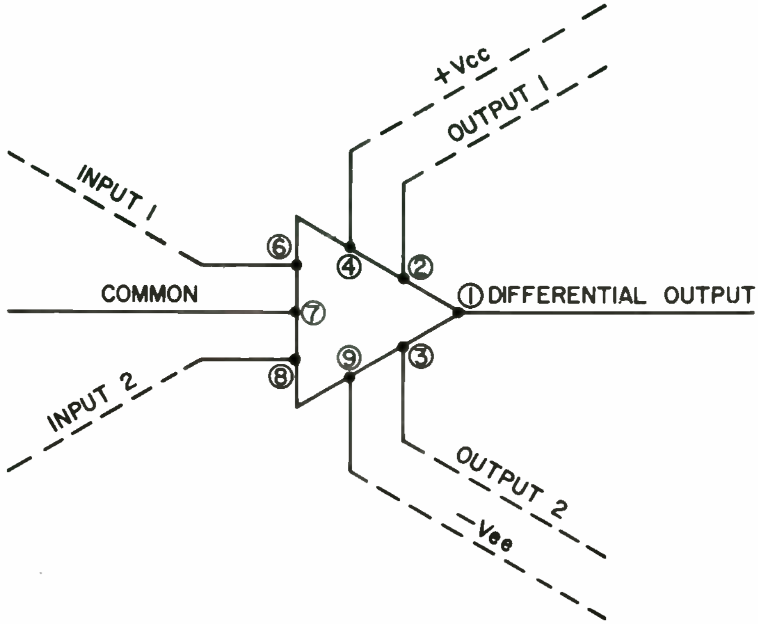


Figure 37 — Block form of an Op Amp.

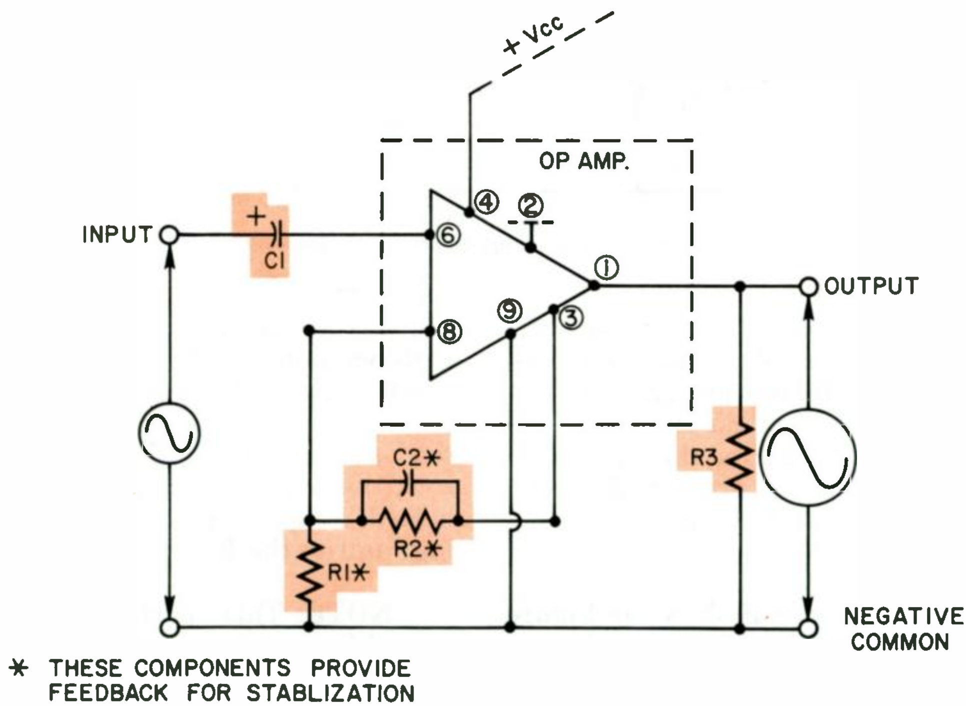


Figure 38 — An IC amp with external components required for amplifier service.

The components indicated by the symbol * in Figure 38 are in a feedback loop and are typical of many IC amplifier circuits. The feedback established through this loop assures linear operation; that is, the stage will provide the same gain at all frequencies. It also helps to reduce distortion.

In Figure 39, we see an amplifier with several external components. These components have been highlighted with color for easy identification. Their purpose in the circuit is:

- R_1 provides isolation between the signal source and the input of the amplifier.
- R_2 provides DC feedback to stabilize the amplifier and establish its DC operating point.
- R_3 C_1 provides AC feedback to reduce distortion and normalize the gain.
- C_2 and C_3 interconnect points within the IC to reduce phase shift and its resulting oscillation at certain frequencies.

Many external components are being eliminated as ICs are developed for specific applications. These

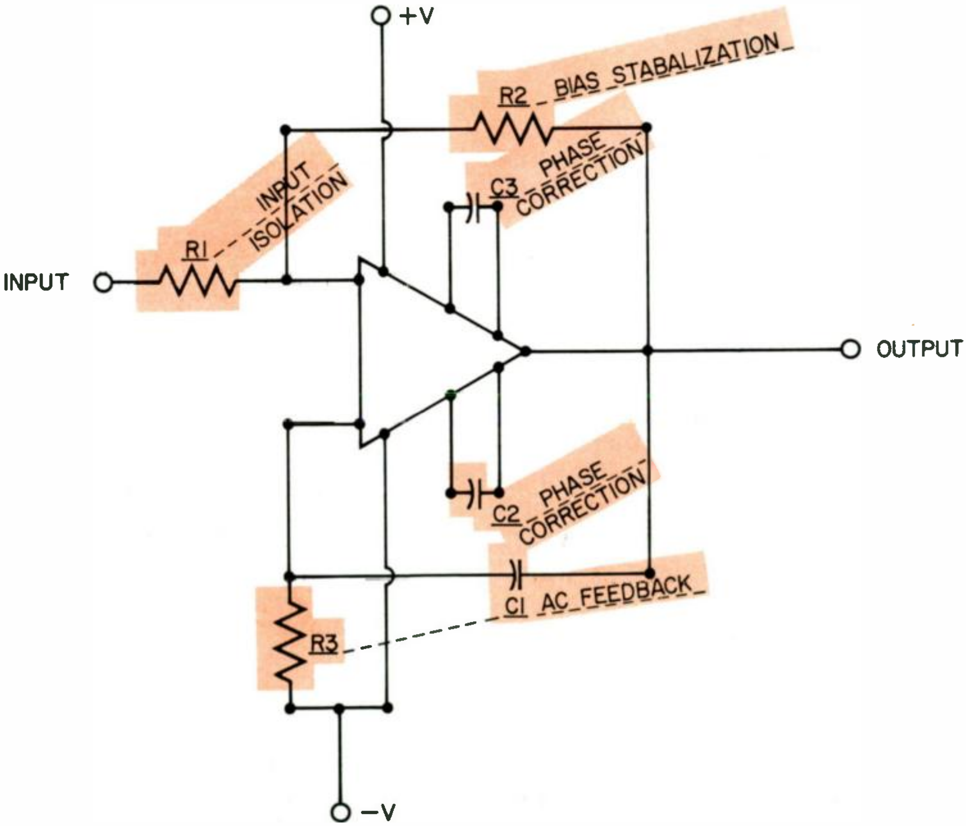


Figure 39 — Functional Op Amp. showing outboard components.

components (resistors, diodes and small capacitors) are now a part of the IC. Certain components, however, cannot at this time be fabricated into an IC and must still be added externally. Some of these are: chokes, coils, transformers, potentiometers, switches, speakers, and large value capacitors.

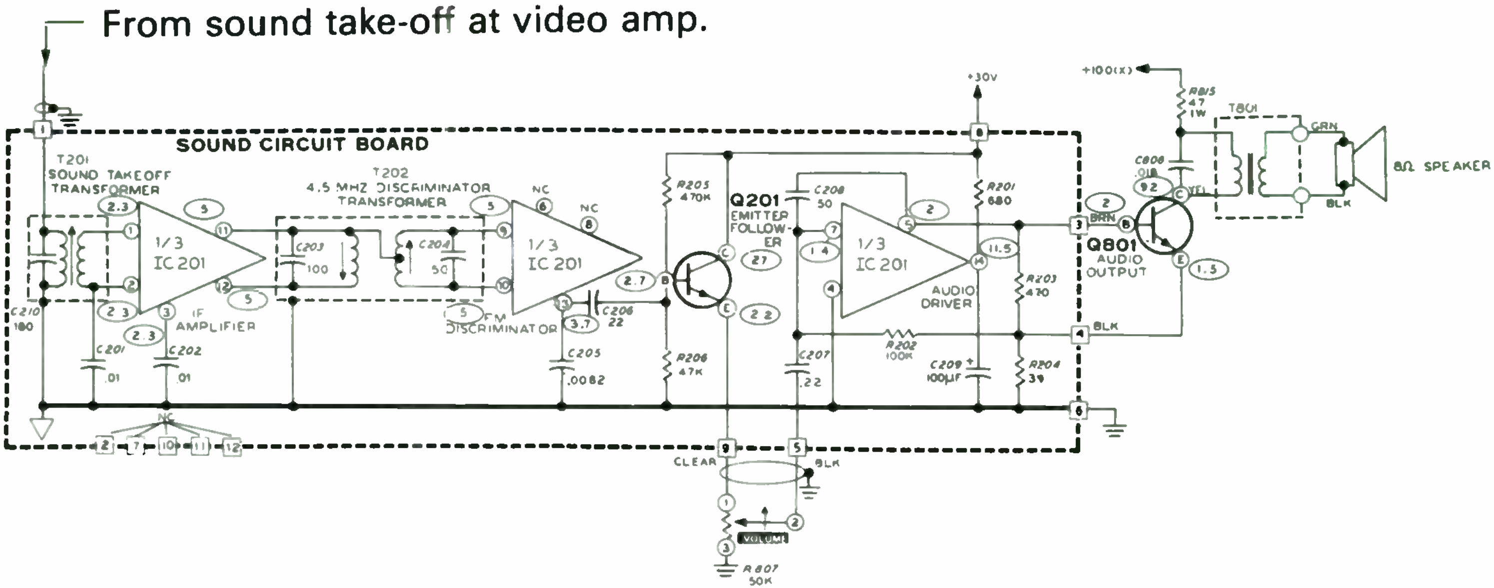
In Figure 40, we see the complete sound section for a television set. This particular section uses one IC and two transistors with discreet components. The internal circuitry of the IC is not shown because this is of little value to the serviceman. The components within an IC are not replaceable; therefore, if one becomes defective the entire IC must be changed.

The IC in Figure 40 has been divided into three blocks to define the stages. Troubleshooting of the sound section in Figure 40 is a relatively simple procedure. By tracing the signal through the circuitry from stage to stage, a technician will soon discover the stage that is defective. That will be the stage which has an input but no output, or a weak or distorted output. On occasion the problem may also occur between the output of a stage and an input of the following stage. In the latter case, a transformer or the interconnecting circuitry may be at fault.

When the signal stops within an IC stage, the experienced repairman would immediately check the voltages associated with that stage. He might also make ohmmeter checks on the *outboard* (externally connected) components. If the voltages are abnormal, he must then decide whether the power supply is at fault or if the wrong voltages are due to a problem within the circuitry.

To illustrate troubleshooting in IC circuits, we will assume that a fault exists in the sound section in Figure 40. The following conditions exist:

> With a 4.5 MHz FM modulated signal injected into terminal 1 of the circuit board, there is IF output on IC pins 11 and 12.
>
> A check at IC pins 9 and 10 shows an IF input signal, but there is no audio at the output of the discriminator on IC pin 13.
>
> An inexperienced serviceman might assume that the trouble is in the discriminator block (middle 1/3) of the IC. If he replaced the IC without further testing, his efforts could prove futile.
>
> The experienced repairman would next perform voltage measurements with his VOM or VTVM before arriving at a conclusion. Whether he uses the VOM of VTVM depends on recommendations in the notes of the service literature.
>
> In our present case we will use a VTVM and begin our measurements at pins 9 and 10 of the IC. A small deviation (only a few tenths of a volt) exists



SYMBOLS

- □ Indicates a circuit board pin
- ▽ Indicates circuit board ground
- ⏚ Indicates chassis ground
- ⬭ Indicates a DC voltage measured from this point to chassis ground
- ○ Indicates pin number on IC

Figure 40 — A complete TV sound section, using a mixture of ICs and transistors with discreet components. "Reproduced with the permission of Heath Company, Benton Harbor, Mich."

from the voltage on the schematic. In this case, the next measurement will be taken at IC pin 13. For purposes of this illustration, we will suppose that the 3.7 VDC is absent from pin 13. This condition can only exist because of one of two possible faults: Fault 1 could be an open or shorted component within the IC; fault 2 could be a shorted capacitor (C205). Capacitor C206 could not cause the problem if it were shorted; it might reduce the voltage at IC pin 13, but it could not provide a direct short to ground.

The remaining check therefore is to determine if C205 is shorted. An ohmmeter check will readily determine its condition. If C205 is shorted, the problem may be solved by changing it. If it is not, the problem is in the IC and it must be replaced.

LARGE SCALE INTEGRATION (LSI)

Figure 40 suggests that complicated systems may be built up comparatively easily by putting together the proper linear and/or digital ICs and adding any required external components. And this method is indeed employed in the design and fabrication of a number of modern electronic systems.

The practice goes further, however, than simple implementations—the assembly of ICs and external discrete components into a larger circuit. A number of separate ICs and external components, together with all "wiring," may now be processed into a single wafer. This practice is referred to as large-scale integration (abbreviated LSI), and it will be increasingly responsible for dramatic size and weight reductions in all kinds of electronic equipment, especially computers, calculators, radar, and television.

A striking instance of size reduction through LSI is seen in the new mini-calculators that seem destined to replace the engineer's slide rule. One model is smaller than a cigar box, weighs only 2.2 pounds and performs the following operations: addition, subtraction, multiplication, division, chain multiplication and division, raising to a power, calculations by a constant, and mixed calculations. Another example is a recently announced solid-state wrist watch. This regular-size timepiece contains more than 40 ICs—equivalent to about 3500 transistors.

FUTURE OF IC's AND LSI

There are different schools of thought relative to the design of consumer electronics products. ICs have been fabricated in which nearly all the components necessary for an AM radio are contained in one chip. Only the volume control, antenna, tuning capacitor, and speakers must be added.

All the parts for a complete AM-FM radio, can be contained in too or three ICs, except the speaker and controls. Some manufacturers believe that this limits flexibility, relative to design and change. Others feel that the resulting cost and size reduction is worth the sacrifice.

It is now possible to produce in one LSI IC nearly all of the small components for a complete TV. How soon this will be available for marketing will depend upon its adoption by major manufacturers. The trend, however, is toward more and more integration of components in radios, TVs, Hi Fis, etc.

Research is now being directed toward including devices into IC packs that will replace large value capacitors and coils, chokes and transformers. These, however, will probably not be available for the consumer for some time.

SUMMARY

The use of both transistors with discreet components and small scale ICs will undoubtedly continue for several years. The technician of today must have a knowledge of all forms of circuitry to become proficient, and also must be ready to adapt his thinking as products are updated to include newer concepts and devices.

TEST

Lesson Number 60

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-060-1.

1. A semiconductor junction that is biased in the forward direction

A. conducts current.
B. does not conduct current.
6 C. conducts electron current only.
D. conducts hole current only.

2. The operation of a junction transistor depends upon

A. contact pressure.
B. light.
6 C. electric fields.
D. dissimilar charges on opposite sides of its junctions.

3. Field effect transistors are

A. multipolar.
B. bipolar.
13 C. nonpolar.
D. unipolar.

4. The term MOS is interpreted to mean

A. metal oxide semiconductor.
16 B. metal on substrate.
C. most often substituted.
D. mask on substrate.

5. An IC is related to a module because it contains

A. nearly all the components for a complete circuit.
17 B. vacuum tubes.
C. semiconductors.
D. passive components.

6. Integrated diodes are processed

A. by interconnecting the leads of ordinary diodes.
18 B. by encapsulating ordinary diodes.
C. in a common wafer.
D. in evacuated containers.

7. IC resistors are processed

A. by interconnecting ordinary resistors.
B. by encapsulating ordinary resistors.
C. in separate wafers.
D. by controlling the resistance of assigned areas in a common wafer.

8. The term DIP is interpreted to mean

A. dual inline positive.
B. dual inline position.
24 C. dual inline plastic.
D. dual inline package.

9. A basic differential amplifier has two inputs and

A. one output plus a differential output.
27 B. two outputs plus a differential output.
C. three outputs plus a differential output.
D. four outputs plus a differential output.

10. Differential amplifiers have the ability to amplify a differential signal and reject interference that is common to both inputs. This ability is called common-mode.

31 A. rejection.
B. resistance.
C. restriction.
D. reluctance.

NOTES

NOTES

NOTES

Portions of this lesson from
A B C's of Integrated Circuits
Rufus P. Turner

A B C's of Transistors
George B. Mann
Courtesy of Howard W. Sams, Inc.

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

REACH FOR SUCCESS

A person's level of success is a good measure of the effort put forth by that person.

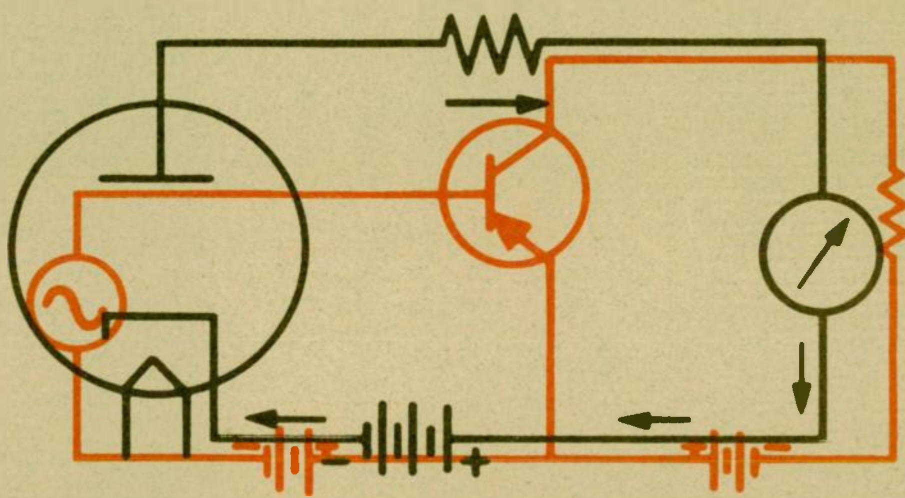
Don't become complacent with the level of success you already have reached. Instead, look for ways to become more successful, and then go after it!

You, and you alone, have the potential to become more successful. Use that potential!

S. T. Christensen

LESSON NO. 61

AM RADIO RECEIVERS PART 1



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-061
407

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

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CONTENTS

Advance Schools, Inc.

52-061

AM RADIO RECEIVERS PART 1

INTRODUCTION

The modern radio receiver is an assembly of stages, each consisting of transistor(s) or tube(s) with other components. Wiring or printed circuitry connects passive components (resistors, capacitors, inductors, or diodes) to elements of the stage's transistor(s) or tube(s).

In general, a stage performs a single function such as amplification (RF, IF, or AF), frequency conversion (mixer-oscillator), or detection. For example, the mixer-oscillator converts all incoming station signals to a single IF frequency that can be more effectively amplified by the IF amplifier stage(s). A detector stage in addition to removing audio from the IF signal also produces an *automatic volume control* (AVC) signal. The latter, however, is a subfunction and not its main purpose. The purpose of a detector is to recover audio. The AVC circuitry is not a stage, it is merely a network of passive components.

Nearly all faults within a receiver develop because of one or more defective components. Therefore, troubleshooting a malfunctioning receiver consists of evaluating the symptoms, isolating the defective stage and then locating and replacing the faulty component(s).

The intent of this lesson is to expand your knowledge of typical circuitry, actually used in various receivers. Much of the basic circuitry presented previously will be detailed in this lesson.

Both solid state and vacuum tube circuitry will be discussed since both are used in home radios. However, additional emphasis will be placed on solid state because of its widespread use over vacuum tubes.

Every receiver uses a power source to supply voltage and current to operate its transistors or tubes. In its most simple form this source may be a single battery or a simple, power line-operated, rectifier supply; or it may be far more complex. Elaborate electronic regulated supplies are occasionally used as well as combination battery-electric versions.

AM BROADCASTING

Nearly all of the principles, circuits, and components discussed in previous lessons are directly applicable to radio receivers. A basic knowledge of them is, therefore, assumed in presenting material for this lesson.

At an AM radio transmitter the RF carrier is amplitude modulated by the audio (voice or music). Amplitude modulation occurs when an audio modulating signal causes the strength or amplitude of an RF carrier to vary at the audio rate and in proportion to the strength of the audio signal. Although there are radios that receive other than amplitude modulated broadcasts, only AM receivers will be discussed in this lesson.

The RF carrier from a station with the audio modulating signal impressed upon it is transmitted through space in the form of an electromagnetic wave. As the wave intercepts a receiver's antenna it induces small RF signals that are coupled into the receiver's input through a coupling coil. The function of the radio set is to select a desired signal from the many present and then amplify it and process it to recover the audio. The receiver first boosts these feeble signals and then recovers the sound information by a process called detection (rectification and removal of the RF component). It then amplifies the recovered audio until it has sufficient strength to operate a loudspeaker or headset.

Two major types of radio receivers are reviewed in this lesson. They are the *tuned radio frequency* (TRF) receiver and the *superheterodyne* receiver. The TRF system will be examined only briefly because of its limited use.

TRF RECEIVER

A tuned-radio-frequency receiver consists of one or more RF amplifier stages, a detector stage, and a series of audio amplifier stages, the last of which drives the speaker and/or headset. The necessary power source is also included. A block diagram of a TRF receiver is shown in Figure 1 along with waveforms associated with each section.

> NOTE: When there are two or more stages in succession that perform the same function the group is called a *section*. Thus, when there are two or more RF amplifiers the group of RF stages comprises an RF section.

The amplitudes of AM signals introduced into the input of a radio are relatively small because of losses in space . . . between transmitter and receiver. A received station signal is composed of the RF carrier with its modulation envelope. Properly operating RF amplifiers boost the strength of this signal but do not alter its shape or content. A detector's rectifying element rectifies the RF signal and produces a pulsating DC signal that pulses at the RF carrier rate. The amplitudes of these RF pulsations vary in accordance with the amplitudes of the AF modulating frequencies.

An RF filter with a suitably selected time constant is included in the detector stage to smooth out the RF pulsations. The output from this filter is a low level signal with

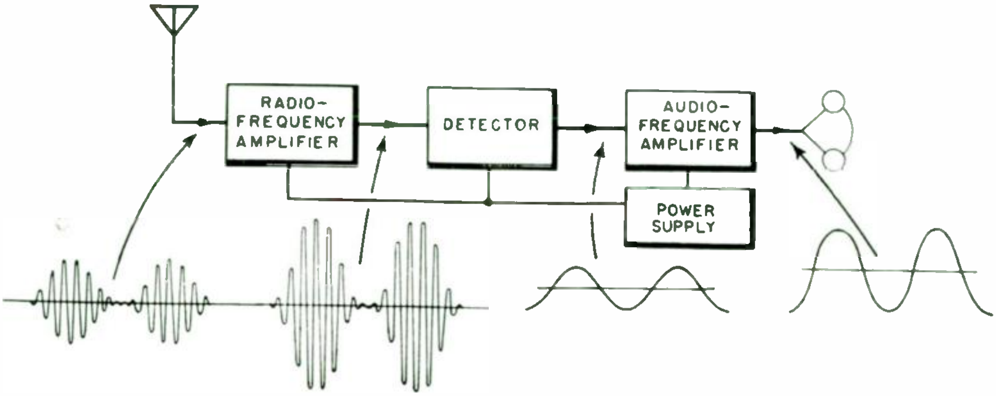


Figure 1 — Block diagram of a T-R-F receiver and waveforms.

nearly all the gaps between pulses filled. Thus, the output is a reproduction of the original audio signal. RF filters are usually RC networks, although LC (inductance-capacitance) networks are occasionally used with certain types of detectors. Detector and audio circuits are generally the same in both TRF and superheterodyne receivers, therefore, they will be discussed only once and in a later topic of this lesson.

Disadvantages of the TRF Receiver

The principle disadvantage of a TRF receiver is its inability to separate signals with equal effectiveness over the entire tuning range. As the set is tuned from the low frequency end of its range to the high frequency end, its signal selectivity becomes progressively less effective. At the high end, the set loses its ability to separate stations, resulting in objectionable interference between them. Also, the amplification, or gain, of a TRF receiver is not constant over the tuning range. This is due in part to non-linear characteristics in its RF transformers. Because of these characteristics most broadcast receivers employ the superheterodyne principle rather than the TRF principle.

SUPERHETERODYNE RECEIVERS

The essential difference between TRF receivers and superheterodyne receivers is that:

> In a TRF receiver all stages preceding the detector are variable tuned RF amplifiers which must be tunable to all stations within the band. When several of these stages are used, *tracking* becomes a problem; that is, at certain positions within the tuning range all stages will not tune precisely to the same frequency. This results in a loss of gain, selectivity, or both.
>
> In a superheterodyne receiver the stages which incorporate

most of the gain prior to detection are fixed frequency amplifiers. They tune to one frequency only (the intermediate or IF frequency) and are called IF amplifiers. Since these stages operate at only one IF frequency they can be designed with both superior selectivity and more than adequate gain.

The principle employed that permits the use of single-frequency, fix-tuned IF amplifiers is called *frequency conversion* or heterodyning. It is accomplished by beating a selected local oscillator frequency with the desired incoming signal to produce an IF signal of one frequency regardless of the incoming signal's frequency. Thus, all incoming signals are converted to an IF frequency which can be more effectively amplified in single frequency stages.

The two signals (oscillator and station) are beat together in a stage called the mixer which can be a *vacuum tube,* a *transistor,* a FET or a *diode.* The mixer is known also as the first detector because it operates as a non-linear device that rectifies the signals it handles.

In Figure 2 we see a block diagram of a superheterodyne receiver typical of many home varieties. Included in this figure are the waveforms associated with various stages or sections in the receiver. Notice that the carrier signal and the oscillator signal are both higher in frequency than the resultant IF signal from the mixer.

Two basic frequencies are available as a result of beating any two signals together in a mixer. One is the sum of the two signal frequencies while the other is a difference signal or the smaller subracted from the larger.

In most home type receivers only the difference signal is used. The higher (sum) frequency is rejected by the IF amplifiers whose tuned circuits are resonant to the lower (difference) beat frequency.

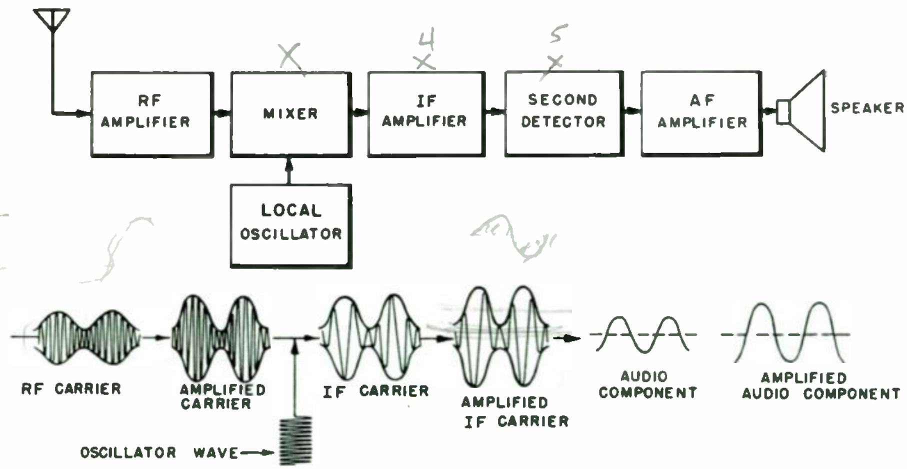


Figure 2 — Block diagram of a superheterodyne receiver and waveforms.

The desired beat frequency from the mixer is amplified in the fix-tuned IF stages and presented to a detector. From this point on to the speaker, signals are handled in basically the same manner for all receivers.

RECEIVER POWER SUPPLIES

Electronic products of the home variety, like nearly all other electronic equipment, operate from a source of DC voltage and current. Whatever this source may be, it must have the capability of providing the necessary current at the required voltage or voltages to operate the unit.

8

Portable radios use various forms of batteries for power. In the past, ordinary dry cell batteries were common but long life alkaline or mercury batteries are becoming increasingly popular. This is especially true of the rechargable varieties. Recently, many good quality portable radios have built in chargers that can restore the batteries whenever a source of line power is available.

Non-portable equipment derives its power from rectifier supplies that operate from ordinary house current. These may or may not use transformers, depending on requirements.

7

Transformerless supplies have been used in a variety of clock radios and table sets for several years and these sets are still quite popular. They are commonly called AC/DC sets.

Figure 3 shows a transformerless power supply that is typical of small vacuum tube table radios. Tube

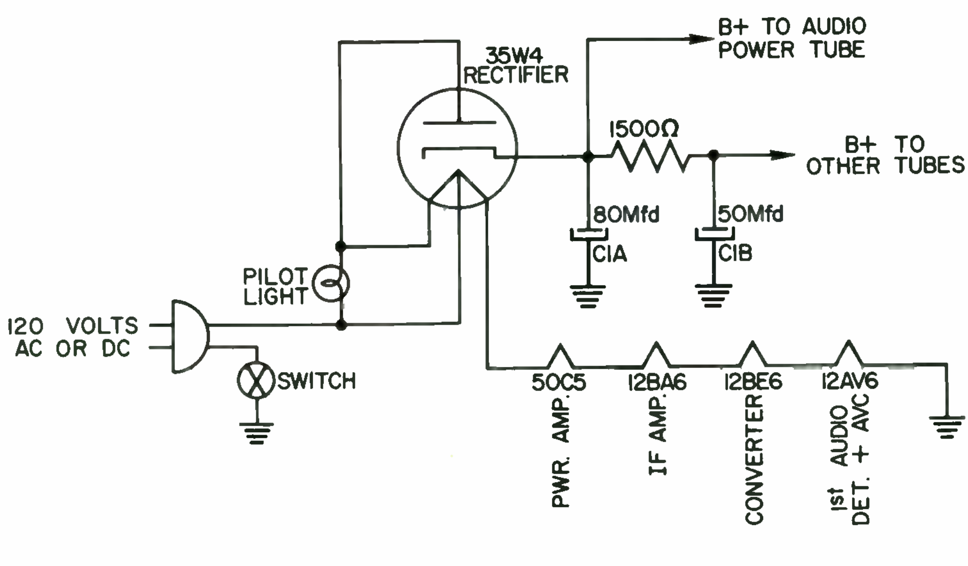


Figure 3 — AC/DC power supply section.

filaments are connected in series across the power line and drop approximately 120 volts. The current requirements for the filament string is 0.15 amps. Notice that the 35W4 half wave rectifier tube has a dual section filament. Ordinary heater current flows through one section while the connection to the rectifier plate is through the remaining section in parallel with the pilot light.

The major portion of the required DC current from the rectifier's cathode supplies the plate of the audio power amplifier tube. This current is taken directly from the rectifier cathode and does not flow through the 1500-ohm, filter resistor. If it did, excessive voltage would be dropped across the filter resistor leaving an insufficient amount to operate the set. The remaining circuitry needs additional filtering; this filtering is supplied by the RC combination of the 1500-ohm resistor and capacitor C_{1B}.

The on-off switch in Figure 3 is placed in series with the ground return line from the power plug.

WARNING: Some AC/DC power supplies have one side of the power line connected to a metal chassis. Dangerous shocks can result by touching the chassis while any part of your body is in contact with either earth ground or any conductive path to earth ground. This danger may exist with the switch in either the off position or the on position depending upon how the power plug is inserted.

Transformer operated supplies have two distinct advantages over transformerless kinds.

1. The transformer isolates the power line from any portion of the circuitry being powered.
2. Various step-up or step-down ratios can be attained to supply any required voltage.

Two transformer half-wave rectifier supplies are shown in Figure 4. One uses a solid state rectifier while the other employs a vacuum tube diode for rectification. The rectifier conducts on alternate half cycles and supplies pulsating DC at the output. This output is ordinarily filtered to remove the pulsations and supply a steady DC voltage.

Solid state diodes are now more frequently used than tubes because

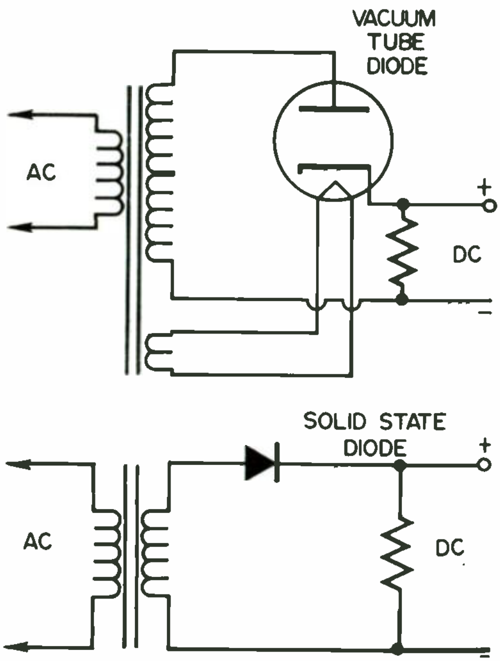


Figure 4 — Halfwave rectifier supplies using transformers.

of their small size and the fact that they do not require an extra transformer winding to supply heater current. Thus, they operate with less heat generation and power loss.

Half-wave power supplies are adequate for many applications but they do exhibit relatively large amounts of ripple. This is because the rectifier conducts only on every other alternation of the input sinewaveform. During the half-cycle of non-conduction the voltage tends to drop causing variations to occur in the DC output, even with good filtering.

Full-wave supplies such as the ones shown in Figure 5 are often used to overcome disadvantages of half-wave rectifier systems. Notice in Figure 5A that a dual diode is used along with a center tapped secondary. A section of the diode conducts during each alternation of the AC sinewave, thus eliminating long periods of non-conduction. Thus, a steady supply of DC current and voltage is maintained.

The bridge rectifier supply in Figure 5B also produces a full-wave output. It requires four diodes, but the center tapped transformer required in Figure 5A is not needed.

Filtering

A filter network is nearly always used to remove variations from a

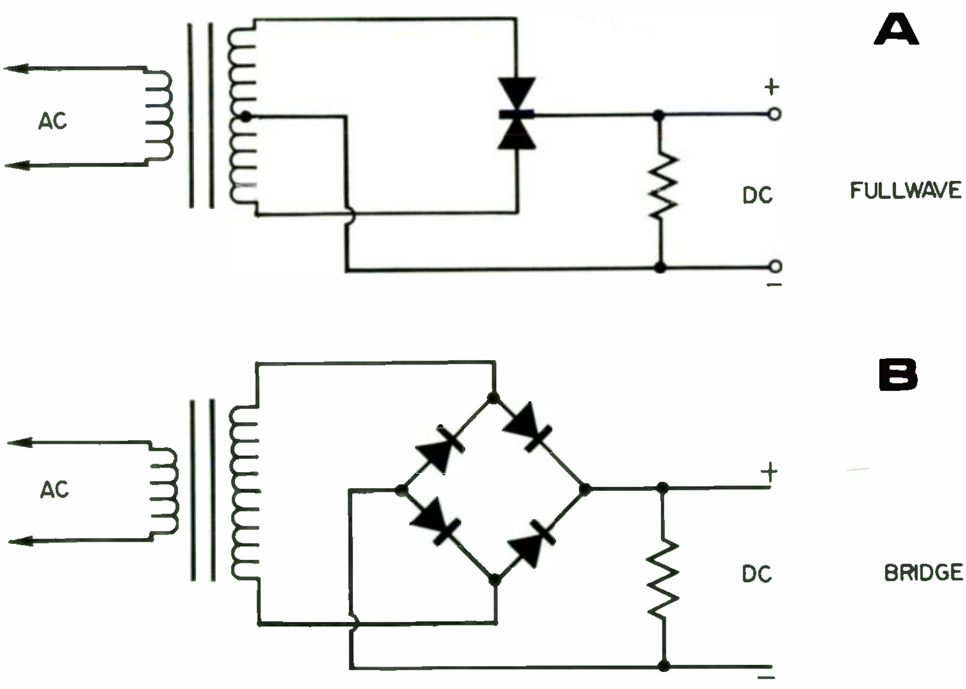


Figure 5 — Transformer—rectifier power supplies.

rectifier power supply. Figure 6 shows the results of adding a simple capacitive filter to both a half-wave and a full-wave rectifier. The capacitor charges to the potential of the peak during rectifier conduction and then discharges a portion of its stored energy into the load when conduction decreases. Notice that the output waveform from the full-wave supply in Figure 6B is smoother (it has smaller dips) than the half-wave supply in Figure 6A. This is because more total energy is supplied to the filter by full-wave rectification because there is conduction on both alternations. Also notice that the ripple frequency of a full-wave supply is twice the input frequency whereas a half-wave supply equals the input frequency. The higher frequency requires less filtering (smaller filter component values) than the lower frequency to obtain the same degree of filtering as the lower frequency.

Figure 7A shows the results of adding inductance to the output of a full-wave supply. The inductor

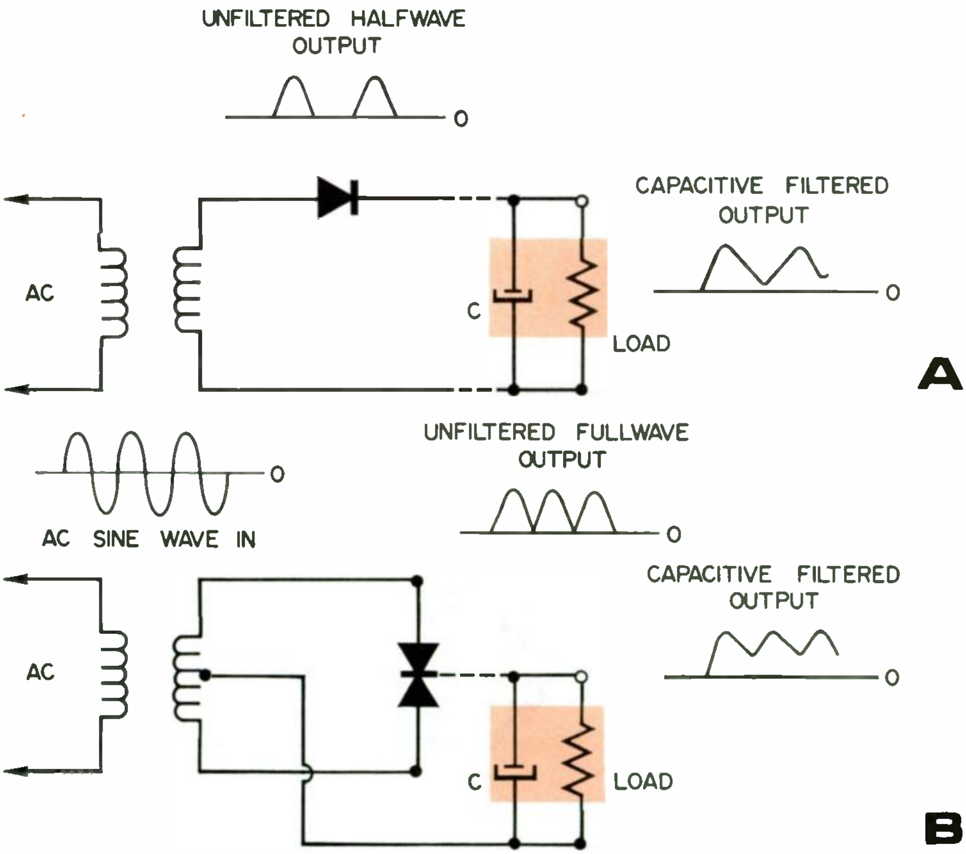


Figure 6 — Simple capacitor filter.

(L) stores energy in its magnetic field during peak current flow and releases it to the load when current begins to dip, thus maintaining a reasonably constant current through the load.

The filter network in Figure 7B is called a PI section filter. It combines L and C to maintain a nearly constant DC level of current and voltage to the load. This is the most effective simple filter, commonly used in electronic equipment.

Often the inductor (L) is replaced by a resistor and this is also an effective means of removing ripple (Fig. 8). It is slightly less effective than an inductive PI section filter because the resistor stores no energy. Also the amount of resistance needed is greater than the resistance in a good quality choke (L) which results in more voltage drop across R and considerably more variation in output voltage when the load current changes.

Regulation

All power sources contain resistance through which current must flow on its way to and from the load. This results in voltage drops across components within the sup-

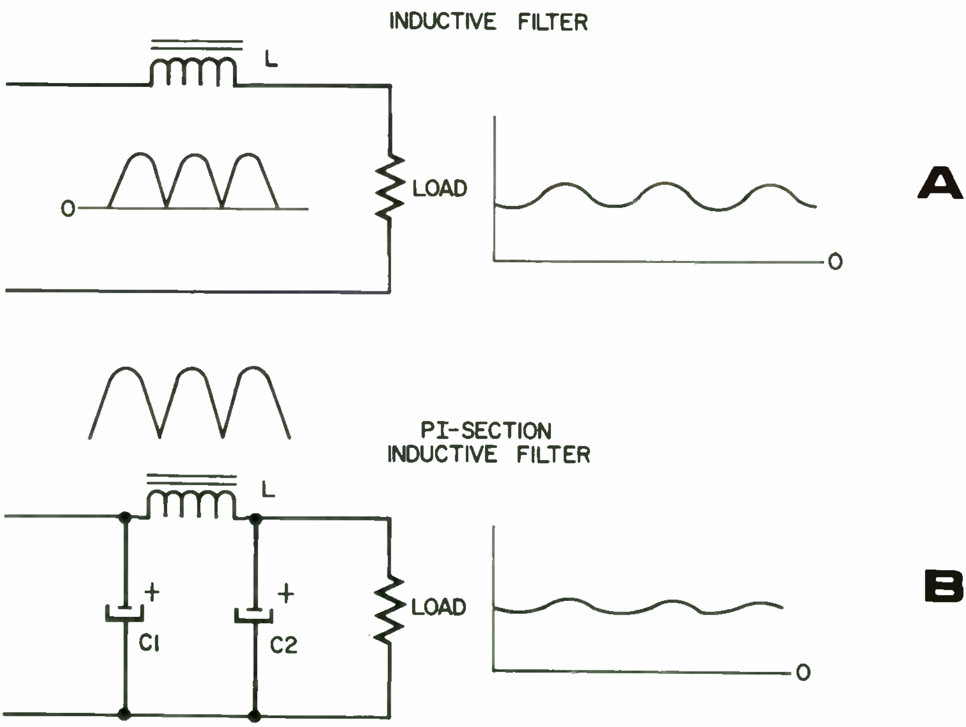


Figure 7 — Filters using inductance.

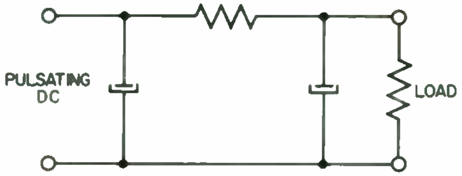


Figure 8 — An RC PI-section filter.

ply. As the current from a supply increases, more voltage is dropped, or lost, across resistive components resulting in progressively less voltage being available to power the load. The amount of change in output voltage over a specified range of currents is called regulation factor and is expressed as a percentage.

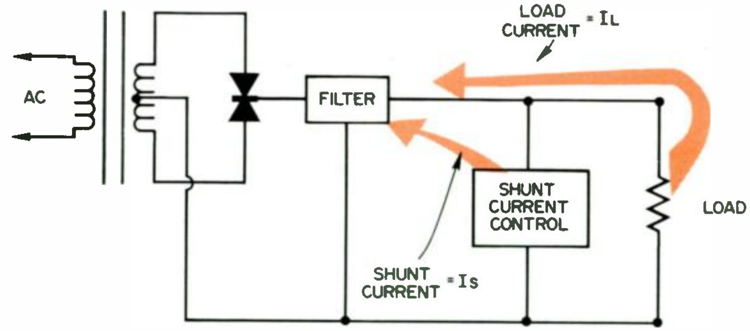
9 Some equipment requires more precise regulation than ordinary power supplies can provide. In this case, some form of electronic regulation is incorporated to hold the output voltage constant over a wide range of currents.

There are several circuits that can hold the output of a power source constant. Basically they are derived from one of two principles. One is called *shunt regulation* and the other is *series regulation.*

Shunt regulation is provided when a controlled current is shunted around the load. The shunt current is made to vary inversely with the current through the load.

Figure 9A shows a basic shunt regulator in block form. Notice that two current components are indicated. One is the load current (I_L) and the other is current through the shunt (I_s). The table in Figure 9B shows how the two might vary under ideal conditions to maintain a constant total current through

A



B

LOAD/SHUNT CURRENT RELATIONSHIPS

I_L AMPS		I_s AMPS		TOTAL CURRENT
0.1	+	0.05	=	0.15
0.0875	+	0.0625	=	0.15
0.075	+	0.075	=	0.15
0.0625	+	0.0875	=	0.15
0.05	+	0.1	=	0.15

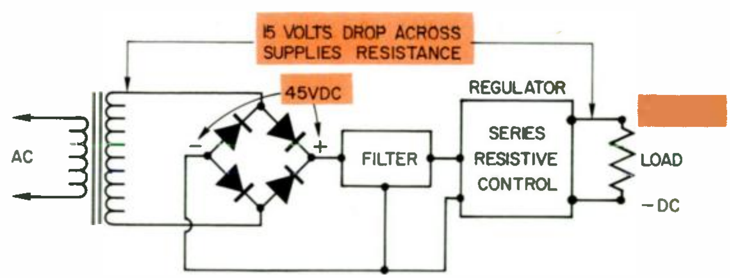
Figure 9 — Load and shunt current.

the resistance in the supply. Maintaining the same total value of current through the supply causes the voltage drops across the supply's resistances to remain constant at all times. Thus, the output voltage is held constant regardless of load current requirements.

Shunt regulators have one undesirable feature. A considerable amount of additional shunt current is needed which increases the demands on the supply. To overcome this requirement series regulators are frequently used. Figure 10A shows a basic series regulator in block form. The regulator is a device or circuit whose resistance varies inversely with changes in current flow. As the current into the load increases the regulator's resistance decreases. Conversely, when current into the load decreases the regulator's resistance increases. Thus, as the output voltage attempts to rise with a decrease in current the voltage drop across the resistance of the regulating element increases to maintain a constant voltage at the load. Also, when the output voltage attempts to decrease with increased load current, less voltage is dropped across the decreasing resistance of the series regulating element. Thus, the resistance in the regulating element changes to vary the overall power supply resistance and maintain a constant ouput voltage.

Figure 10B is a chart showing three values of load current and the resulting power supply resistance (a large portion of which belongs to the series-resistive control element). In the right hand column the voltage drop across the supply's resistive components (including the regulator) has been calculated for three different currents, by using ohms law. In all three instances the drop across the supply's resistance is constant at 15 volts.

A



B

	I_L AMPS	SUPPLY R OHMS	I x R = E
A.	0.1	150	0.1 x 150 = 15 VOLTS
B.	0.075	200	0.075 x 200 = 15 VOLTS
C.	0.05	300	0.05 x 300 = 15 VOLTS

Figure 10 — Series regulation using variable resistive element.

The voltage required from this particular supply is indicated as 30 VDC. To maintain this amount and supply the additional amount needed for regulation requires that a voltage greater than 30 volts be available from the bridge rectifier. The actual voltage at this point is 45 volts which provides the necessary 30 volts output plus the 15 volts dropped across the supply's resistance.

The zener diode has become a very important tool for use in power supply regulation. It is basically a constant voltage device that permits current to vary while maintaining a constant voltage. It can, therefore, be used directly as a shunt regulating element.

In Figure 11, a shunt regulating system is shown using a zener or constant voltage diode. The small R indicated is often the internal resistance of the power supply itself. If the load current in the circuit of Figure 11 decreases the output, voltage will attempt to rise. However, the zener diode will conduct additional current through R which results in more drop across R due to zener current. The zener current thus increases to compensate for less load current and maintains a constant output voltage. If current through the load increases, the output voltage attempts to drop. However, the zener will, in this instance, conduct less current with the result that a constant output voltage is still maintained.

Zener diodes are used in association with transistors, tubes, or FETs to form series regulating elements. Figure 12 illustrates one such arrangement using a zener as a clamping diode. In this case it controls the current into the base of a transistor. Current through R (Fig. 12) splits; a portion flows through the zener diode while the remainder flows through the base emitter junction of the transistor. Since a transistor maintains a constant voltage drop between its base and emitter, and the zener in Figure 12 provides a constant voltage at the base of the transistor, then the voltage at the emitter will be only a few tenths of a volt less than that appearing at the base. Therefore, the output voltage will remain relatively constant.

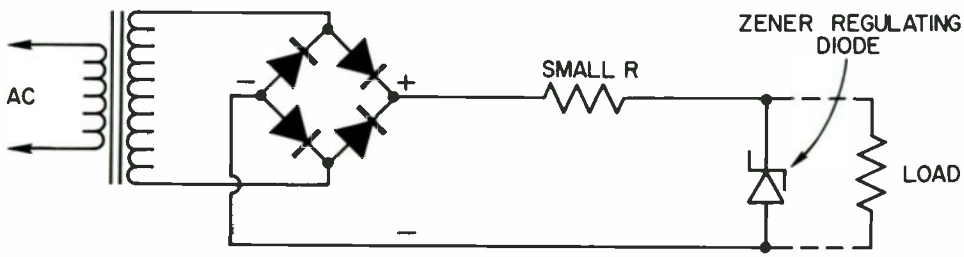


Figure 11 — Zener diode as a shunt regulator.

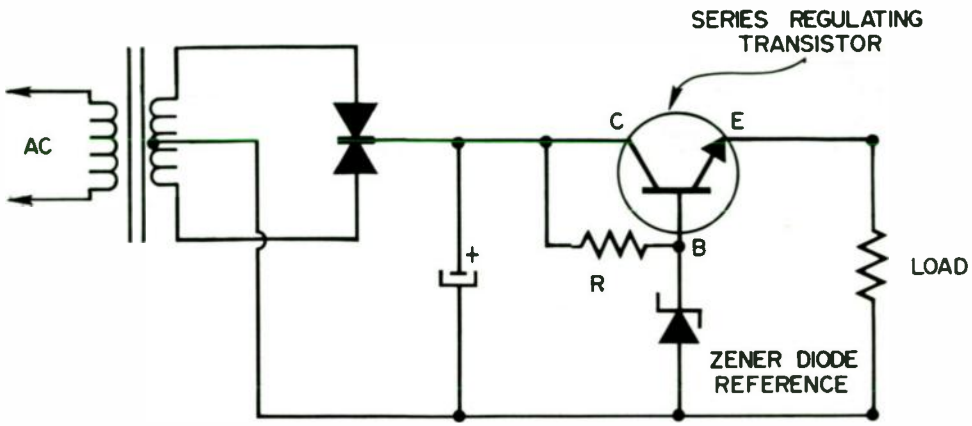


Figure 12 — Series transistor regulator using zener diode as a base clamp.

A more precise regulating circuit results by using a zener diode to control a transistor reference element which, in turn, controls the series regulating element.

The reference element of the regulated supply shown in Figure 13 consists of a transistor which has its emitter clamped with a zener diode. This raises the voltage at which reference current may be supplied to the base from the load sensing voltage divider consisting of R_2 and R_3. Resister R_1 serves as both a collector-current path for Q_1 and a base drive-current path for Q_2. Transistor Q_2 is the series regulating transistor.

In this type of regulated supply the current flow through Q_1 is determined by the base current supplied from the output of the supply. The amount of base current into Q_1 depends, then, upon the power supply's output voltage. Thus, if the output voltage attempts to rise more current flows into the base of Q_1 causing it to conduct a larger share of the total current through resistor R_1. Less current now flows into the base of Q_2 causing it to conduct less collector-emitter current. The output voltage is thereby reduced back to the desired level.

If the output of the supply in Figure 13 attempts to drop, less current will now flow into the base of Q_1 causing Q_1 to conduct less of the total current supplied through R_1. This results in a greater amount of current flowing into Q_2 causing Q_2 to conduct a greater volume of collector-emitter current. Thus, the supply delivers the additional current to the output to maintain a constant output voltage.

Regulating systems often include additional transistors and zener diodes to effect more precise control, when required. However, you will seldom find these complex systems in AM radio sets.

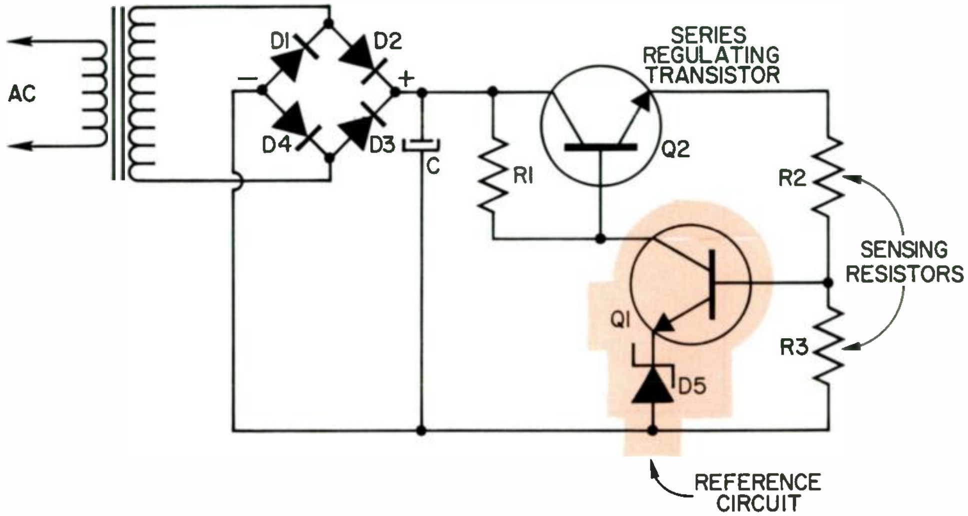
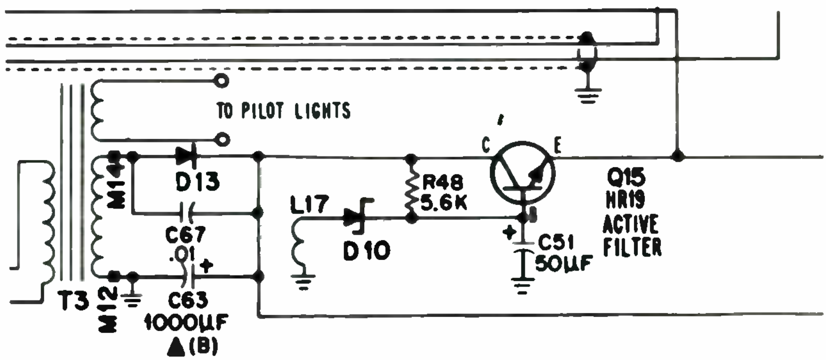


Figure 13 — Functional electronically regulated power supply using transistor-zener reference element.



Courtesy of Philco-Ford

Figure 14 — Base clamped regulator in a high quality receiver's power supply.

Figure 14 shows a base clamped, series regulator which is currently used in a high quality receiver. This regulator shows a capacitor C_{51} from the base of Q_{15} to ground. By placing the filter capacitor at this point a much smaller one can be used. Its effectiveness is multiplied, somewhat, by the gain (Beta) of transistor Q_{15}.

In Figure 15, a line-powered battery charging supply is shown. This supply is used in a popular all band receiver intended for use by Hams (amateur operators) and serious short wave listeners. The system incorporates two rectifier diodes, one to charge each of the two batteries. Each diode conducts a surge of charging current through a bat-

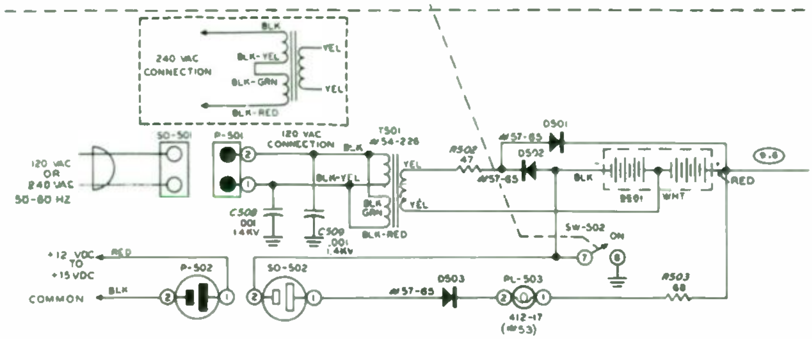


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Figure 15 — Line powered battery charging system

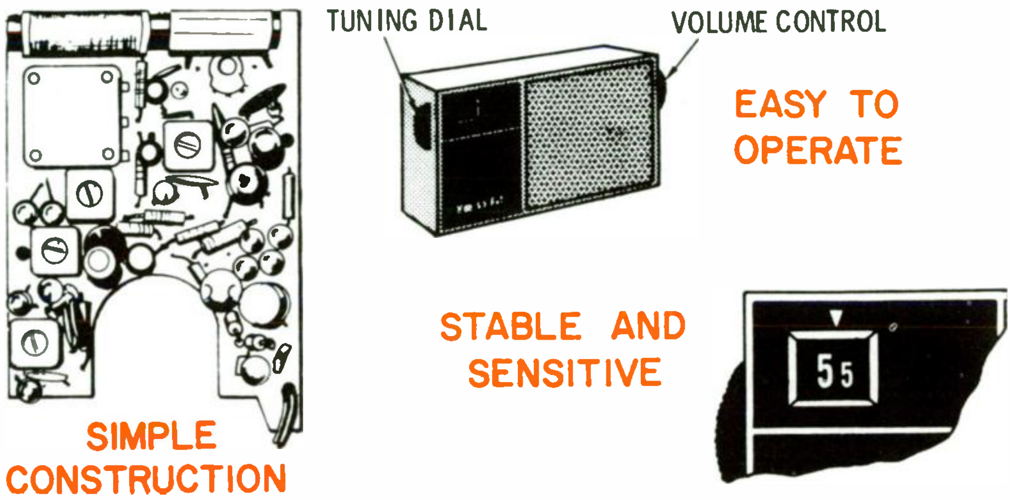


Figure 16 — Reasons for universal use of superheterodyne circuit.

tery on its associated alternation. The set actually operates from the batteries and the supply is used only for charging.

SUPERHETERODYNE APPLICATIONS

The basic superheterodyne radio circuit is probably the most widely used electronic circuit. Virtually all radio transmissions, whether from broadcasting stations or space capsules in flight, are received by means of superheterodyne radio receivers. Even at the heart of enormous radiotelescopes used to probe the far reaches of the universe you will find a superheterodyne circuit.

There are many reasons for the almost universal use of this circuit in radio-reception equipment (Fig. 16). Some of these are:

a. Ease of tuning and operation
b. Excellent stability and sensitivity
c. Simplicity of construction

The basic superheterodyne circuit is easily modified to meet the demands of individual applications. Certain applications may require a fixed-tuned receiver—that is, a receiver of extreme stability at one particular frequency. Such an application might be the receiver in a fire truck, which must respond to calls from a dispatcher. Drift of the receiver would be intolerable. For such applications a *crystal-controlled* superheterodyne receiver would be used, in which the receiving frequency is set by a quartz crystal. Such crystals are very insensitive to mechanical shock and temperature variations.

Amplitude Modulation

The block diagram of a basic amplitude-modulated transmitter is shown in Figure 17. Note that the instantaneous power input to the radio-frequency power amplifier is regulated by the audio modulator.

Without modulation, a continuous wave (cw) is radiated. When fully modulated, the amplitude of the radiated wave varies, at the audio rate, from zero to twice its unmodulated value. This process, when displayed on an oscilloscope, results in the *modulated envelope* shown in Figure 18.

In order for the receiver to recover the modulating signal, it must reproduce in some way *only* the amplitude *variations* of the carrier at the audio rate. This process of recovering the audio is known as *detection*. One way of detecting an AM signal is by rectification and selective filtering. Figure 19 illustrates this process.

The rectified signal consists of rapidly pulsating DC voltage (similar to the output of a half-wave power-rectifier supply). However, the amplitude of the RF pulses varies with the audio modulation. By applying the rectified signal to a small filter capacitor, the rapid radio-frequency ripple is filtered out, causing only a DC voltage proportional to the RF signal strength plus the low-frequency audio variations to appear across the capacitor. This method of detection is the most widely used in AM receivers of all kinds. The original "cat's whisker" detector used 60 years ago was actually the forerunner of the modern semiconductor-diode detector.

TRANSISTORIZED SUPERHETERODYNE RADIO

The illustration in Figure 20 is a block diagram of a simple superheterodyne radio.

Radio waves reaching the receiver cause small radio-frequency voltages to be induced across the antenna. Generally, a large antenna will produce more voltage than a small one, but in most cases the voltage developed will not be more than 50 or 100 microvolts. These

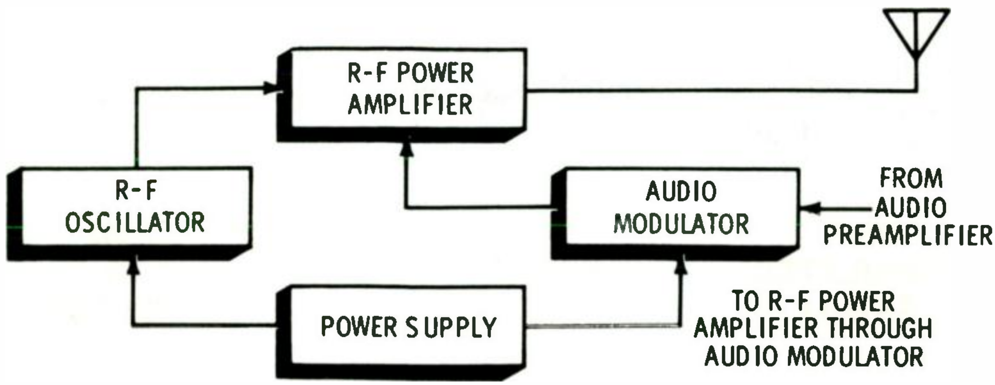
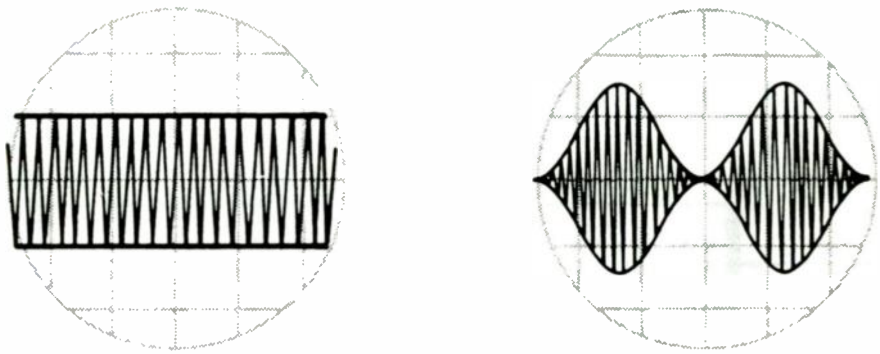


Figure 17 — Basic AM transmitter block diagram.



A - CW signal.

B - AM signal.

Figure 18 — Two types of radiated waves.

small voltages must be amplified hundreds of thousands or even millions of times before detection takes place.

In a simple superheterodyne, virtually all of this amplification takes place in the intermediate-frequency (IF) amplifiers. The IF amplifiers are all fixed-tuned to the same frequency—usually 455 kHz in a standard AM broadcast receiver. The IF amplifiers are carefully shielded from each other to prevent instability due to the very high gain of the circuits.

In order to use the IF stages to amplify the weak RF signal at the antenna, it is first necessary to change the frequency of the incoming signals to the intermediate frequency. This change is accomplished in the mixer stage with the help of the local oscillator.

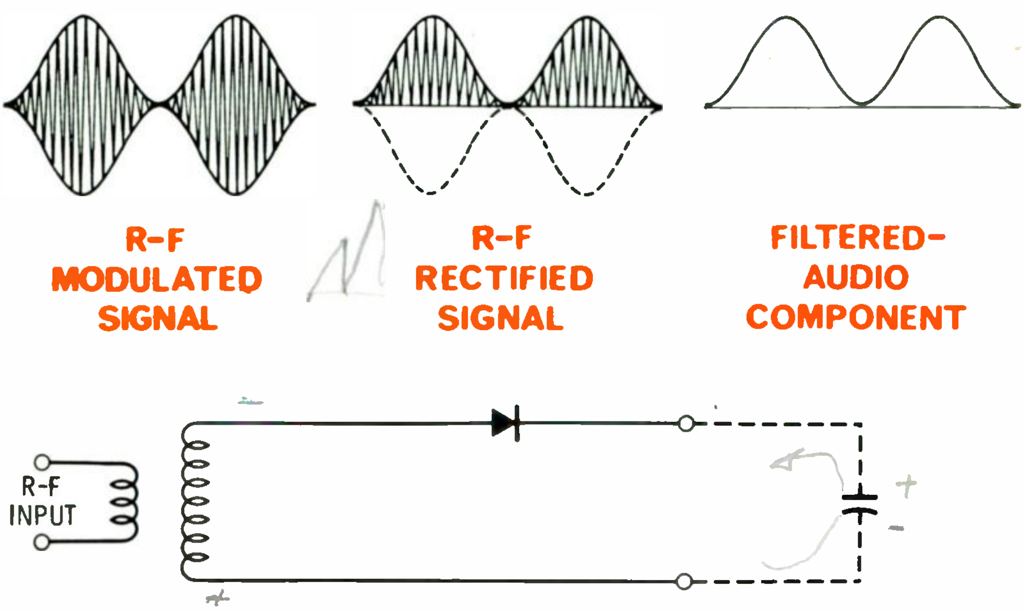


Figure 19 — Detecting an AM signal.

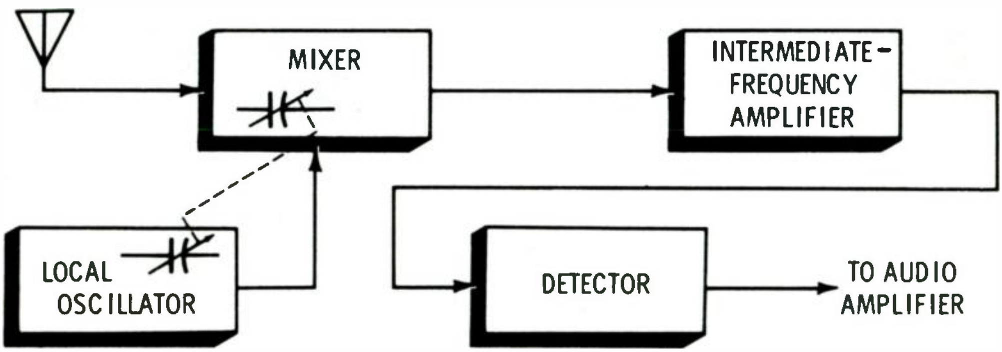


Figure 20 — Block diagram of simple superheterodyne radio.

6 The heart of the mixer stage in Figure 20 is the variable tuning capacitor. This is a two-section capacitor which tunes two circuits simultaneously. One of these circuits is the mixer-input circuit. This circuit selects the desired incoming signal from the large number of signals present at the antenna and feeds it to the RF signal input of the mixer stage. The second section of the tuning capacitor tunes the local oscillator. The tuning capacitor and the oscillator and mixer coils are so designed that the local oscillator is always tuned 455

kHz higher than the mixer-input circuit. That is, at any setting of the tuning capacitor there is always a 455-kHz frequency difference between the local oscillator and the incoming signal. The local oscillator signal is fed to the oscillator input of the mixer stage.

The mixer combines the RF input signal and the local oscillator signal and generates two new frequencies. These new frequencies are called *beat frequencies.* The beat frequencies are equal to the sum and difference of the two input signals. Since the difference between the RF input signal and the local oscillator signal is always maintained at 455 kHz, a 455-kHz beat frequency is always produced. It is this beat frequency which is amplified in the intermediate-frequency amplifier.

The output of the last IF amplifier is applied to a diode detector. The detector produces an audio voltage proportional to the strength of the RF signal at the antenna. This audio voltage is applied to a power amplifier which in turn drives the speaker. The simple superheterodyne radio described previously lacks one refinement which is used almost universally in radios and television sets. This refinement is *automatic volume control (AVC).*

AVC Application

As a radio dial is tuned, the signal strength of the stations received may vary over an enormous range. These variations are due to differences in transmitted power and varying directions and distances between transmitters and the receiver. Very strong stations tend to overload the IF amplifiers, unless some means of lowering the gain is available. Volume-control settings for each station vary widely in radios without AVC. Automatic volume-control circuits eliminate all of these problems.

As shown in Figure 21, part of the output of the detector is fed to a filter network which removes all of the audio variations from the detected signal. This leaves only a DC voltage which is directly proportional to the RF input signal. The stronger the RF signal, the larger the DC voltage. This DC voltage is then used to vary the bias and

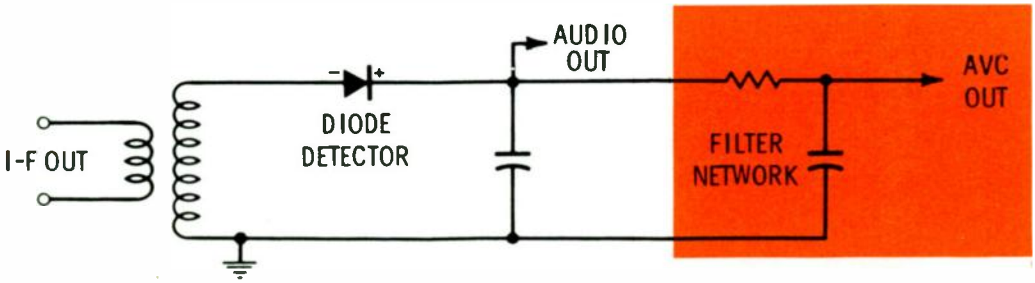


Figure 21 — Filter network removes audio variations from detected signal.

therefore the gain of one or more IF amplifier stages. If the signal fades, the gain automatically rises; as the dial is tuned across the band, the AVC circuit automatically sets the gain on each station.

The preceding discussion of superheterodynes was based on the average portable or table radio. Many additional circuits and variations of those circuits described are found in specialized receivers, such as short-wave radios. Some common "extras" found in short-wave receivers are shown in Figure 22. See if you can find them and determine their functions.

Mixer-Oscillator Circuits

In the basic mixer-oscillator circuit shown in Figure 23, note that split tuning capacitor C1A and C1B simultaneously tunes the mixer input and the local-oscillator tank circuits. The RF input signal is applied to the base of mixer transistor Q1 and the local oscillator signal is applied to the emitter. This provides a certain amount of isolation between the local oscillator and the input signal. The oscillator is a simple "tickler" oscillator capacitor coupled to the emitter of the mixer. The collector of the mixer transistor is connected to the primary of IF transformer T2 which is in parallel with capacitor C3. The primary coil and this capacitor form a 455-kHz resonant circuit.

Very often, in designing a superheterodyne radio, space and cost considerations require that it be built with a minimum number of parts. This always means a sacrifice in performance, but performance adequate for portable and table radios can be obtained.

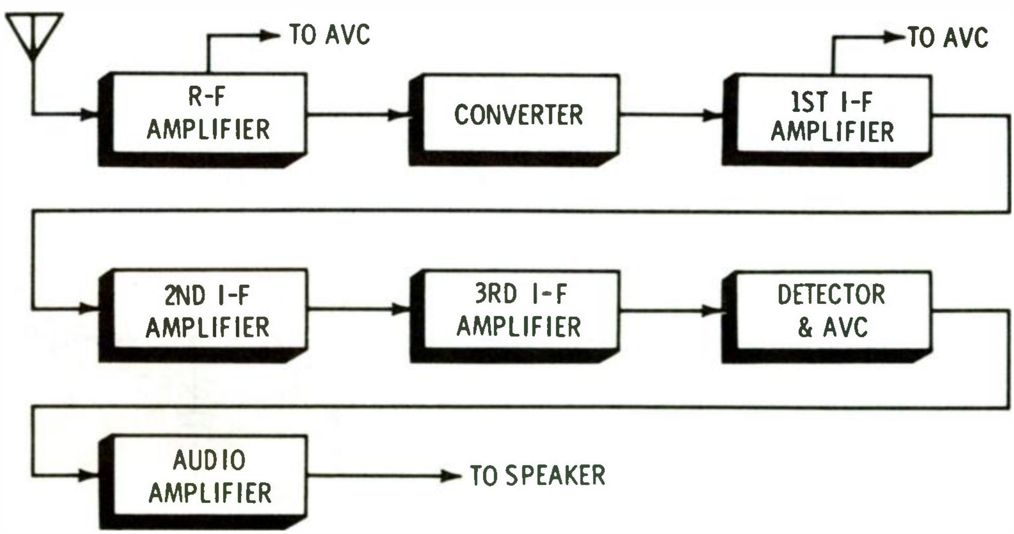


Figure 22 — Block diagram of some common "extras" in short-wave receivers.

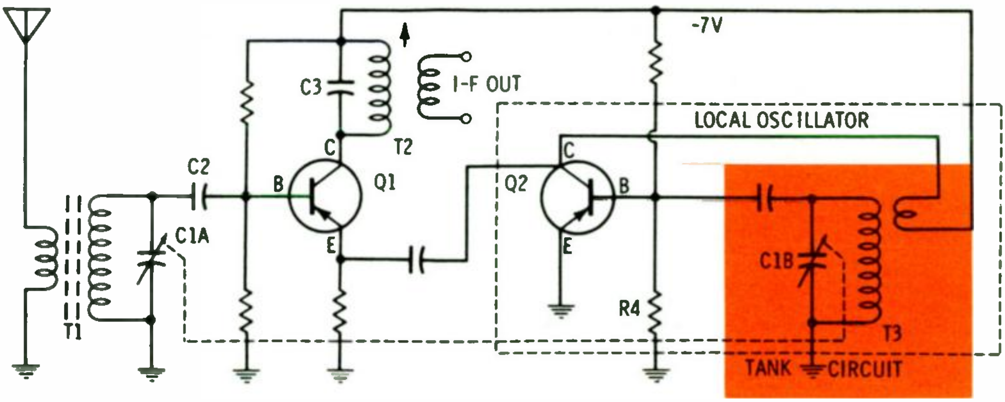


Figure 23 — Basic mixer-oscillator circuit.

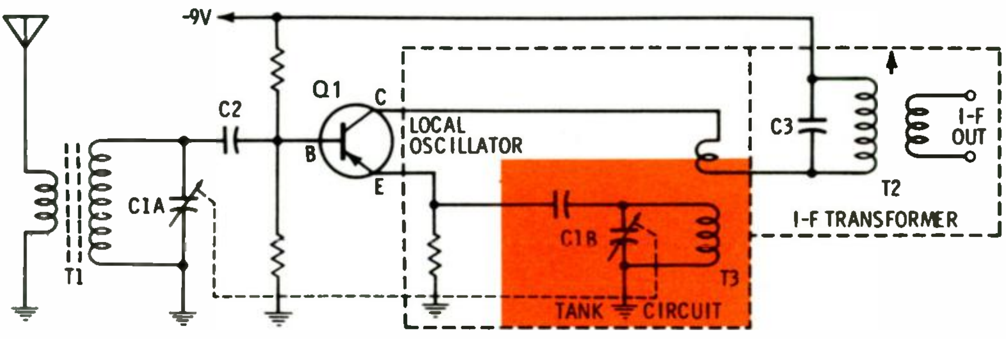


Figure 24 — Use of self-oscillating mixer stage reduces cost and space.

One way to cut costs and space is to use a self-oscillating mixer stage known as a *converter,* shown in Figure 24.

In this circuit, the small tickler coil (part of T_3) placed in the collector of Q_1 feeds back enough energy to the local-oscillator circuit in the emitter to cause oscillation. The RF input is fed to the base and mixing takes place as in the mixer stage on the previous page. Drawbacks of the converter are a high noise level and less stability than a separate mixer and oscillator. However, due to its simplicity it is widely used. A further saving can be realized by winding the antenna and the mixer coil on the same ferrite rod. One problem in superheterodyne receivers is to maintain a difference of exactly 455 kHz between the local oscillator and the mixer input tuning at all dial settings. If the circuits do not tune

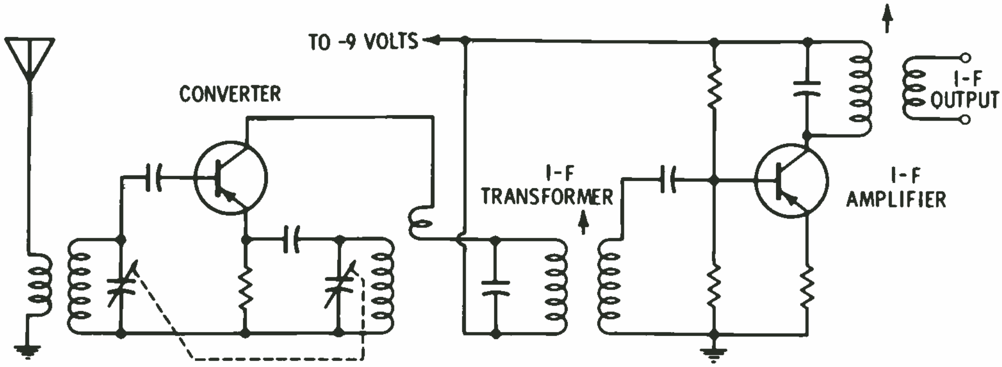


Figure 25 — IF amplifier added to converter stage.

together accurately, the receiver is said to have poor tracking. Small "padding" capacitors are often used in parallel with the main tuning capacitor to help compensate for tracking error. These capacitors can be adjusted by the service technician for optimum performance, if necessary.

Intermediate-Frequency Amplifiers

Figure 25 shows an IF amplifier added to the converter circuit described on the preceding page.

The resonant circuit in the collector of the converter stage, which is tuned to the intermediate frequency, is now used as the primary of a transformer. The secondary of this transformer is used to couple the 455-kHz signal to the base of the IF amplifier stage. The IF transformers are manufactured as pretuned completely wired units, and are packaged in small aluminum cans. (See Figure 26.)

Exact alignment (tuning) of the transformer is done by means of a threaded powdered-iron slug, which is run in and out of the primary winding. Access to the slug is through a small hole in the top of the aluminum shield can.

The collector of the IF amplifier is connected to the primary of another "IF can," which couples the amplified output to the input of the next stage.

Automatic volume control voltage is applied to the IF amplifier's bias network (Fig. 27). R_1, R_2, and

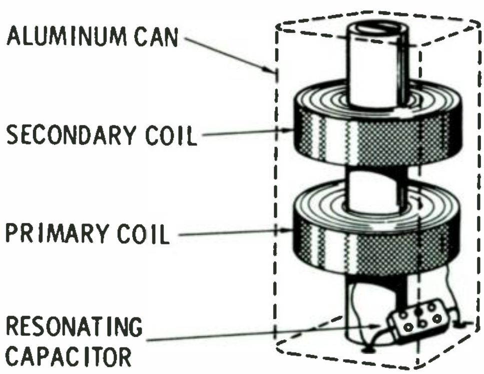


Figure 26 — IF transformer construction.

R_3 form a voltage divider, which applies full-bias voltage to the stage in the absence of AVC voltage. A *positive* AVC voltage applied at the junction of R_2 and R_3 tends to neutralize the negative voltage drop across R_3, thus lowering the base-bias voltage and reducing the gain of the stage. In many receivers, AVC is applied to two or more stages, which results in better AVC action with less tendency toward distortion.

Detection, AVC, and Audio

The detector, AVC, and audio circuits are shown added to the converter and IF amplifier stages in Figure 27.

10

The diode X_1 rectifies the 455-kHz signal from the secondary of the IF output transformer. The high-frequency ripple is then filtered by C_1, which develops a positive charge proportional to the RF signal strength and an audio signal which contains all the modulation information. The audio portion is fed to the volume control and then through blocking capacitor C_3 to the audio amplifier. The amplifier has enough output power to drive a headset or a power amplifier for loudspeaker operation. The DC signal developed by the detector is filtered of all audio frequencies by the network consisting of R_1 and C_2. The filtered DC voltage is then fed back to the IF amplifier as the AVC control voltage.

The superheterodyne radio developed previously is typical of millions of portable transistor radios in use today. Although the circuitry is the simplest possible for superheterodyne operation, it forms the basis for even the most elaborate receivers. You will find as you work as an electronic technician that a full understanding of the circuits presented in this lesson will set a firm foundation for effective troubleshooting of radio, television, and other communications equipment.

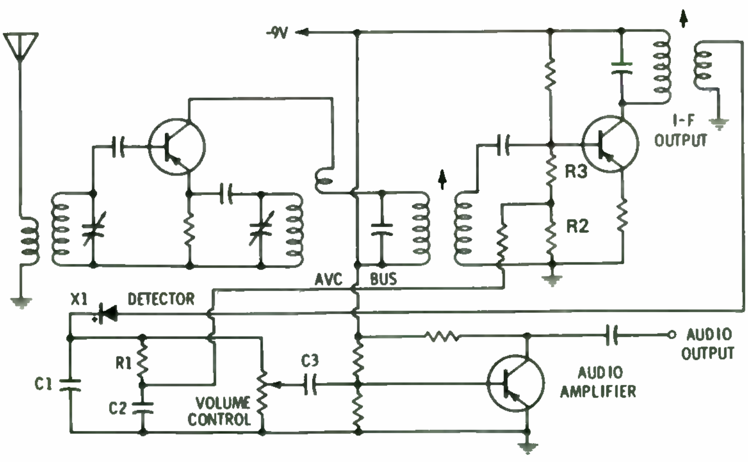


Figure 27 — Adding the detector, AVC, and audio circuits.

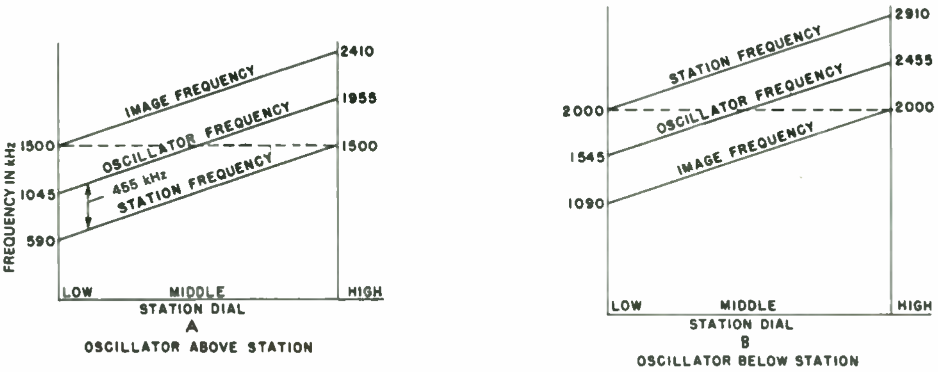


Figure 28 — Relation of image frequency to station frequency in a superheterodyne receiver.

RF Amplifier

If an RF amplifier is used ahead of the mixer stage of a superheterodyne receiver it is generally of conventional design (Fig. 29). Besides amplifying the RF signal, the RF amplifier has other important functions. For example, it isolates the local oscillator from the antenna-ground system. If the antenna were connected directly to the mixer stage, a part of the local oscillator signal might be radiated into space. This signal could be picked up by other receivers and cause interference.

Also, if the mixer stage were connected directly to the antenna, unwanted signals, called *images*, might be received, because the intermediate frequency is produced by

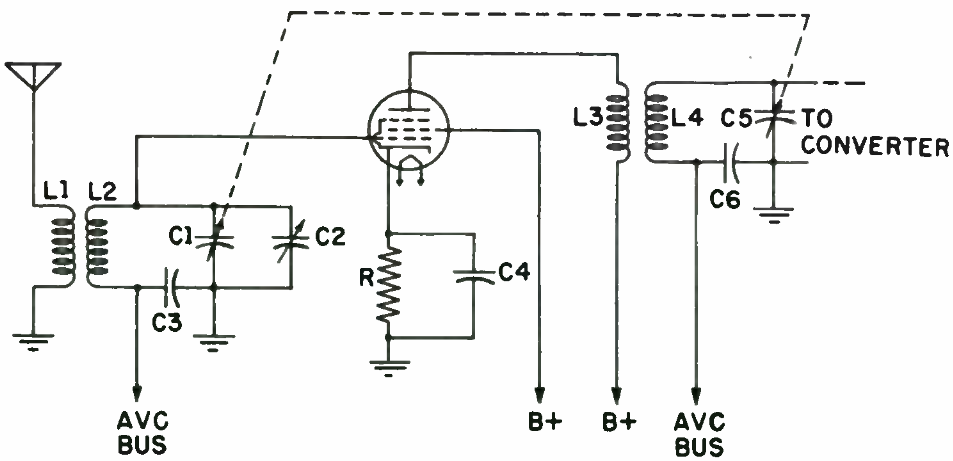


Figure 29 — Typical superheterodyne preselector stage.

heterodyning two signals whose frequency difference equals the intermediate frequency.

The image frequency always differs from the desired station frequency by twice the intermediate frequency—Image frequency = station frequency ± (2 X intermediate frequency). The image frequency is higher than the station frequency if the local oscillator frequency operates above the station frequency (Fig. 28A). The image frequency is lower than the station frequency if the local oscillator tracks below the station frequency (Fig. 28B). The former is nearly always used in home variety receivers.

For example, if such a receiver having an intermediate frequency of 455 kHz is tuned to receive a station frequency of 1500 kHz (Fig. 28A), and the local oscillator has a frequency of 1955 kHz, the output of the IF amplifier may contain two interfering signals—one from the 1500-kHz station and the other from an image station of 2410 kHz (1500 kHz + (2 X 455 kHz = 2410 kHz). The same receiver tuned near the low end of the band to a 590-kHz station has a local oscillator frequency of 1045 kHz. The output of the IF amplifier contains the station signal (1045-590 = 455 kHz) and an image signal (1500-1045 = 455 kHz). Thus the 1500-kHz signal is an image heard simultaneously with the 590-kHz station signal.

It may also be possible for ANY two signals having sufficient strength, and separated by the intermediate frequency to produce unwanted signals in the reproducer. The selectivity of the preselector tends to reduce the strength of these images and unwanted signals.

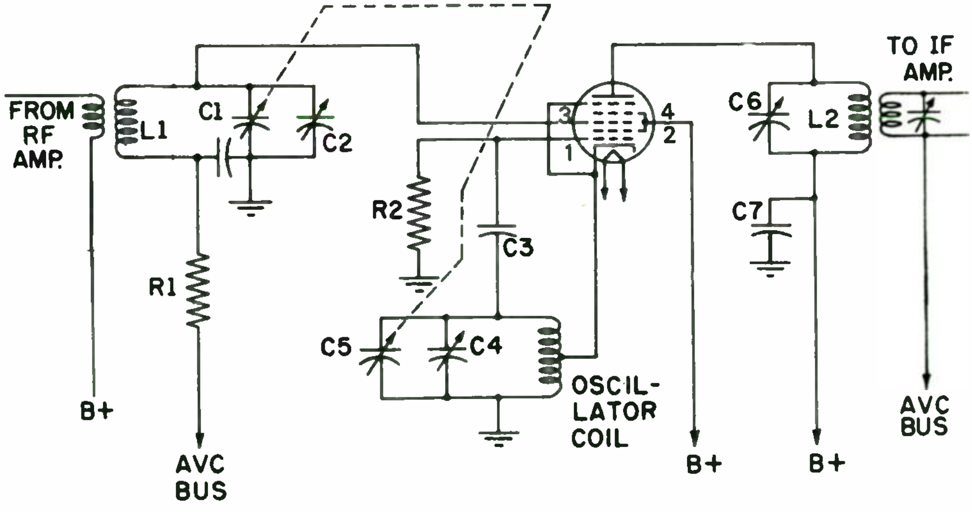


Figure 30 — First detector employing a pentagrid converter.

VACUUM TUBE RADIOS

First Detector

The first detector, or frequency-converter, section of a superheterodyne receiver is composed of two parts—the oscillator and the mixer. In many receivers, particularly at broadcast frequencies, the same vacuum tube serves both functions, as in the pentagrid converter shown in Figure 30. The operation of the tube may be simplified somewhat if both stages (oscillator and mixer) are considered as exerting two different influences on the stream of electrons from cathode to plate. These electrons are influenced by the oscillator stage (grids, 1, 2, and 4) and also by the station input signal on grid number 3. Thus, coupling between the input signal and the oscillator takes place within the electron stream itself.

The oscillator stage employs a typical Hartley circuit in which C_5 and the oscillator coil make up the tuned circuit. Capacitor C_4 is the trimmer capacitor used for alignment (tracking) purposes. Capacitor C_3 and resistor R_2 provide grid-leak bias for the oscillator section of the tube. Grid 1 is the oscillator grid, and grids 2 and 4 serve as the oscillator plate. Grids 2 and 4 are connected together and also serve as a shield for the signal input grid, 3.

Grid 3 has a variable-mu characteristic, and serves as both an amplifier and a mixer grid. The tuned input is made up of L_1 and C_1, with the parallel trimmer C_2. The dotted lines drawn through C_1 and C_5 indicate that both of these capacitors are ganged on the same shaft (in this example with the preselector tuning capacitor).

IF Amplifier

The IF amplifier is a high-gain circuit commonly employing pentode tubes. This amplifier is permanently tuned to the frequency difference between the local oscillator and the incoming RF signal. Pentode tubes are generally employed, with one, two, or three stages, depending on the amount of gain needed. As previously stated, all incoming signals are converted to the same frequency by the frequency converter, and the IF amplifier operates at only one frequency. The tuned circuits, therefore, are permanently adjusted for maximum gain consistent with the desired band pass and frequency response. These stages operate as class-A voltage amplifiers and practically all of the selectivity of the superheterodyne receiver is developed by them.

Figure 31 shows the first IF amplifier stage. The minimum bias is established by means of R_1C_1, and automatic volume control is applied to the grid through the secondary of the preceding coupling transformer.

The output IF transformer, which couples the plate circuit of this stage to the grid circuit of the second IF stage, is tuned by means of capacitors C_2 and C_3. Mica or air-trimmer capacitors may be used. In some instances the capacitors are fixed, and the tuning is accomplished by means of a mov-

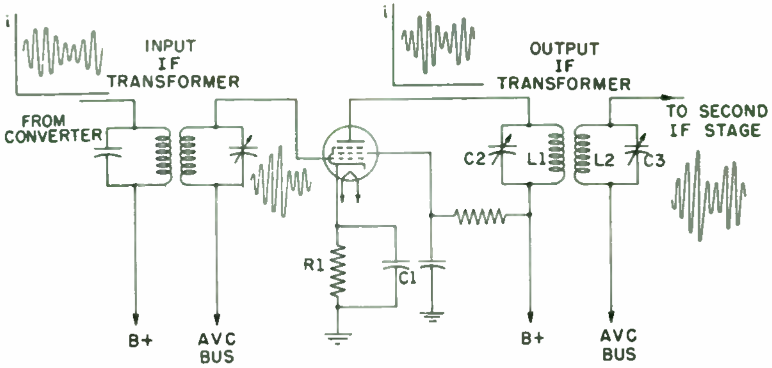


Figure 31 — First IF amplifier stage.

able powdered-iron core. This method is called PERMEABILITY tuning. In special cases the secondary only is tuned. The coils and capacitors are mounted in small metal cans which serve as shields, and provision is made for adjusting the tuning without removing the shield.

Second Detector

Most superheterodyne receivers employ a diode as the second detector. This type of detector is practical because of the high gain as well as the high selectivity of the IF stages. The diode detector has good linearity and can handle large signals without overloading. For reasons of space and economy, the diode detector and first audio amplifier are often included in the same envelope in modern superheterodyne receivers.

Automatic Volume Control

10

Under ideal conditions, once the manual volume or gain control has been set, the output signal should remain at the same level even if the input signals vary in intensity. The development of variable-mu tubes makes it possible to devise a practical automatic gain control (AGC) circuit or automatic volume control (AVC) circuit, since the amplification of the tube may be controlled by varying the grid bias voltage. All that is required is a source of bias voltage that varies with the signal strength. If this voltage is applied as bias to the grids of the variable-mu RF amplifier stages, the grids will become more negative as the signal becomes stronger. The amplification will thus be reduced, and the output of the receiver will tend to remain at a constant level. Unless the selectivity of the IF stages is good, strong adjacent-channel signals will reduce receiver gain when a weak signal is tuned in. When no interference is present, AVC holds the audio output constant as the input signal amplitude varies over a wide range.

The *load resistor* of a diode detector is an excellent source of this

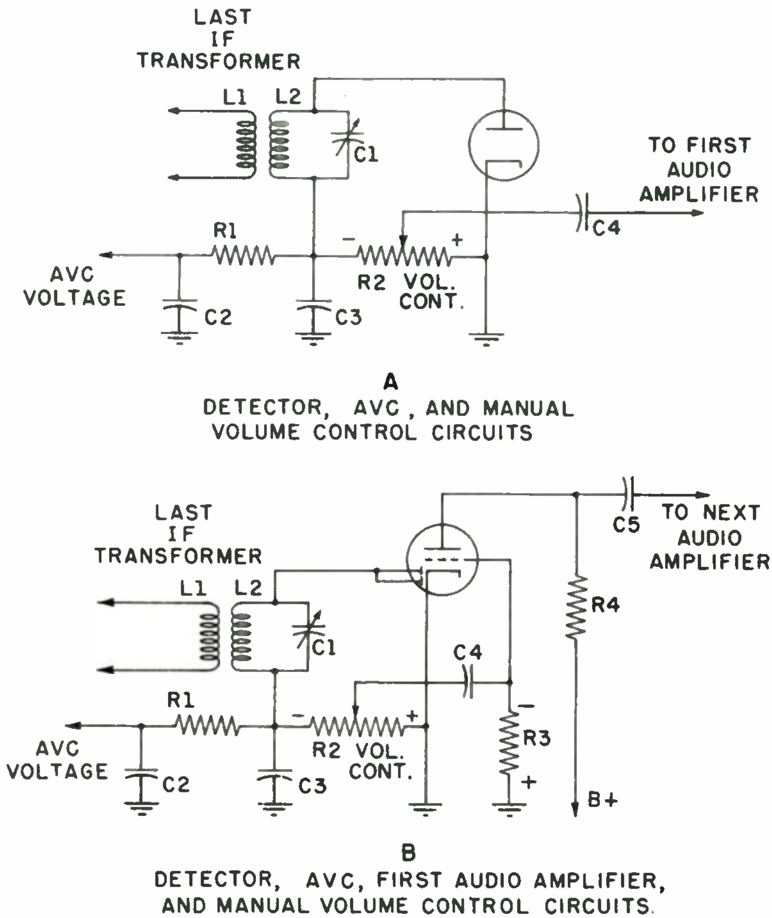


Figure 32 — Manual and AVC circuits.

voltage, since the rectified signal voltage will increase and decrease with the signal strength. A filter is used to remove the AF component of the signal and at the same time to prevent the AVC circuit from shorting the audio output. Only the slower variations due to fading or change of position of the receiving antenna, and so forth, will then affect the gain of the RF amplifier stages because the AVC circuit cannot compensate for very fast or extreme variations.

Figure 32 shows how the AVC voltage is obtained. The AVC voltage is tapped off at the negative end of the diode load resistor, R_2 (Fig. 32A), which is also the manual volume control. The AF component is removed by the filter circuit that is composed of C_2 and R_1. One or more of the RF amplifiers may be controlled by the voltage thus obtained. A customary value for R_1 is 2 megohms and for C_2 is $0.05\mu f$.

Figure 32B, shows an AVC circuit used with a duodiode triode in a conventional diode detector circuit. The two plates of the diode are connected together to form a half-wave rectifier in the RF portion of the circuit. The output of the diode detector is fed to the grid of the triode section which acts as a class-A voltage amplifier.

Low voltage bias is obtained by utilizing the contact potential developed across R3 resulting from the dissimilar elements in the grid and cathode.

PREAMPLIFIER OPERATING CHARACTERISTICS

A function common to all preamplifiers is increasing the voltage level of small signals. Ideally, this amplification should take place with a minimum of noise added to the signal. In addition, the amplified signal should be a faithful reproduction of the input signal. That is, it should not be *distorted* in any way. Another point which cannot be overlooked is that the actual voltage gain of the amplifier should be predictable and stable.

Modern preamplifiers frequently incorporate *negative feedback* to achieve stable gain and low distortion. Such an amplifier is called a *feedback amplifier.*

Feedback Amplifiers

A feedback amplifier can be considered as two separate amplifiers with both outputs combined. A positive voltage applied to one input causes its output voltage to rise. This input is called the ***noninverting input.*** A positive voltage applied to the other input causes its output voltage to fall. This is called the ***inverting input.*** If the ***same*** signal is fed to both inputs simultaneously there is *no* output as the two output signals are 180° out of phase and neutralize each other completely. This is shown in Figure 33.

The feedback amplifier can be block diagrammed as shown in Figure 34. However, since the feedback amplifier is actually a single amplifier unit having two out-of-phase inputs and one combined out-

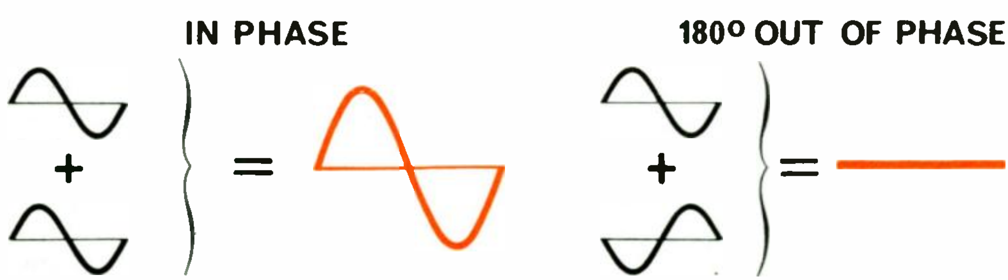


Figure 33 — Example of inverting input.

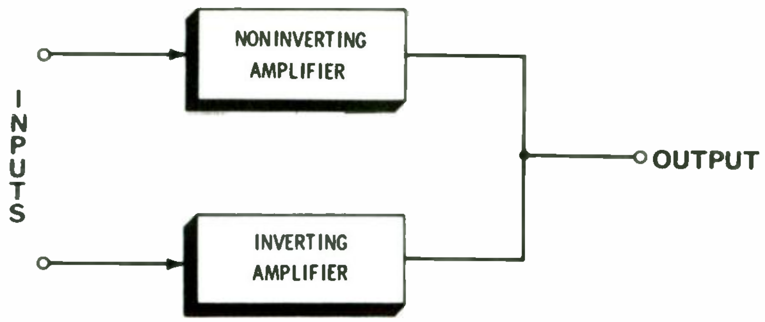


Figure 34 — Block diagram of feedback amplifier.

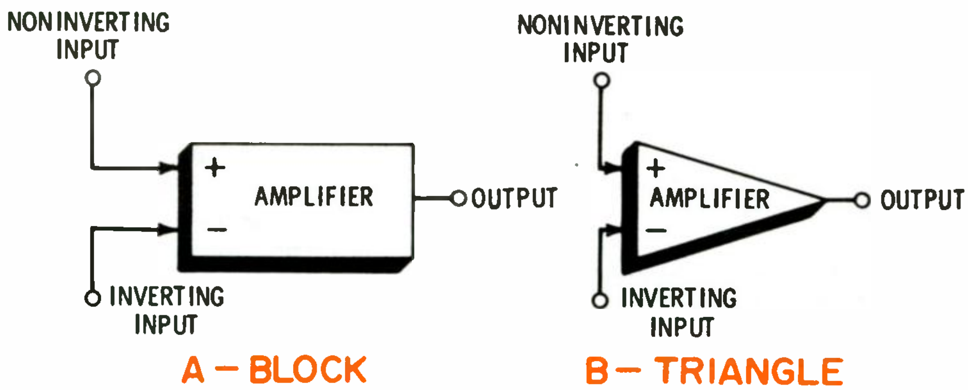


Figure 35 — Feedback amplifier diagram symbols.

put, it is usually drawn as a single block or triangle shown in Figure 35. The (+) sign indicates the noninverting input and the (−) sign indicates the inverting input.

Voltage Gain in Feedback Amplifiers

Figure 36 illustrates a feedback amplifier with the output connected to the inverting input.

With this connection, any signal applied to the noninverting input will apparently be instantaneously amplified and *fed back* to the inverting input. The output voltage actually rises to only 1 volt. It cannot rise any further, since the signal at the inverting input (being larger than the input signal) would then cause the output voltage to drop. If you apply 2 volts to the noninverting input, the output will rise to 2 volts. You should be able to see that any voltage applied to the noninverting input will be exactly reproduced at the output. Such an amplifier has a voltage gain of one

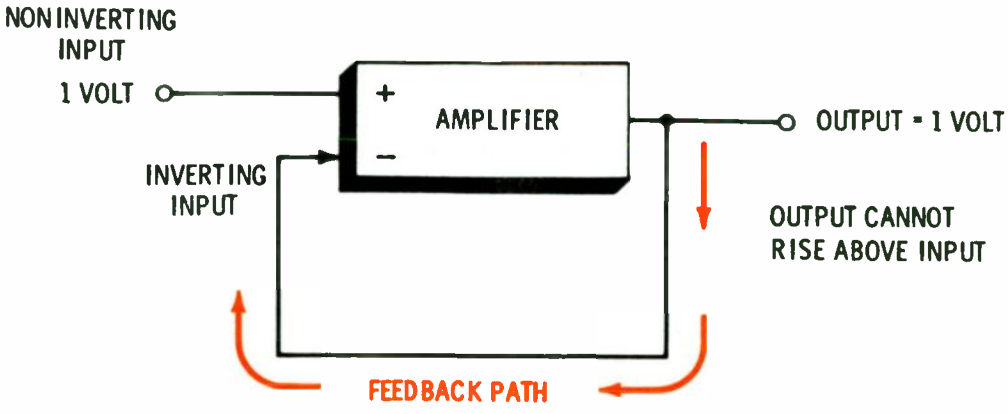


Figure 36 — Feedback amplifier with output connected to inverting input.

and is called a *voltage follower.* Although it does not amplify voltage, it may have *current gain.* That is, the input of the voltage follower is a high impedance which draws very little current from the input device, but the output is a low impedance which can supply power to a low-resistance output device.

Note that the voltage gain of the amplifier before the feedback path is connected is completely unimportant. As long as the amplifier does have gain, as soon as the output is connected to the inverting input, the unit becomes a voltage follower with unity gain. In fact, the higher the gain of the amplifier before the feedback is connected, the more closely it will approach a perfect voltage follower with feedback. Note that the signal flow through the inverting input, the amplifier, the output and the feedback connection form a *closed loop.* This path is shown as the feedback loop in Figure 37. If the feedback path is broken, the amplifier reverts back to its high, (unspecified) *open-loop* gain.

Since many transistor characteristics vary depending on signal levels, temperatures, supply voltage, and other operating conditions, signal distortion in open-loop amplifiers can run as high as 10 to 20 percent. In the voltage follower of Figure 37, you can see that any distortion produced by the amplifier is fedback and cancelled out. The voltage follower is almost distortionless—typically running under 0.01 percent.

A feedback amplifier with a voltage divider connected to the output is shown in Figure 38. The inverting input is connected to the low tap on the divider.

Let us see what happens if *one tenth* of the output voltage is fed back to the inverting input. If 1 volt is applied to the noninverting input, the output will rise to 10 volts. With 10 volts applied to the voltage

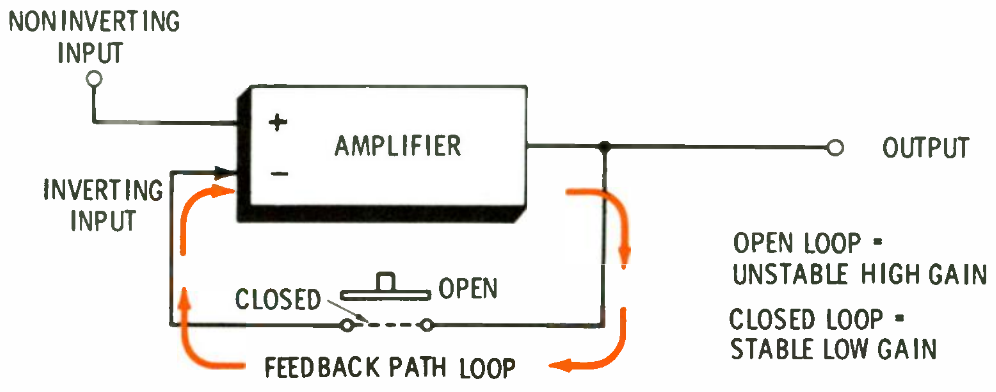


Figure 37 — Voltage-follower circuit.

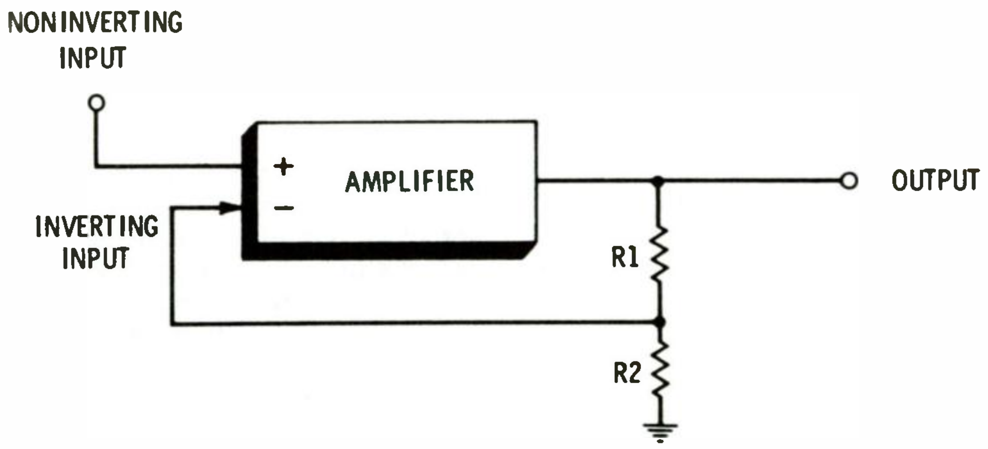


Figure 38 — Feedback amplifier with voltage divider connected to output.

divider, 1 volt will appear at the inverting input, balancing the amplifier exactly as in the case of the voltage follower. To establish any voltage gain, it is necessary to change only the ratio of the feedback voltage divider resistors. Of course, you cannot get more gain than the open-loop gain of the amplifier. Usually, the open-loop gain of a single-stage transistor amplifier does not run above about 5000. To achieve very high gain circuits, it is necessary to use two or more cascaded stages.

POWER AMPLIFIERS

Class-A Amplifiers

Class-A power amplifiers usually consist of a single stage utilizing

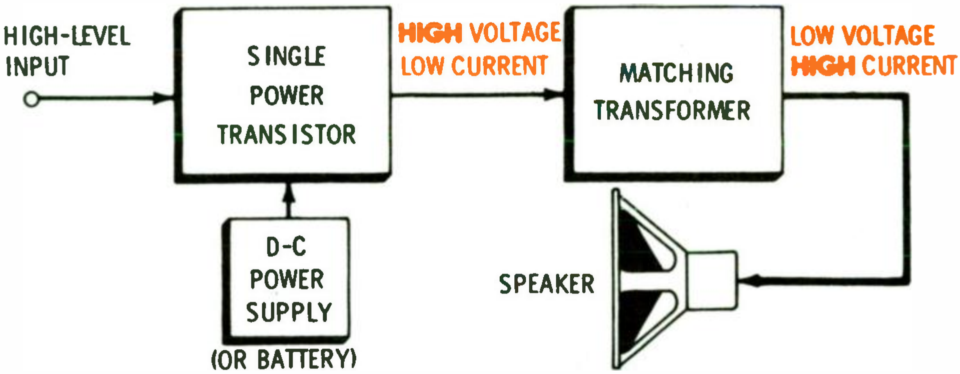


Figure 39 — Typical class-A power amplifier.

one transistor or tube, although higher power applications require two transistors or tubes in push-pull. The amplifier in Figure 39 is a typical automobile radio output amplifier.

Class-A power amplifiers are used whenever heat, high battery drain, and low-output power can be tolerated. The high battery drain is due to the constant amplifier stand-by current, whether or not a signal is present. The low efficiency of class-A amplifiers makes them serviceable only when a low power output is required. An *output transformer* is used to match the impedance of the transistor to the speaker or other output device.

Class-B Amplifiers

A simple class-B amplifier uses a total of three transistors, two of which, in the output stage, are connected in push-pull. This amplifier shown in Figure 40, draws almost no standby power and assures maximum transistor power output. The driver transistor is a low-power stage which provides a small push-pull current to the output stage. As in the class-A amplifier, an output transformer is used for impedance matching.

OUTPUT DEVICES

The output of every audio power amplifier is commonly connected to an *output device* which converts high-level audio signals into sound. These devices are usually ***head sets*** or ***speakers***.

Headsets

Magnetic Headset. The magnetic headset in Figure 41 consists of a thin iron diaphragm held in front of a permanently magnetized pole piece wound with fine wires.

Due to the presence of the permanent magnet, the diaphragm is flexed toward the pole piece. When an audio signal is applied to the pole-piece windings, it causes the strength of the magnetic field to vary. The diaphragm is pulled toward and pushed away from the

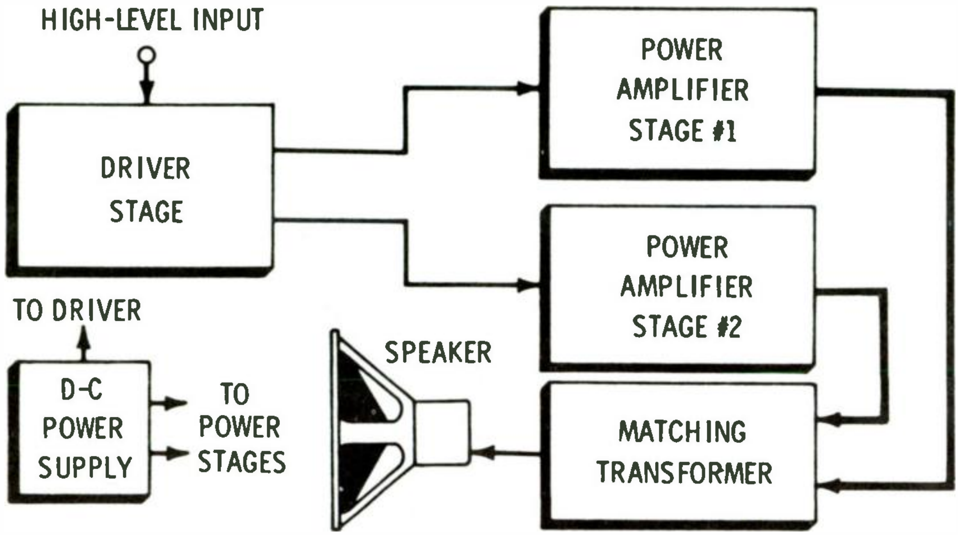


Figure 40 — Typical class-B power amplifier.

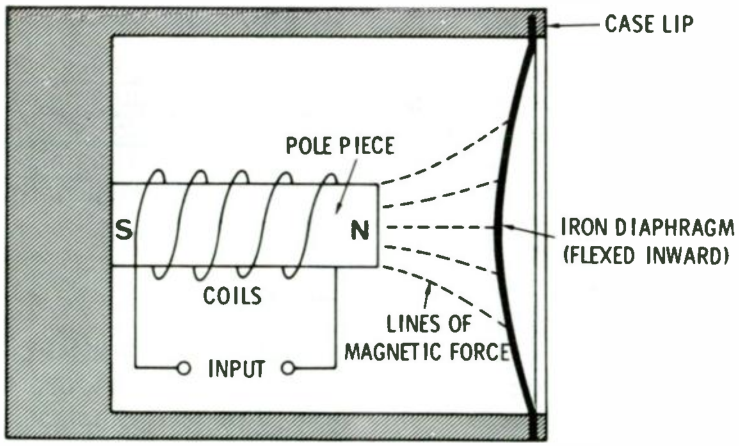


Figure 41 — Magnetic earphone.

pole piece translating the applied signal into audible vibrations. The magnetic headset is a fine general-purpose device for use with the average radio set or audio amplifier.

Crystal Headset. The crystal headset shown in Figure 42 is basically a crystal microphone operating in reverse. If an audio signal is applied to the piezoelectric crystal, the crystal flexes in accordance

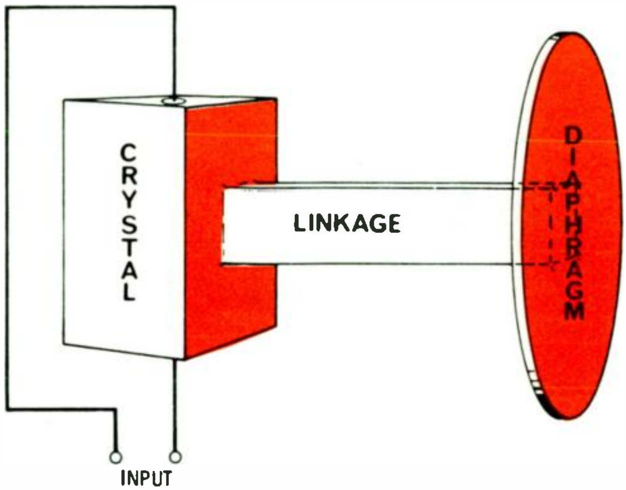


Figure 42 — Crystal earphone.

with the fluctuations in the signal. The vibrations of the crystal are transmitted to the ear by means of a diaphragm. Compared to a magnetic headset, the crystal headset is extremely sensitive, requiring only a very small drive voltage. However, it is considerably more expensive than the ordinary magnetic headset.

Speakers

Permanent-Magnet Speaker. The most widely used speaker is the permanent-magnet type illustrated in Figure 43. This speaker is almost a replica of the dynamic microphone, the main difference being size. Its basic components are a permanent magnet, a *voice coil* suspended in the field of the magnet, and a diaphragm called a *cone,* ranging in diameter from about 2 to 15 inches.

The magnetic field of the voice coil varies with the fluctuations of the applied audio signal, causing the coil to vibrate. These vibrations occur as the polarity of the coil's magnetic field changes with the variations in the signal. The coil is attached to the speaker cone which transmits vibrations of the coil to the surrounding air.

Electrostatic Speakers. The electrostatic speaker shown in Figure 44 is basically a charged capacitor whose metal-foil plates are free to vibrate.

The charge on the capacitor plates fluctuates in accordance with an applied audio signal. These fluctuations vary the amount of attraction between the plates, causing them to vibrate and thus creating sound waves in the air surrounding the plates.

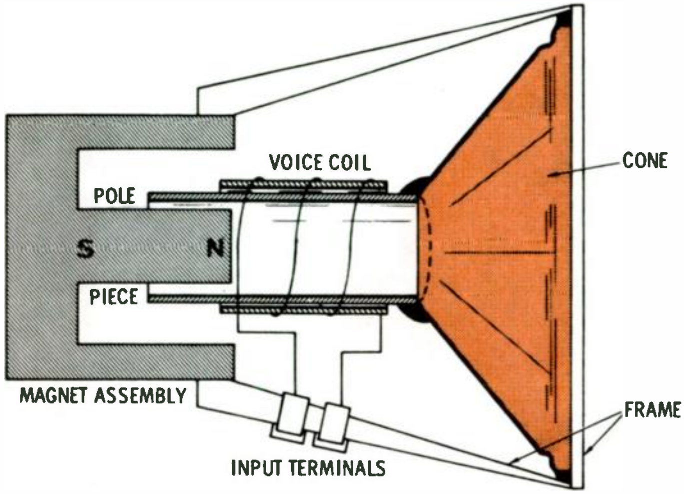


Figure 43 — Magnetic speaker.

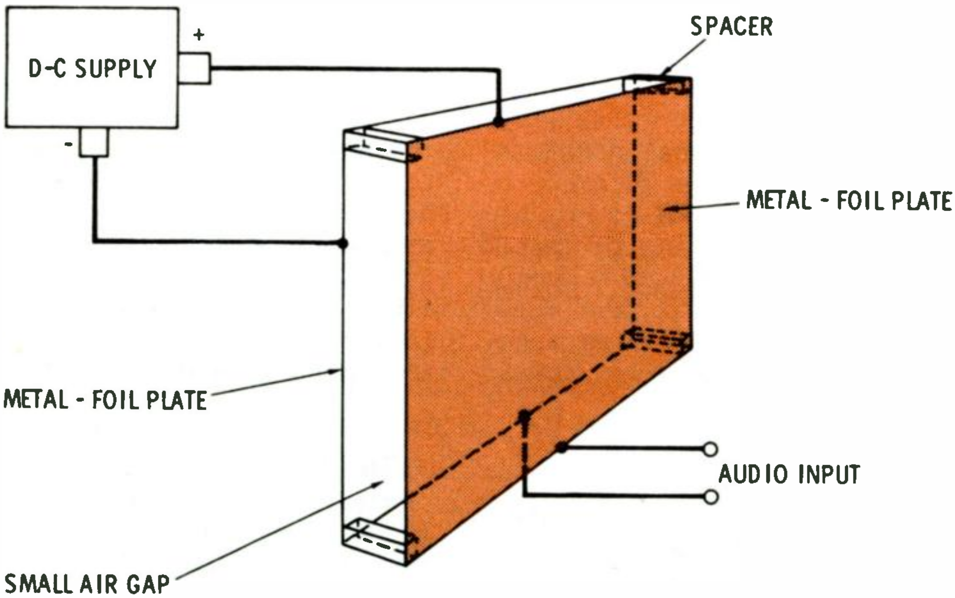


Figure 44 — Electrostatic speaker.

Speaker Systems. Speakers of large diameter cannot vibrate efficiently at high frequencies. In high-fidelity systems, when a natural, balanced sound is desired, a large speaker is used for lows and a small speaker is used for highs. The term *woofer* means a speaker which reproduces low frequencies. A *tweeter* is a speaker which reproduces high frequencies only. A speaker system contains at least one woofer and one tweeter working together in the same cabinet.

TEST

Lesson Number 61

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-061-1.

1. Audio output devices convert ________ signals to sound.
A. acoustical
B. mechanical
33 C. audio
D. RF

2. Speakers receive their driving power from
33 A. the audio power amplifier.
B. RF power amplifiers.
C. IF power amplifiers.
D. none of the above.

3. The incoming signal in a superheterodyne receiver is converted to the intermediate frequency (IF) by the
A. IF amplifier.
4 B. mixer.
C. AF amplifier.
D. RF amplifier.

4. In a superheterodyne receiver most of the gain prior to the detector is supplied by the
4 A. IF amplifier.
B. mixer.
C. RF amplifier.
D. oscillator.

5. In a superheterodyne receiver the audio is removed from the IF by the
A. IF amplifier.
4 B. mixer.
C. 2nd detector.
D. oscillator.

6. **The variable tuning capacitor located in the RF section of the superheterodyne radio receiver tunes the**
   A. AF amplifier.
   B. detector and AF amplifiers.
   18 C. mixer input circuit and the local oscillator.
   D. audio output transformer.

7. **The most commonly used power supply in small vacuum tube table radios is the________type.**
   A. transformer full-wave
   5 B. transformerless half-wave
   C. transformer half-wave
   D. transformer bridge

8. **Portable AM radios normally operate from________power.**
   A. AC/DC
   5 B. transformer
   C. power line
   D. battery

9. **Some exceptionally high quality radios may require very precise voltages from their power supplies; in this case their supplies will be**
   A. electronically regulated.
   10 B. full-wave unregulated.
   C. bridged-unregulated.
   D. half-wave unregulated.

10. **In most receivers a control signal is supplied by the 2nd detector that maintains a constant output unaffected by signal conditions. This control is called**
    A. AFT.
    B. AFC.
    23, C. AVC.
    27 D. ACC.

Portions of This Lesson from
Transistor Fundamentals
by Martin Gersten
Courtesy Howard W. Sams, Inc.

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ORDERING PARTS

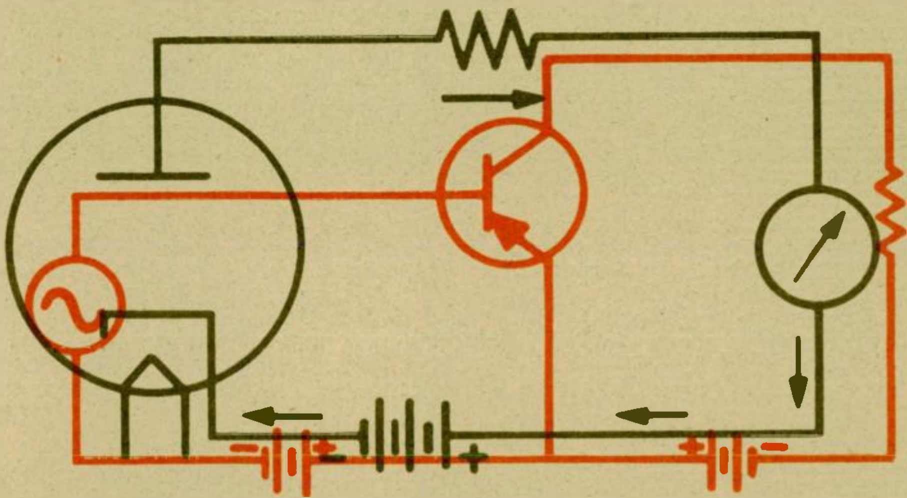
Next time you're ordering replacement parts from the manufacturer or service center don't forget to include the *model* and *serial number* of the unit. You will find this information along with the manufacturer's name and address on the nameplate.

It's always best to give as much information as possible when ordering parts.

S. T. Christensen

LESSON NO. 56

TRANSISTOR TESTERS



RADIO and TELEVISION SERVICE and REPAIR

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CONTENTS

TRANSISTOR TESTERS

INTRODUCTION

There are various practical limitations to the testing capabilities of a transistor checker because, in order to check the condition of a transistor, its characteristics must be measured and compared with its design-center values. Generally, this is an impossible testing requirement because transistors are applied in a wide range of circuit actions, such as rectification, detection, amplification, oscillation, mixing, and modulation. These actions are employed under various temperature conditions, and their characteristics change with temperature. These changes are not the same in the three fundamental configurations, such as common-base, common-emitter, and common-collector arrangements.

Other practical limitations in testing transistors stem from the multiplicity of characteristics in each of the fundamental configurations that provide information concerning device characteristics. For example, collector families of characteristic curves are incomplete, and are necessarily associated with emitter families of characteristic curves, or with base families of characteristic curves. An initial step in the simplification of testing procedures would be to check the transfer characteristic of a transistor. A transfer characteristic shows the relation of collector current to base-emitter voltage. However, we still must contend with a family of transfer characteristics with respect to temperature variations. Moreover, a transfer characteristic is a function of frequency, and this contingency must be contended with if we are to devise a comprehensive transistor tester.

This lesson deals with transistor testers and discusses how each characteristic of a transistor is checked. The material in this lesson explains the relationship that exists between the separate elements of a transistor. It also shows how a change in voltage or current existing at one of the elements causes a change in voltage or current at each of the other two elements. Being able to measure the effect of these changes with a transistor tester will give you insight into how a transistor operates. As an explanation is given of how each of the circuits in a transistor tester operates, you will gain a further understanding of transistor operations.

It is important to know about all of the circuits used in the more advanced transistor testers, but it is not necessary that these expensive testers be used in routine servicing. Some of these testers are used in the design and development of electronic equipment and provide valuable information when used properly. However, service work usually requires a simple transistor tester that will indicate whether a particular transistor is defective and requires a replacement. It is this type of tester that is most valuable for busy servicemen.

TYPES OF TESTS

Two types of simplified transistor tests can be made in routine servicing procedures. One of these is an out-of-circuit test, and the other is an in-circuit test. It is always possible to make an out-of-circuit test, but an in-circuit test is sometimes impractical due to the particular configuration of the circuit. A quick check can be made out-of-circuit with an ohmmeter, with the test being applicable to both small-signal and power-type transistors. This test consists of measuring the resistance between each pair of transistor leads in turn. Forward and back resistance values are noted for each pair of leads. In general, the resistance between emitter and base should be greater than 10,000 ohms in one direction, and less than 100 ohms in the other direction. Similarly, the resistance between collector and base should be greater than 10,000 ohms in one direction, and less than 100 ohms in the other direction.

The resistance between collector and emitter leads depends to a great extent on the fabrication details of the transistor, and generally shows a much smaller front-to-back ratio. For example, a good transistor might measure about 1000 ohms in the forward direction, and approximately 25,000 ohms in the back direction. Note that the resistance values indicated by an ohmmeter will depend considerably on the range that is used, because different ranges apply different test voltages. Since a transistor is a nonlinear device, the voltage/current ratio that is measured depends on the amount of applied voltage. In any case, it is good practice to avoid the R x 1 range of an ohmmeter, because excessive current could flow in an emitter-base test, which might damage the emitter junction.

Resistance Tests

Figure 1 depicts the resistance tests that are made on a small, low power, transistor. If both forward and back resistance values are low in either the collector or the emitter test, the transistor is very leaky or shorted, and should be discarded. If both the forward and the back resistance values are high, the transistor is open and should be discarded. Forward-to-back

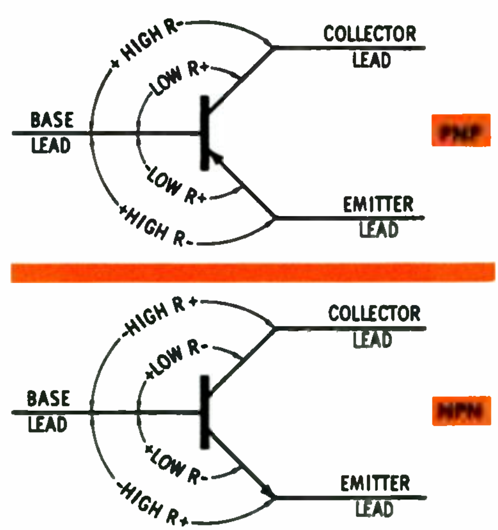


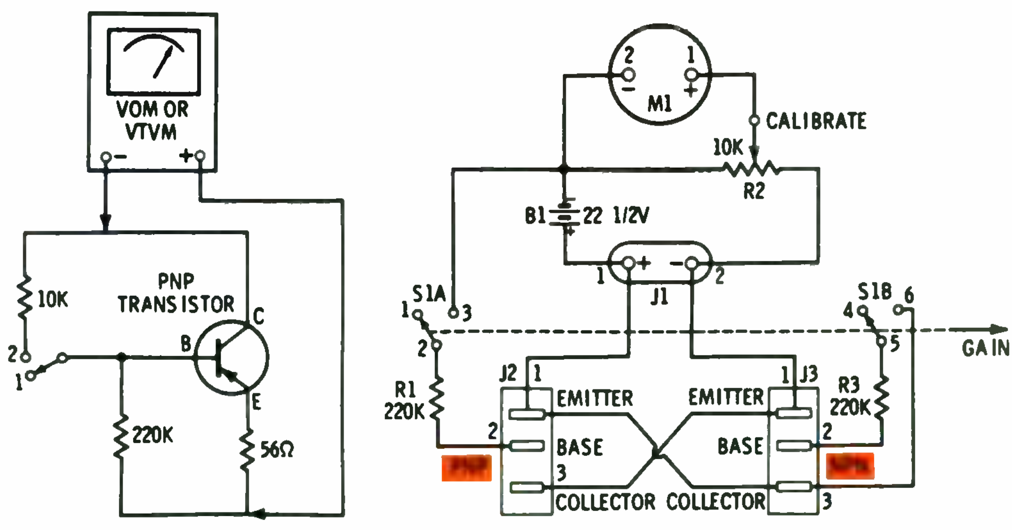
Figure 1 - Comparative ohmmeter readings for typical low-power PNP and NPN type transistor.

resistance ratios for good transistors range from 25-to-1 up to 100-to-1, depending on the transistor type, the ohmmeter type, and the ranges used in the test. In the collector-to-emitter test on a power transistor, a small front-to-back ratio indicates that the transistor is defective.

A more informative ohmmeter test of a transistor is depicted in Figure 2A. This is a test of control action; it requires three resistors in addition to the ohmmeter. The ohmmeter battery is used to power the test circuit, and applies a source potential of about 1.5 volts for the majority of ohmmeters. With the switch in position 1, the current flow is normally very slight, or there may be no visible scale indication. However, with the switch in position 2, the amount of base current is determined chiefly by the 10k resistor. Normally, the current flow is quite appreciable, and the pointer will swing upscale on the ohmmeter. An audio-frequency transistor provides at least eight times as much deflection in switch position 2. If both readings are high, or if both readings are low, the transistor tested is defective.

Note that the ohmmeter test leads must be polarized so that the collector is reverse-biased in Figure 2A. This can sometimes be a tricky point because some ohmmeters have reversed test-lead polarity on the ohmmeter and DC voltmeter functions. In case of doubt, check the polarity of the ohmmeter voltage with another voltmeter. If another voltmeter is not available, consult the instruction manual to determine the test-lead polarity on the ohmmeter function.

A simple commercial transistor checker that employs the foregoing principle is diagrammed in Figure 2B. When the switch is open, the base-



A - Ohmmeter test of transistor.

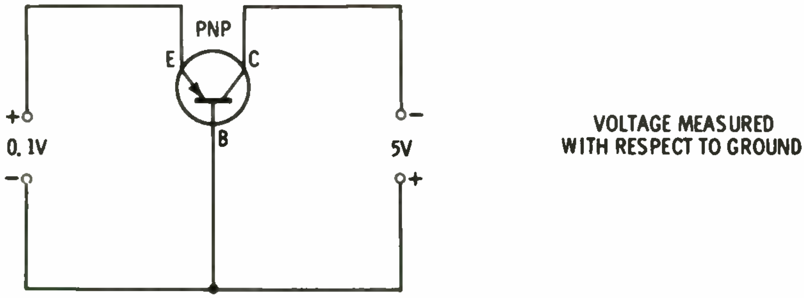
B - Simple transistor and diode checker.

Figure 2 - Checking transistors.

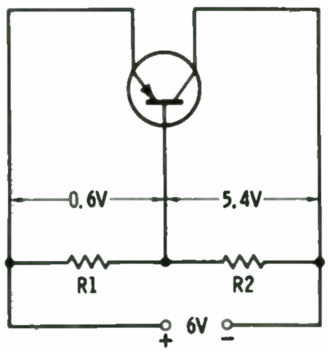
emitter circuit of the transistor under test is open-circuited. Therefore, the only current in the collector circuit and the meter is due to saturation current and leakage current. With a good transistor, this current flow is extremely small. Next, a control-action test is made by closing the switch. This applies a forward bias voltage to the base or a forward current of 100 microamperes. In turn, the current gain is indicated on the meter scale. Semiconductor diodes are checked for front-to-back ratio by inserting the diode leads into J-1.

In-Circuit Tests

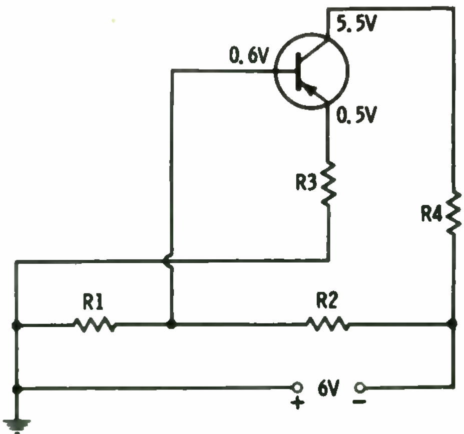
Next, let us consider some simple in-circuit transistor tests. In the basic PNP common-base configuration, the collector voltage is normally negative, and the emitter voltage is normally positive, as shown in Figure 3. The base of the transistor should be negative with respect to the emitter in this example, and the base should be positive with respect to the collector. On the other hand, in the basic NPN common-base configuration, these polarities are reversed. The normal



A-Basic PNP transistor circuit.



B-Biasing with one battery and voltage divider.



C-Postive end of battery is grounded.

Figure 3 - Common-base configuration.

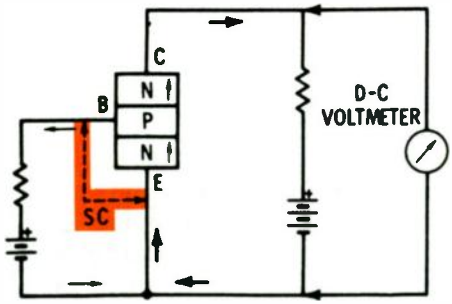
base-emitter bias voltage in Class-A operation depends on the transistor material. Germanium PNP or NPN types carry from 0.1 to 0.4 volt; silicon PNP or NPN types carry from 0.4 to 0.8 volt bias. If the measured voltages are significantly incorrect, it is indicated that the transistor is defective. The foregoing bias voltages apply also to the common-emitter configuration.

Short-Circuit Tests

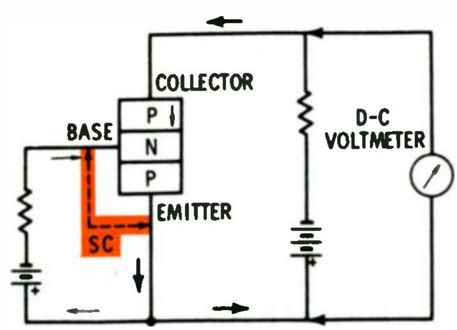
Some configurations lend themselves to a very informative test of transistor control action, as depicted in Figure 4. A DC voltmeter can be connected from collector to emitter in this example, and a short-circuit applied between base and emitter. In turn, if the transistor has normal control action, the collector voltage rises to the supply-voltage value. This is a cutoff test; when the short-circuit is applied, the emitter-base voltage becomes zero. In turn, current flow normally stops through the collector load resistor. Thererore, there is no IR drop across the collector resistor, and we measure the supply-voltage value.

Let us consider the configuration depicted in Figure 5A. A short-circuit test for control action is impractical because a 75k resistor is present betweeen collector and base, and the test would be somewhat inconclusive. However, a limited control-action test can be made. For example, a DC voltmeter can be connected across the collector load resistor. Then, if the 75k resistor is bridged with another 75k resistor, the voltage drop across the collector load resistor will normally increase, and will approximately double in value. This is a limited test because borderline collector-junction leakage is difficult to detect. In comparison, if borderline collector-junction leakage were present in Figure 4, the collector voltage would fall somewhat below the supply voltage in the short-circuit test.

With reference to Figure 5B, a short circuit test of control action is practical because the collector is not connected to the base through a resistor. Therefore, we can connect a DC voltmeter across the collector load resistor, and short-circuit the base to the emitter. If the transistor control

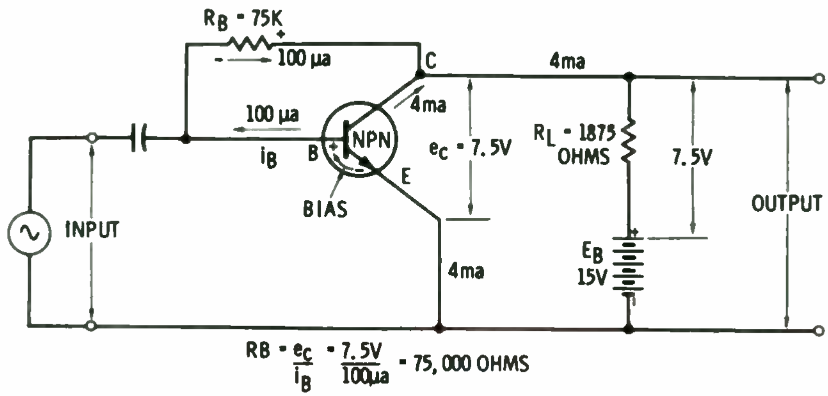


A - In-circuit test of NPN transistor.

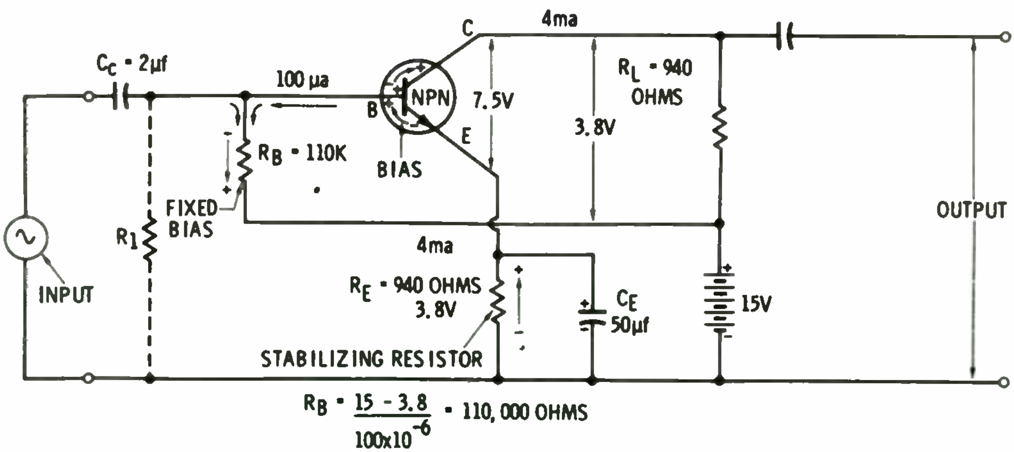


B - In-circuit test of PNP transistor.

Figure 4 - Testing PNP and NPN transistors.



A-Limited control-action test can be made.



B-Control-action test can be made in this circuit.

Figure 5 - Testing NPN transistors.

action is normal, the voltmeter reading drops practically to zero, or may be unreadable. Note that if you use a voltmeter with a low first range, such as 1-volt full scale, you might observe a very small movement of the pointer from zero in this short-circuit test. You may be able to observe the voltage drop produced by saturation current flow through the collector load resistor. If you use a sensitive voltmeter with a ¼-volt full scale indication, you will expect to definitely see the effect of saturation current flow. For example, for a good transistor, you might measure a 2-millivolt drop across R_L.

The amount of voltage drop due to saturation current flow that you measure in the foregoing test will depend, of course, on the value of R_L. For example, if you are testing in a circuit that employs a 4700-ohm load resistor, you will measure about 10 mv for a good transistor. The saturation current is practically constant, regardless of the value of the collector load resistor. Therefore, the voltage drop produced by the load resistance is directly proportional to the resistance value:

$$E = IR_L$$

where,

E is the voltage drop,
I is the saturation current,
R_L is the load resistance.

TUNNEL DIODE TEST

A simple test can also be made for tunnel diode control action, as depicted in Figure 6. This is called a switching test. We set the DC voltmeter to its lowest range, and set the power supply initially at zero volts. Then, we slowly advance the output from the power supply while observing the voltmeter reading. As the applied voltage is increased, the voltmeter will read a very small value. Suddenly, as a critical voltage is reached, the tunnel diode will switch if it is not defective and the voltmeter reading jumps to a value of 0.5 volt in a typical situation. At this time, the variable power supply might be set to about 200 volts.

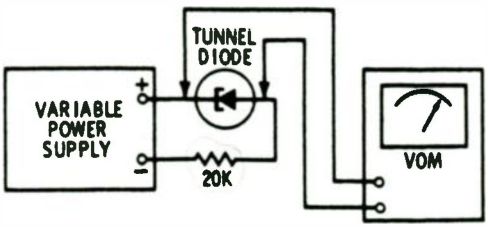


Figure 6 - Testing tunnel diode for switching action.

As the power-supply output voltage is reduced, the voltmeter reading declines slightly until a critical voltage is reached, at which time the tunnel diode suddenly switches back to its former state, and the voltmeter reading falls to a very low value. The principle of the switching test is shown in Figure 7. A tunnel diode is stable and has positive resistance from 0 to P_3. On the other hand, the diode has negative resistance and is unstable

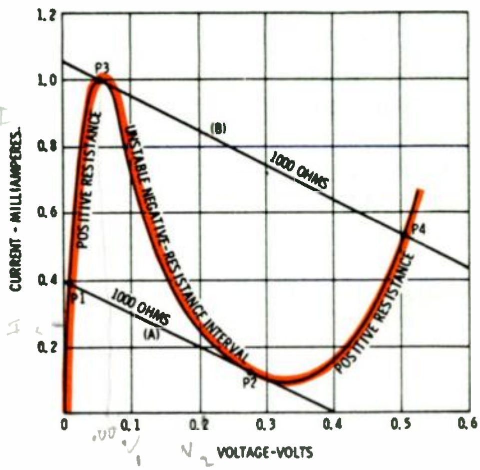


Figure 7 - Current is double-valued function of voltage in this circuit.

(in the test circuit) from P_3 to P_2. From P_2 to P_4 the resistance again becomes positive and stable. When a load line intersects the tunnel-diode characteristic in two points, as in Figure 7, the intersections for stable operation may be either at P_1 and P_2 or at P_3 and P_4.

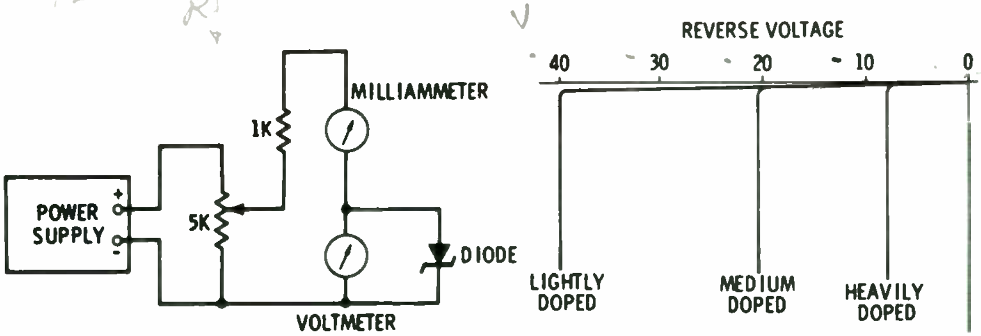
If we increase the supply voltage, with intersections at P_1 and P_2, the load line is forced to intersect the characteristic at three points. Because this is an unstable circuit condition, the circuit switches and the operating points jump to P_3 and P_4. The voltage drop across the diode initially corresponds to P_1; as soon as the diode switches, the voltage drop corresponds to P_4. This is why we first read a very small voltage value, and then read about 0.5 volt after the diode switches. Be careful to observe correct polarity when testing a tunnel diode.

When tunnel diodes are employed as negative-resistance devices instead of switching devices, a low value of load resistance is utilized. In turn, the load line is very steep and it intersects the diode characteristic at only one point. When a load line intersects the negative-resistance interval only, the circuit is stable and negative resistance is developed. Such circuits are used in dip meters and other electronic instruments.

ZENER DIODE TEST

A simple test for a zener diode is shown in Figure 8. The power supply should provide sufficient voltage to check the zener point. For example, if the diode is rated for 8 volts, a 10- or 12-volt power supply is ample. We first set the potentiometer to zero, turn the power on, and then advance the potentiometer, watching the milliammeter reading. As a critical voltage value is reached, the milliammeter will suddenly start to indicate, and will rise rapidly as the voltage is increased. (Be careful not to burn out the diode.) The voltmeter reading indicates the zener voltage. This is a useful test to check for matched pairs of diodes, as well as to determine whether a zener diode may be defective.

Note that if the diode is connected in incorrect polarity, zener action is not observed. The milliammeter will indicate current flow with very small values of applied voltage, for in this case we are merely observing the forward characteristic of the diode. When a zener diode is connected in correct polarity, we apply reverse voltage. Therefore, the current flow is extremely small until the zener point is reached. Therefore, the diode resistance suddenly becomes very low, and the current rises with great rapidity as the applied voltage is increased.



A - Test setup.

B - The zener voltage depends on doping concentration.

Figure 8 - Checking the zener diode.

COMMERCIAL SEMICONDUCTOR TESTERS

Commercial semiconductor testers of the service type are often designed as individual instruments, but they can be built into combination instruments that also test tubes. A typical semiconductor tester measures the following parameters: ICBO (collector cutoff current flow), AC *beta* (small-signal current-transfer ratio at 1-kHz), DC *beta* (DC current-transfer ratio), three collector-leakage currents (I CEO, ICES, and ICBO), VCE (sat) (collector-saturation voltage), and the AC input impedance at a given operating point. Let us see what these various terms mean, and how their values are measured.

ICBO Test

In an ICBO test, a reverse voltage is
7 applied between the collector and base of a transistor, as shown in Figure 9. The emitter is open-circuited in this test. A meter is connected in series with the collector to indicate the ICBO current flow. The meter has a full-scale value of 100 microamperes. To measure small values of ICBO, the meter is not shunted. However, shunts are provided for full-scale value of 1 ma and 10 ma to measure larger values of ICBO. A PNP transistor is depicted in Figure 9; if an NPN transistor is to be tested, the supply voltage is reversed in polarity. Application of an incorrectly polarized test voltage will result in a heavy current flow that could damage the meter. Or if the transistor is defective, meter damage could result. Therefore, it is common practice to provide diode protection for the meter, as shown in Figure 10.

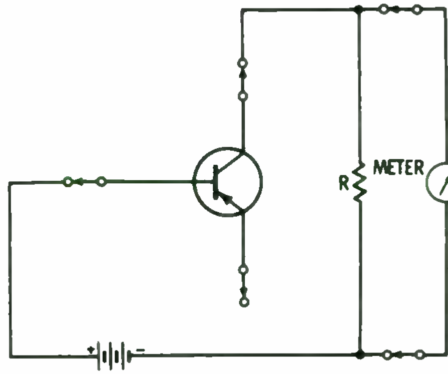


Figure 9 - Basic ICBO test circuit.

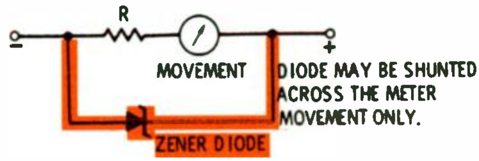


Figure 10 - Meter is protected by overload diode.

The value of the test voltage in Figure 9 is not at all critical. The reason for this is that we are measuring saturation current. Saturation current does not obey Ohm's law in the way that current flow through a resistor obeys Ohm's law. Saturation current is due to charge carriers that are thermally generated in the collector-junction region of the transistor. Application of a fairly small reverse voltage sweeps out all of the charge carriers as fast as they are generated. Therefore, the current value is saturation-limited, and we do not measure a higher current value if a higher voltage is applied.

Saturation current increases rather rapidly with temperature. Therefore, if we warm the transistor by holding it between our fingers, the value of ICBO will increase in the test shown in Figure 9. Both semiconductor diodes and transistors have this thermal characteristic. Figure 11 shows how the reverse current of a silicon diode increases with temperature. Note that reverse current flow across a junction may consist of both saturation current and leakage current, if the junction is leaky. Therefore, if a test indicates excessive reverse current flow, the junction leakage is appreciable.

ICEO Test

Next, let us consider the ICEO test depicted in Figure 12. Saturation current is measured between collector and emitter, with the base open. This test normally gives a higher current reading than an ICBO test because the saturation current that flows through the base-emitter junction is stepped up by the beta value of the transistor. The transistor operates as a DC amplifier for the saturation current in an ICEO test. Of course, if the base should short-circuit the emitter due to an emitter-junction defect, we will read the same current values in both the ICBO and the ICEO tests.

ICES Test

To make an ICES test, the same arrangement is used as shown in Figure 12, except that the base is

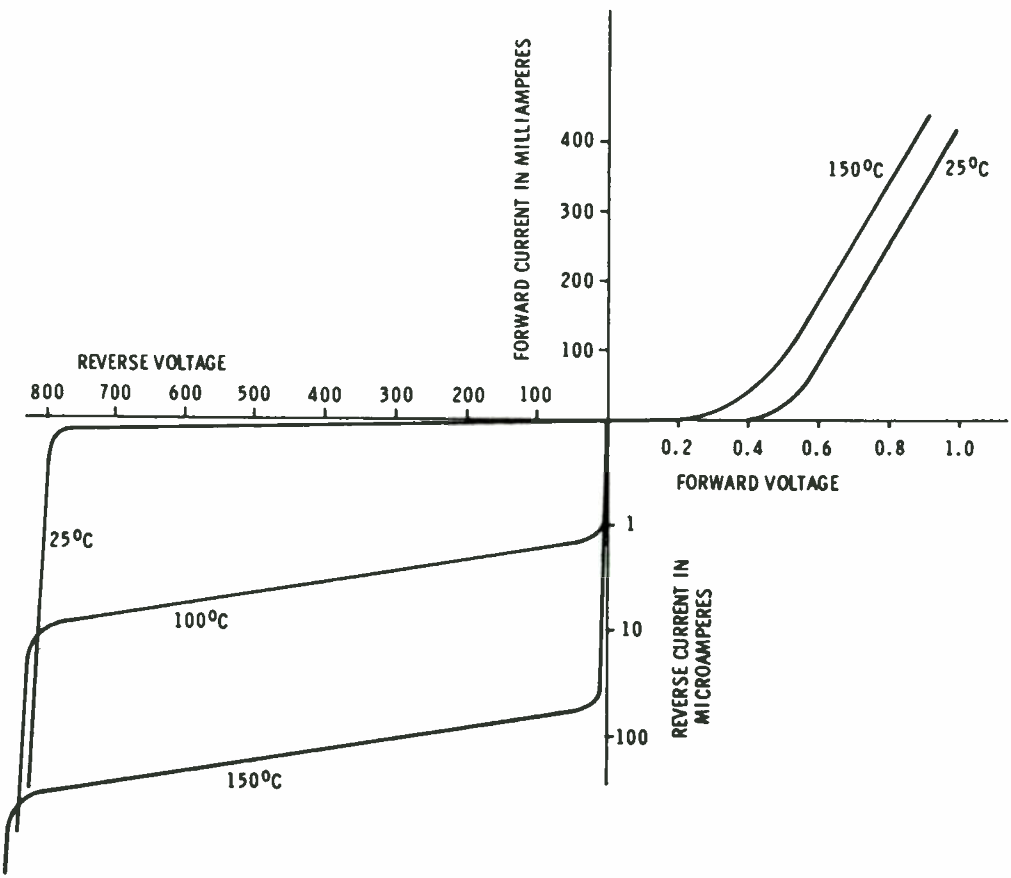


Figure 11 - Temperature effects on typical silicon diode.

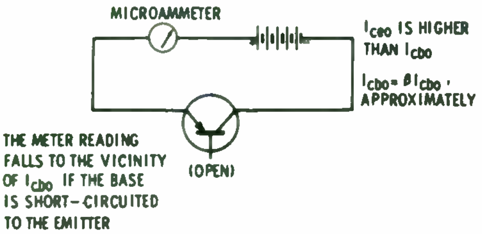


Figure 12 - ICEO test circuit.

short-circuited to the emitter. As previously noted, these tests do not break down the current indication into its saturation and leakage components. Actually, we are measuring the value of the saturation current plus the leakage current. Maximum permissible values of ICBO, ICEO, and ICES are specified for various types of transistors, and if the measured current value is excessive, the transistor is rejected.

VCE (sat) Test

Next, let us see how VCE (sat) is measured. This term refers to the value of collector voltage at which the transistor goes into collector saturation. Figure 13 depicts a typical collector saturation region. Note that the characteristics drop and fall off to zero at very low values of collector voltage. The current at which the characteristics level off is measured in the test circuit shown in Figure 14. A meter is connected in series with a collector load resistor to measure the collector current. A fixed forward bias voltage is applied to the base. Adjustable collector voltage is applied through a resistor. As the value of collector voltage is increased, the collector current rises steadily at first, and then levels off as the saturation

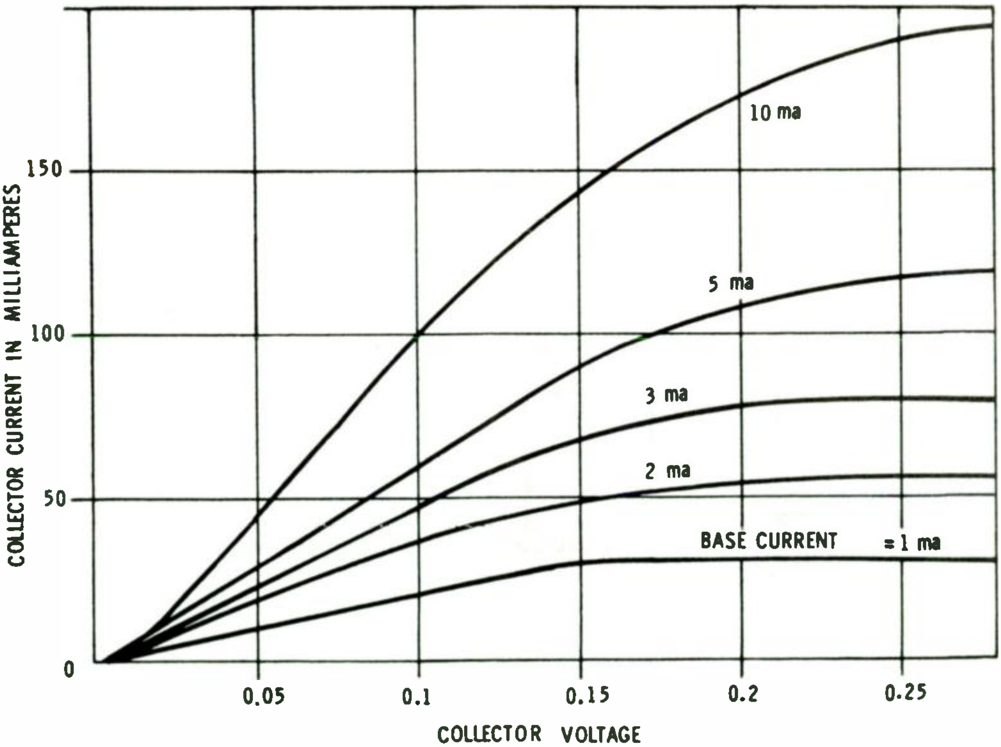


Figure 13 - Typical collector saturation characteristics.

region is passed. This is the first step in the test.

With the collector supply voltage set at the edge of the saturation region, the meter in Figure 14 is then switched to indicate the voltage between collector and emitter. Since this is a current meter, it is switched across a suitable value of resistance; the meter is also calibrated in volts, and in this second part of the test it is used to measure the collector voltage. In turn, we measure the value of V_{CE} (sat) illustrated in Figure 15. This test shows whether a transistor has suitable saturation characteristics for use in a forward agc circuit. If a transistor is leaky, V_{CE} (sat) will be out of rated limits.

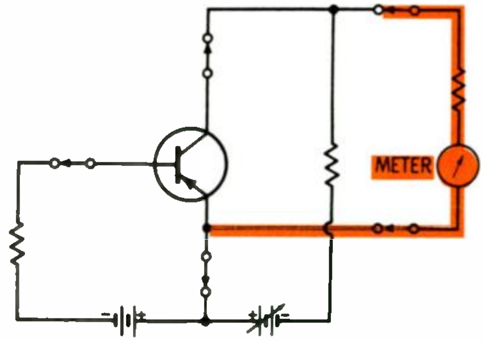


Figure 14 - Collector saturation-current test configuration.

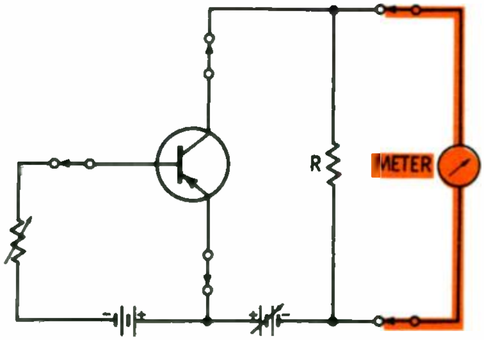


Figure 15 - Test circuit for measuring bias V_{CE} (sat).

AC Beta Test

Next, let us consider an AC *beta* test. Since a transistor is a nonlinear device, the AC current gain usually has a different value from the DC current gain, as previously explained. We generally find that the DC *beta* and AC *beta* values are different, unless the DC *beta* is measured over a comparatively small interval. An accurate AC *beta* measurement can be made by applying a calibrated 1-kHz drive voltage in the test circuit shown in Figure 16. This is the test frequency most commonly employed in AC *beta* specifications. The AC *beta* calibration control is typically adjusted for 1 volt peak-to-peak input. Of course, the drive voltage to the base is less, in accordance with the value of series resistance that is employed.

Since a rather high value of series resistance is employed in Figure 16 between the oscillator and the base of the transistor, we are using essentially a constant-current source. This means simply that the current flow remains practically constant in spite of variations in base-emitter junction resistance. A typical test current value is 5 microamperes. This base current, of course, causes a collector-current flow which is *beta* times greater than the 5 μa test current. To measure this AC collector current, resistor R is switched in series with the collector. In turn, the output from the AC bridge amplifier is rectified and fed to the meter, which is calibrated in AC *beta* values.

The bridge amplifier in Figure 16 provides stabilization against drift, as well as current amplification. It also

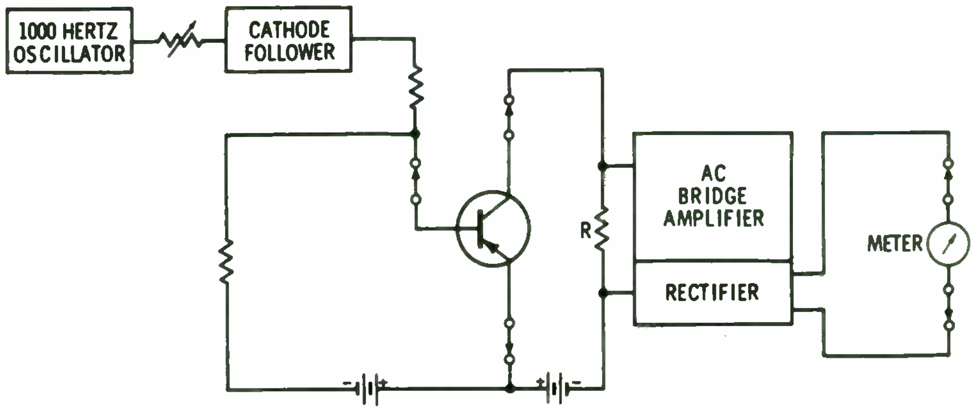


Figure 16- AC beta measuring circuit.

blocks passage of direct current, so that the meter indicates alternating current only. Amplification is required to read low values of AC *beta* accurately by avoiding small current flow through the rectifier. That is, when amplification is provided, the rectifier operates at a higher level over its comparatively linear region. Also, amplification avoids the necessity for using a meter with extremely high current sensitivity.

A typical DC *beta* and DC *beta*-calibration test circuit is depicted in Figure 17. The DC *beta* value of a transistor is defined as the ratio of collector-current change to a given base-current change. Note in Figure 17 that the measurement depends on the relative values of the base and collector resistors R1 and R2. That is, the R2/R1 ratio is established to correspond with the DC *beta* scale on the meter. Preliminary calibration is made by measuring the voltage drop across R1. We adjust R3 to a reference point marked on the meter scale. The meter is then switched from the calibration position to the DC *beta* position. In turn, this simple procedure provides a measurement of the DC *beta* value.

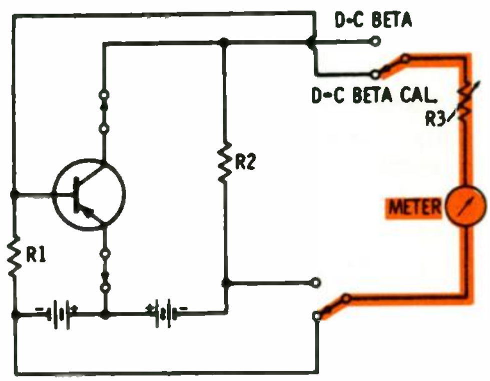


Figure 17 - DC beta test circuit.

The AC *beta* test depicted in Figure 16 can also provide a measurement of the transistor input impedance at 1-kHz. A simple auxiliary circuit is employed, consisting of a 100-mfd capacitor in series with a 10k potentiometer. This RC circuit is connected between emitter and base of the transistor. A preliminary *beta* measurement is made with the RC circuit disconnected. Then, another measurement is made with the RC series circuit connected to base and emitter. The 10k potentiometer is adjusted to reduce the original *beta* reading to one-half. Finally, the potentiometer resistance is read with an ohmmeter, and this resistance value is equal to the base input impedance. The capacitor is used merely to block DC flow.

IN-CIRCUIT TRANSISTOR TESTERS

We have seen that various circuit configurations lend themselves to an in-circuit short-circuit test of transistor control action. On the other hand, we find circuits that cannot be tested in this manner. Most transistor portable radios and television receivers employ transistors that are directly soldered into the circuit, usually on printed-wiring boards. Removal of a transistor for testing is a nuisance, not only because unsoldering is inconvenient, but also because transistors and PC boards are easily damaged by heat or physical force during the unsoldering operation. Although DC voltage measurements are valuable, they are not always entirely conclusive. Therefore, various in-circuit transistor testers have been made available.

Several of the front-panel controls in a transistor tester have calibrations and functions that may not be immediately obvious. The purpose of each control and the test functions can be best understood by a brief summary of the operating procedure. To achieve good accuracy, an in-circuit tester must take into account the shunting action of the transistor circuitry. Several preliminary steps are performed before the current gain of the transistor is measured. Current flow through any external shunt path between transistor elements must be subtracted from the indicated collector circuit current to obtain the true collector current of the transistor.

To perform this subtraction, the following procedure is used. After setting the tester for PNP or NPN polarity, and setting the collector test voltage to a specified value, such as 1.5 volts, the Ic (collector-current) control on the tester is turned to minimum, which cuts off collector current through the transistor. The three test leads are connected to the transistor electrodes, and the tester effectively short-circuits the base and emitter of the transistor so that any current that flows in the collector circuit is due solely to the shunt resistance present in the circuit. Therefore, the reading on the Ic scale is the shunt current that flows in the circuit.

Next, the Ic control (Fig. 18) is turned up so that emitter-base current flows due to the applied forward bias voltage. For small-signal transistors, the Ic control is advanced sufficiently to increase the Ic reading by 1 ma. This 1 ma is, of course, flowing through the transistor. Note that a power transistor may require a higher current setting. The shunt impedance across the base-emitter terminals is measured next with the test circuit shown in Figure 19. The selector switch is set to the Z-ohms position, and the *beta*-calibration control is advanced to make the AC voltmeter read at half-scale. Then, the Z-ohms control is adjusted for a minimum deflection, or null. The scale on the Z-ohms control now reads the shunt-

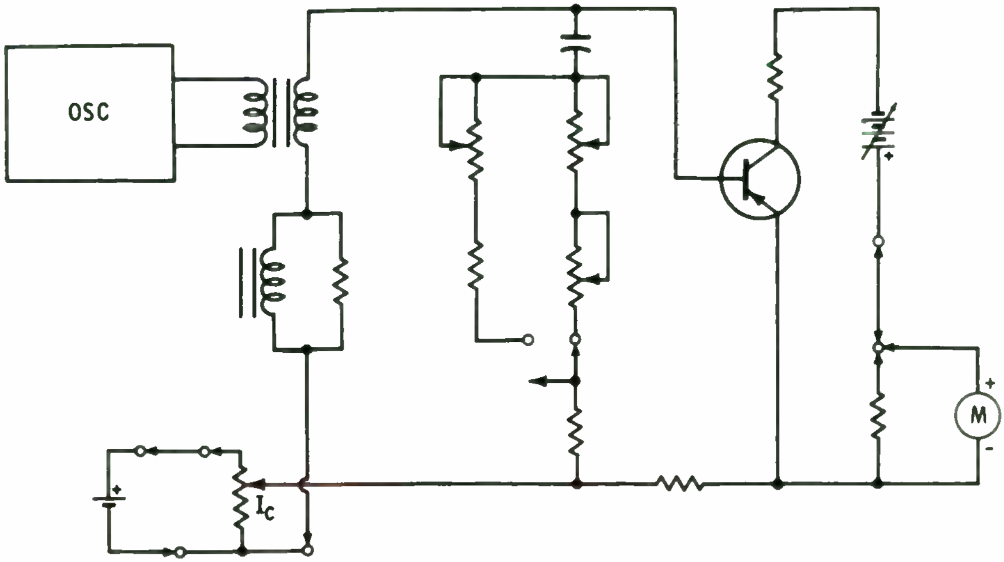


Figure 18 - Ic test circuit.

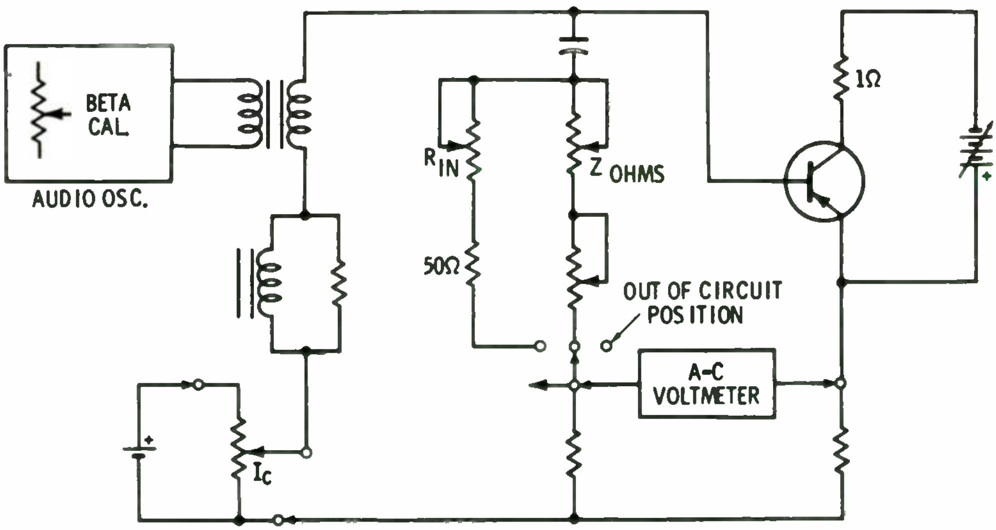


Figure 19 - Z-ohm test circuit.

impedance value of the circuit. Note that the transistor is reverse-biased in this test.

Note in Figure 19 that a bridge circuit is employed. The Z-ohms control (initially set to zero) is in one arm of the bridge. The other resistance in this arm is a maintenance control. After calibration to the center-scale reference point, the Z-ohms control is advanced to make the resistance in the arm equal to the base-emitter impedance. At this point, the AC voltmeter indicates zero because the bridge is balanced. Of course, the scale on the Z-ohms control indicates the value of the circuit resistance because the transistor is reverse-biased. The next step is to measure the input resistance of the transistor itself. The selector switch is set to the RIN position, which provides the test circuit depicted in Figure 20. When the RIN control is adjusted for a null (minimum) reading on the voltmeter, the RIN dial reads the input-resistance value. This provides the basis for measurement of the transistor *beta* value. Note that the transistor is forward-biased in this test.

We observe in Figure 20 that the RIN branch represents the input resistance of the transistor, and the ZOHMS branch represents the circuit resistance. To measure the *beta* value, the selector switch is turned to its *beta* calibration position. In turn, the *beta* calibration control is adjusted to deflect the voltmeter to a reference mark. Then, the selector switch is set to its *beta* position, and the *beta* value is indicated on the meter scale. In the *beta* calibration and *beta* measurement procedure, the test circuit is the same as in Figure 20, except that the meter is first connected across the 50-ohm calibrating resistor, and then across the 1-ohm resistor. The meter indicates the reference current flowing into the base of the transistor, and then indicates how many times this

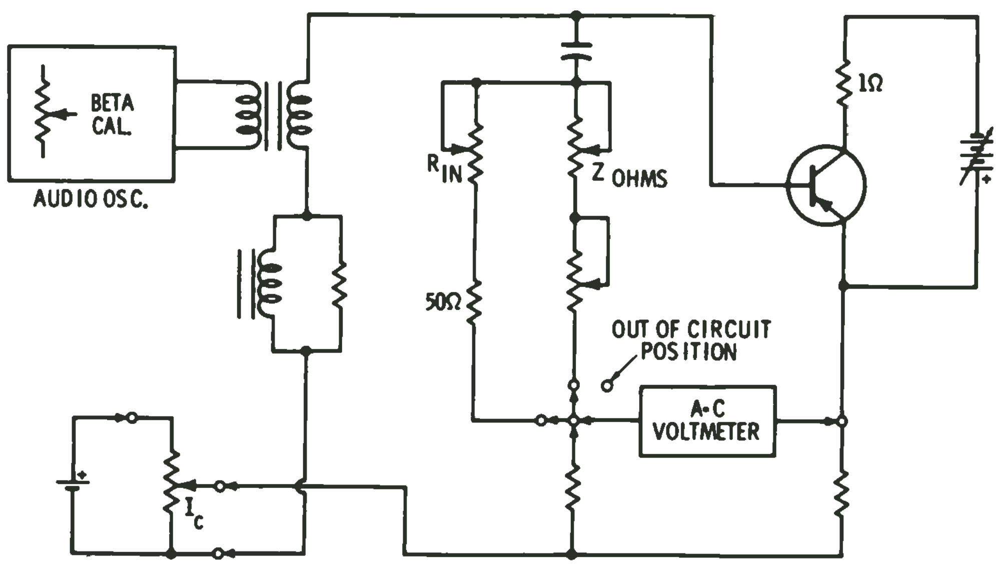


Figure 20 - RIN test circuit.

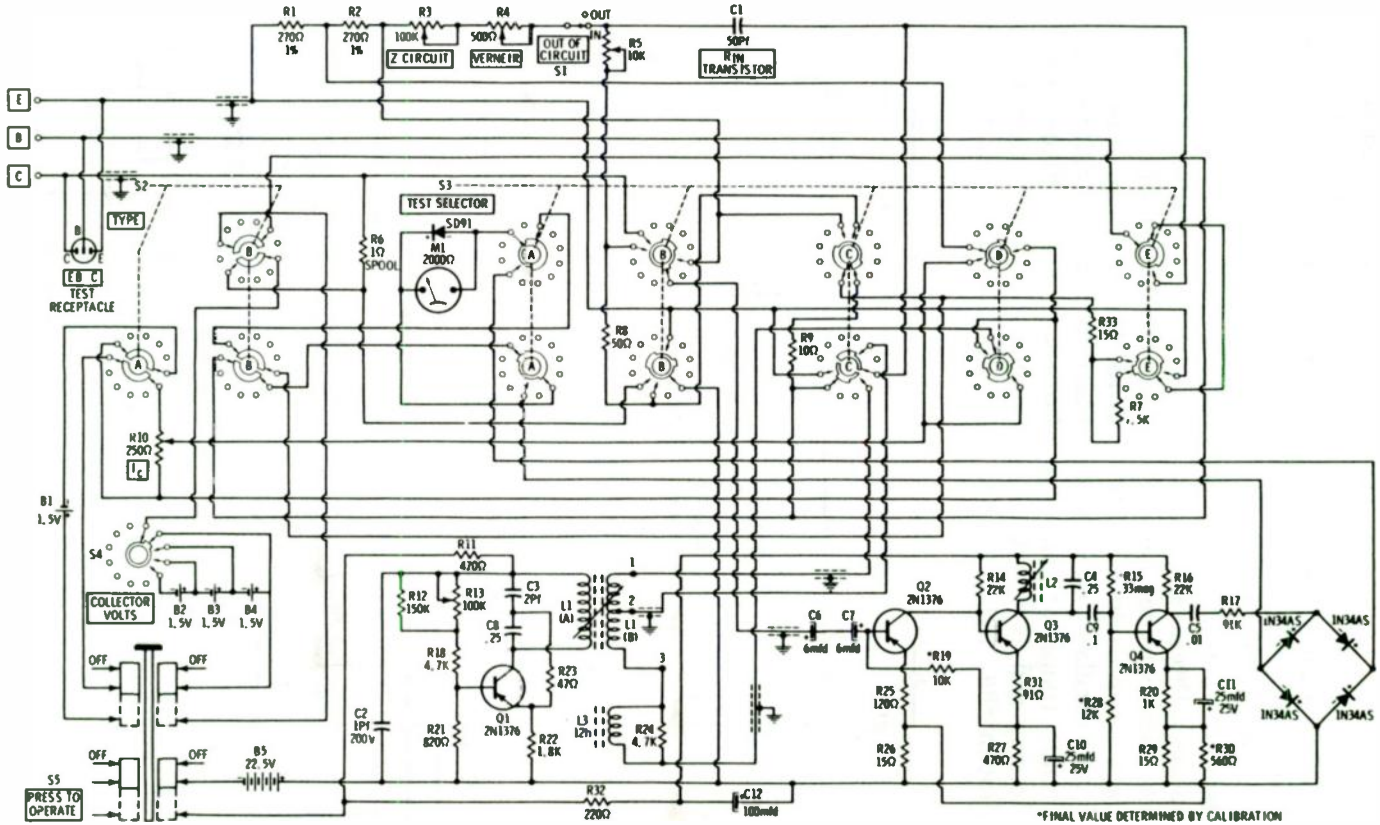


Figure 21 - Complete circuit diagram for in-and-out-of-circuit transistor tester.

current is stepped up by the transistor.

The foregoing in-circuit check is combined with out-of-circuit test functions in the configuration depicted in Figure 21. The AC voltmeter circuit comprises a three-stage transistor amplifier with considerable negative feedback to provide stability. The 1-kHz audio oscillator consists of a tuned circuit, transistor, and its associated biasing and feedback networks. Although the circuit for the complete tester appears complex, its operation can be followed by reviewing the out-of-circuit and in-circuit tests that have been described.

Another type of in-circuit tester is depicted in Figure 22, which is a combination instrument that provides conventional out-of-circuit test functions, plus an in-circuit oscillatory test function. The in-circuit test configuration is shown in Figure 23. An LC feedback oscillator network is connected to the transistor, which is

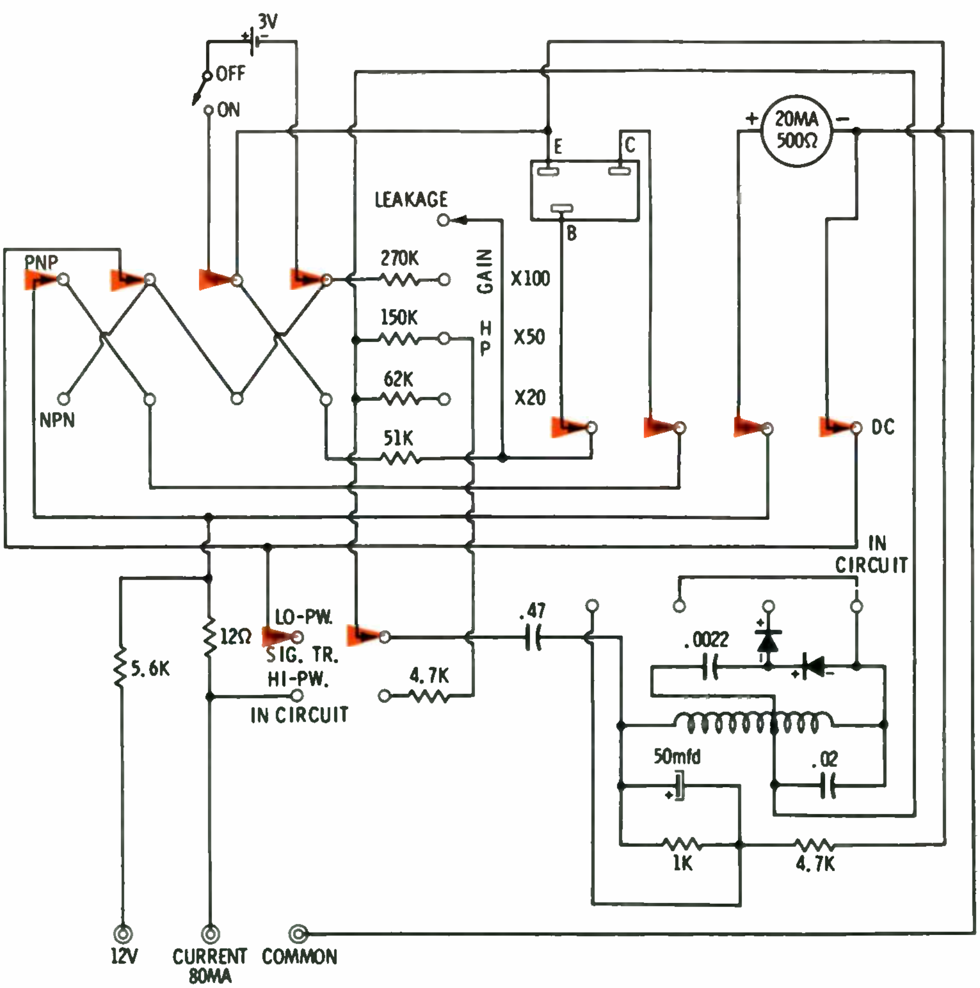


Figure 22 - Oscillator-type transistor tester for in-circuit checking.

biased by its associated circuit. If the transistor has normal gain, the network causes oscillation, provided the associated circuit does not have unusually low impedances. Oscillation causes an AC voltage to be generated between the emitter and collector terminals of the tank circuit; this AC voltage is fed to a voltage-doubler rectifier and indicated by the meter. This is a go/no-go type of test.

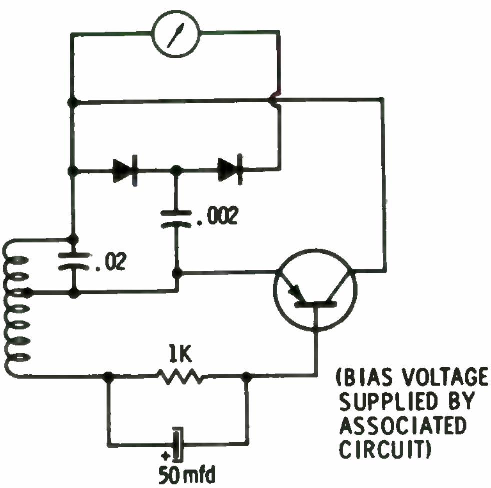


Figure 23 - Configuration of oscillator-type in-circuit transistor tester.

SUMMARY

Transistor checkers are designed to test transistors both in-circuit and out-of-circuit. The test values of a transistor being checked in-circuit will be affected by the components associated with it. Thus the out-of-circuit test is easier to make.

The resistance between the collector and emitter should be greater than 10,000 ohms in one direction and less than 100 ohms in the other direction. Similarly, these same resistance values should exist between the emitter and the base. These tests can be made with an ohmmeter. Tests that check the current gain of a transistor usually are made on a tester designed for this purpose.

Transistor testers generally provide a circuit to test diodes. The procedure for testing a tunnel diode can be conducted using a variable voltage supply and a voltmeter. The same general test procedure can also be used to check a zener diode.

The larger types of commercially built semi-conductor testers usually cover the entire range of transistor characteristics. The testers will give values of *beta*, collector leakage current, collector saturation voltage, and AC input impedance. Testers used in service work are simpler as they are only required to determine whether a transistor is defective.

TEST

Lesson Number 56

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-056-1.

1. The resistance between the collector and emitter leads
   A. cannot be determined with an ohmmeter.
   B. always shows a much smaller back-to-front ratio.
2 —C. shows a much smaller front-to-back ratio.
   D. is always equal in the forward and the backward direction.

2. When the forward and back resistance tests are low or have about the same value in both directions, the transistor should
2 —A. be replaced.
   B. be considered good.
   C. have these low values.
   D. be used in another set.

3. The commercial tester in Figure 2B is designed to indicate the
   A. saturation current.
   B. leakage current.
4 C. current gain, after biasing the base.
   — D. all of the above.

4. Figure 7 shows that a tunnel diode has a
   A. negative voltage characteristic.
   B. uniform resistance of 1000 ohms.
7 C. continually increasing resistance.
   —D. positive resistance characteristic at low and high voltages, with a negative resistance region between the two.

5. The resistance characteristics of the tunnel diode plotted in Figure 7 indicate the tunnel diode is

- A. stable and has a positive resistance from O to P_3.

7 B. stable and has a positive resistance from P_3 to P_2.

C. unstable and has a negative resistance from O to P_3.

D. unstable and has a negative resistance from P_2 to P_4.

6. A zener diode is a two-element rectifier that

A. increases its resistance gradually.

B. decreases its resistance gradually.

8 C. maintains its high resistance until the critical voltage is reached.

D. always indicates a high value of current flow under test.

7. An I_{CBO} test of a transistor applies

A. an AC voltage only.

9 B. a DC voltage of either polarity.

C. a reverse voltage between the collector and the base.

D. a reverse voltage between the collecter and the emitter.

8. The I_{CES} test of a transistor is similar to the I_{CBO} test with the exception that the I_{CES} test checks the

A. current flowing through the base.

10 + 11 B. voltage between the collector and the emitter.

C. current flowing from the collector to the emitter.

D. current flowing from the base to emitter.

9. The value of *beta* indicated on a transistor tester is

A. the collector current divided by the base current.

B. the collector current divided by the emitter current.

C. the ratio of the emitter current to the collector current.

D. applicable only to silicon type transistors.

10. In-circuit testers can

A. always give foolproof results.

14 B. check a transistor as accurately as an out-of-circuit tester can.

C. give a true test of a transistor without any allowance for the effect of components connected in parallel with it.

D. give a reasonable indication of the condition of a transistor if proper allowance is made for its location in the circuit.

Notes

Notes

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Portions of this lesson from
Know Your Tube and Transistor Testers
by Robert F. Middleton
Courtesy of Howard W. Sams, Inc.

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

EXTRA SOMETHING

There are many things to consider if you are planning to have your own business—capital, site, partners, attitude, etc. Your attitude toward prospective customers warrants careful consideration.

While a customer may not understand the work you are doing, he will always recognize good service.

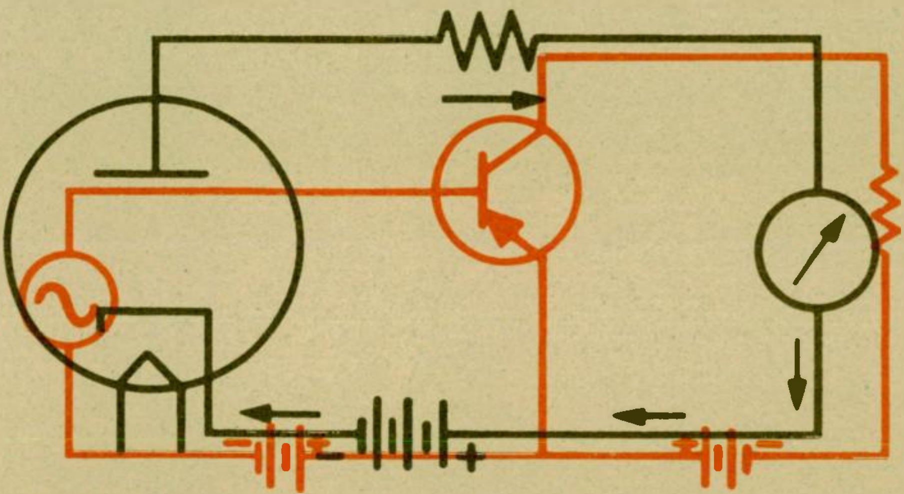
Your customer knows the difference between "good" service and "get-by" service. The thing that will keep him coming back time and again is that extra something in job performance, courtesy extended, and recognition of his problem.

Give that little *extra something* in your service!

S. T. Christensen

LESSON NO. 57

TUBE TESTERS



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CONTENTS

TUBE TESTERS

INTRODUCTION

Tube testers are necessary in service work because of the very large number of tube types that are in common use. Although the ultimate test of a tube is a performance check in a receiver or other equipment, this is often impractical. A service-type tube tester is necessarily limited, because it cannot simulate functional parameters of high- and low-frequency circuits, high- and low-voltage circuits, high- and low-impedance circuits, high- and low-power circuits, and so on. Therefore, the design of a service-type tube tester is at best a judicious compromise.

The fundamental requirements for a tube test include indications for shorts, leakage, gas current, grid emission, cathode emission, transconductance, and power output capability. A screen-grid knee test and a plate-cutoff test are often considered to be included among the fundamental requirements. All tube testers provide at least limited facilities for adjusting the test voltages applied to the tube. Most testers are arranged to supply accurate voltages to filaments or heaters. Provision is frequently made for checking individual elements for open circuits. Some tube testers provide a performance test at reduced heater voltage (life test). However, the most accurate prediction of tube life is provided by checking mutual-conductance (G_m) values at regular intervals, such as one or two months. When the G_m of a tube starts to drop off noticeably, we know that it is nearing the end of its useful life, although it will provide a reasonable amount of future service.

If a tube passes the basic test, it is probably satisfactory for application in any conventional circuit. On the other hand, it could still refuse to operate in certain critical circuits, such as a multivibrator oscillator configuration. If a tube fails to pass the basic tests, it is definitely defective and should be rejected.

TEST CIRCUITRY

All tube testers provide an initial checkout for interelectrode short-circuits or leakage. A typical test circuit is shown in Figure 1. The .05-mfd capacitor has a reactance of approximately 50,000 ohms at 60

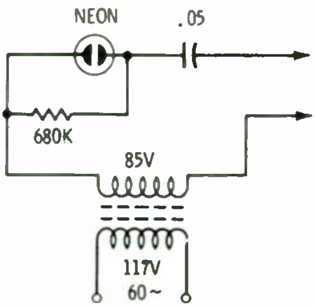


Figure 1 — Short-and-leakage test circuit.

Hz. It forms a voltage divider in combination with the 680k resistor. Accordingly, the sensitivity of the leakage test is determined by the relative values of the series capacitor and shunt resistance. It is easy to check the sensitivity of the leakage test. Simply insert the leads of a fixed resistor (or potentiometer) in the socket, and determine the maximum resistance that will make the bulb glow. If you wish to change the sensitivity of the leakage test, replace the 680k resistor (Fig. 1) with a higher or lower value. A typical leakage sensitivity is .25 megohms, with considerable variation among different types of testers.

Some tube testers provide an ohmmeter scale to measure leakage resistance. A typical configuration is depicted in Figure 2. The source voltage of 85 volts rms is rectified and filtered to produce a 120-volt DC supply for the ohmmeter circuit. A single resistance range is provided to indicate leakage values from 0 to 10 megohms. Leakage tests are made with the heater of the tube at operating temperature, because leakage which is thermally responsive, sometimes disappears when the tube is cold. A calibration

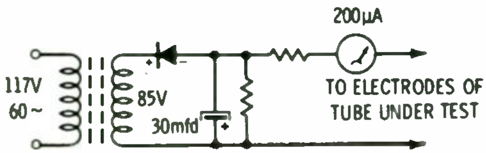


Figure 2 — Meter indicates shorts and leakage.

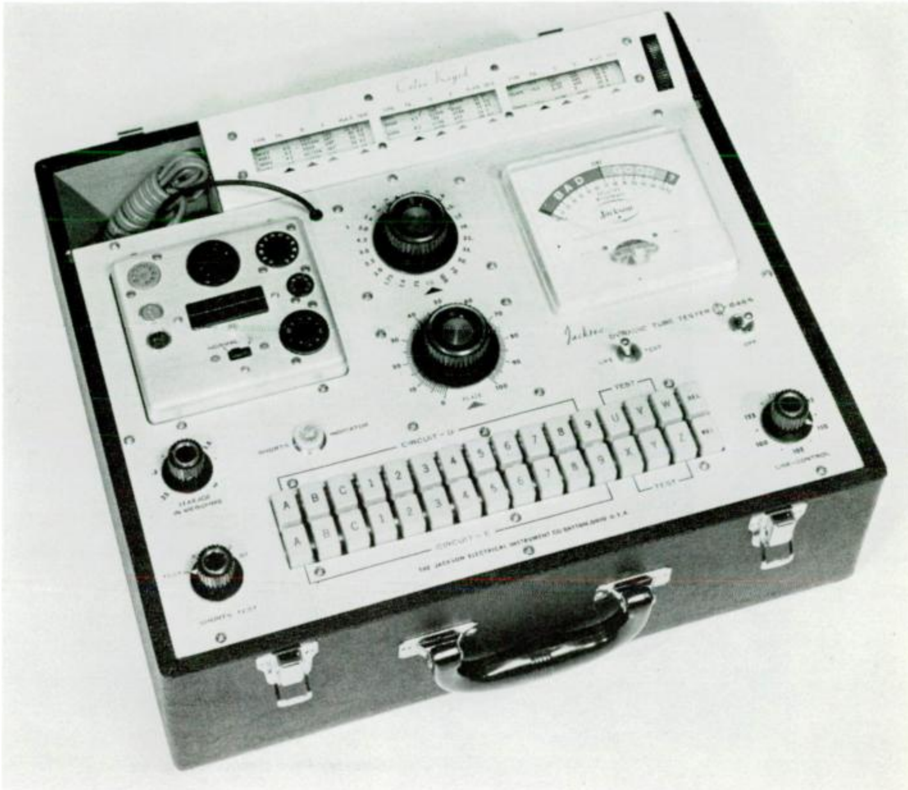
check is easily made by fixed resistors inserted into one of the sockets. Other tube testers, like that in Figure 3, have a leakage control that is calibrated in megohms.

Testing for Shorts

A tube should always be tested for shorts or leakage before other tests are begun. The reason for this precaution is that a short-circuit can cause meter damage in an emission test, for example. Tests should also be conducted for loose elements in the tube by tapping the tube lightly to discover whether a short exists under vibration. The simplest and least expensive tube tester provides only a heater or filament continuity test, without a leakage test. The continuity function can also be used for checking fuses, or circuit continuity of coils, power cords, and so on. Simplified testers may operate either from internal batteries or from the power line. For example, the continuity checker shown in Figure 4 operates from an internal battery. Neon-bulb indication is employed. Several tube sockets are provided to accommodate the more common tube types. No switching facilities are provided in this type of inexpensive tube tester.

Electron Emission Testing

Figure 5 shows a typical emission test circuit. All the grids and



Courtesy Jackson Electrical Instrument Co.

Figure 3 — Leakage control is calibrated from 0.25 to 2 megohms.

the plate are tied together to obtain diode operation. Current flow is determined by the rheostat setting, which is adjusted to a specified value for each tube type. Since the emission drops off as a tube ages, the meter reading gives an indication of whether the tube is able to supply a normal emission current. If the meter is connected in the plate circuit, the instrument is generally called a plate-conductance tester, or simply an emission tester. If the meter is connected in the cathode circuit, the instrument may be called a cathode-conductance tester. The same emission reading is obtained in either case. This basic arrangement is often elaborated to some extent, as explained subsequently.

An emission test cannot weed out tubes that might have cathode "hot spots." Since the grids are tied together with the plate, a test of grid-control action is not provided. When a cathode has a "hot spot," most of the emission current stems from this restricted area on the cathode. A control grid does not have normal valving action under this condition. Therefore, other types of test circuitry are required to weed out tubes that have cathode "hot spots." Rectifier tubes can be tested only for emission and gas. It is difficult to design a definitive gas

Courtesy Paco Electronics Co., Inc.

Figure 4 — Filament continuity tester.

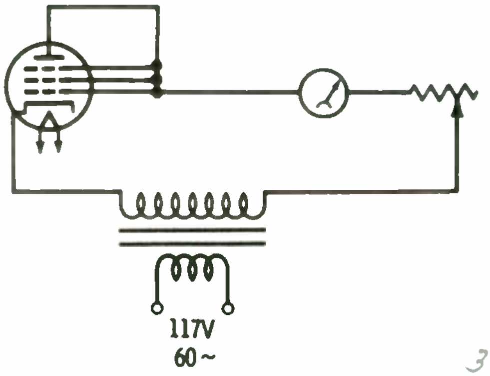


Figure 5 — Typical emission test circuit.

test for a diode; however, when gas is present, we will often see a blue glow inside the tube. This gas glow must not be confused with fluorescence. When fluorescence is present, we observe a blue or purple glow on the inside surface of the glass bulb. This does not indicate that the tube is defective, because fluorescence is caused merely by high-speed electrons striking the glass envelope.

Testing Diodes

It is very desirable to test diodes at their maximum rated values of plate current because rectifiers are commonly operated near maximum ratings. Larger types of tube testers with heavy power transformers can test all diodes at maximum rated current. However, small tube testers may not be able to provide maximum rated current demand for large rectifier tubes. Beam-power tubes and power pentodes should also be tested near their rated maximum power-dissipation values. It is preferable to check each section of a duo-diode tube individually. Most of the larger tube testers with switching facilities provide tests of individual diode sections. However, simplified testers used in supermarkets, for example, generally check both diode sections in parallel. Card-type tube testers usually provide a pair of cards for duo-diode tubes, so that the emission of each section can be checked.

Tube Tester Sockets

7

Since the sockets on a tube tester receive hard usage, socket-savers are often provided. These are basically test adapters with central mounting screws, that can be inserted into a socket on the tester. In turn, the socket-saver receives the wear; when it becomes defective, it can be easily replaced. Worn sockets are very objectionable in a tube tester because they will make good tubes test bad. If socket wear is suspected, it is advisable to "rock" the tube in its socket, while observing the meter.

POWER OUTPUT TEST

A number of tube testers provide a power-output test, as depicted in Figure 6. Some tube manufacturers state that a properly set up power-output test is the most reliable single test for determining tube quality. In the preferred configuration, DC potentials are applied to the grids and plate of the tube to establish normal operating conditions. A specified AC drive voltage is applied to the control grid, and the resulting AC power in the plate circuit is indicated by a meter. In less elaborate test configurations, AC voltages are applied to all electrodes. The AC drive voltage for the grid is often arranged to be 180 degrees out of phase with the screen and plate voltages. This permits the grid to swing negative as the screen and plate swing positive, thus providing a comparatively normal operating condition.

If the tester has extensive switching facilities, as shown in Figure 7, open electrodes in a tube can be detected. To check for open electrodes, the switch for each grid is opened in turn. If the electrode is

$P = I^2 R$

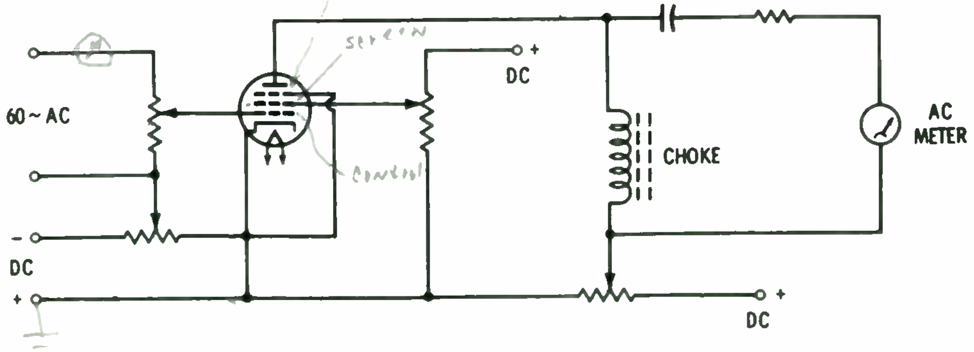
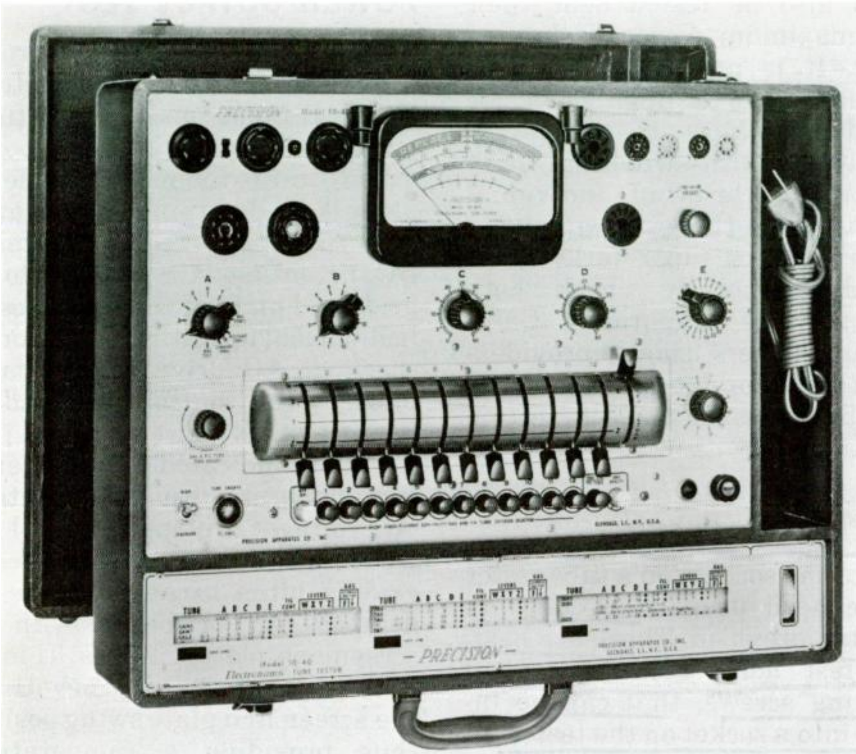


Figure 6 — Typical power-output test circuit.

$X_L = \omega L$



Courtesy Precision Apparatus Co., Inc.

Figure 7 — Tube tester with extensive switching facilities.

open, there is no change in the meter reading; if the electrode is operating normally, the pointer will drop on the scale when a grid switch is opened. Various types of tests are commonly provided for gas and grid emission. Either gas or grid emission will cause grid-current flow, although the grid is biased negatively. In the basic test, a negative voltage is applied to the control grid through a high resistance, such as 10 megohms. A microammeter connected in series with the grid is used to indicate the presence of grid current. More sensitive tests can be obtained by a DC amplifier, as depicted in Figure 8.

The cathode of the tube under test is biased positively (Fig. 8). This is equivalent to biasing the grid negatively. If there is no gas or grid emission in the tube under test, it exhibits an open circuit, and the grid of the 6BJ8 rests at contact potential (approximately 1 volt negative). R4 is normally set so that M1 is set to zero. Next, if any grid current flows in the tube under test, the grid loses electrons and the 6BJ8 becomes biased more or less in a positive direction. In turn, plate current flows, and is indicated by M1.

PLATE CURRENT CUTOFF TEST

In critical applications, such as

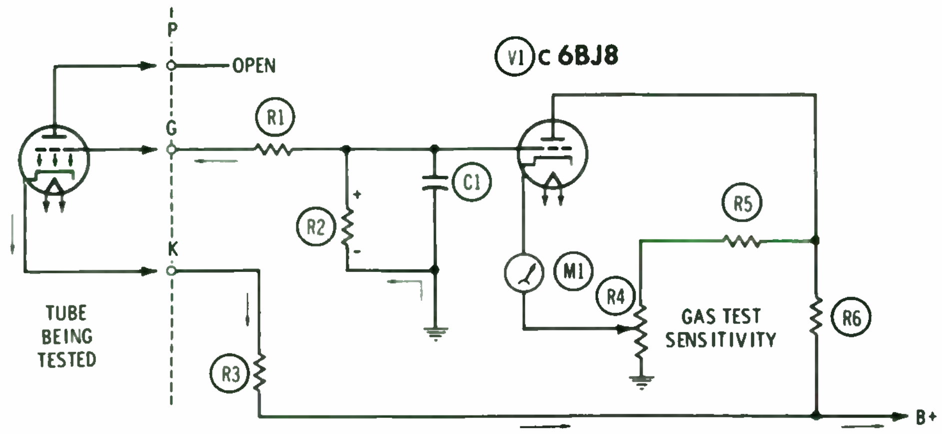


Figure 8 — Sensitive gas test configuration.

certain horizontal-oscillator and output circuits, a tube must have a comparatively sharp cutoff to operate properly. If the cutoff point is somewhat remote, the tube must be rejected for these critical applications. Therefore, some tube testers provide a configuration in which the control-grid bias voltage can be set to an indicated value for zero reading on a meter connected in the plate circuit of the tube under test. In turn, the value of grid-bias voltage necessary to produce plate-current cutoff can be checked against the specified value in a tube manual. Another arrangement provides fixed grid-bias voltages for particular types of tubes; if the plate current does not fall to zero in this test, the tube is rejected for critical applications.

The cutoff points of dual triodes are often of interest in applications such as computer flip-flop circuits, integrator, and memory circuits. Some blocking oscillators will refuse to operate if the cutoff is not sufficiently sharp. On the other hand, a tube that is AVC- or AGC-controlled must have a suitably remote cutoff point. Therefore, a plate-cutoff test is useful in a range of tube applications. Of course, a cutoff test is also very helpful in weeding out tubes that have cathode "hot spots," because this defect produces a remote cutoff characteristic.

Knee Test

An associated test that is sometimes provided is called a "knee" test. That is, the total space current is essentially constant, but divides between the screen grid and plate, as shown in Figure 9. The tube is less efficient below the knee point A, and if the knee point occurs at too high a value of E_{bb}, it will usually be unsatisfactory in horizontal-output application, although the tube is good otherwise. Therefore, a knee test is made by providing operating voltages to the tube at point A to determine whether the value of i_b is normal. If the plate current is subnormal (and the screen current abnormal) at the rated knee point, the tube is rejected for horizontal-output application.

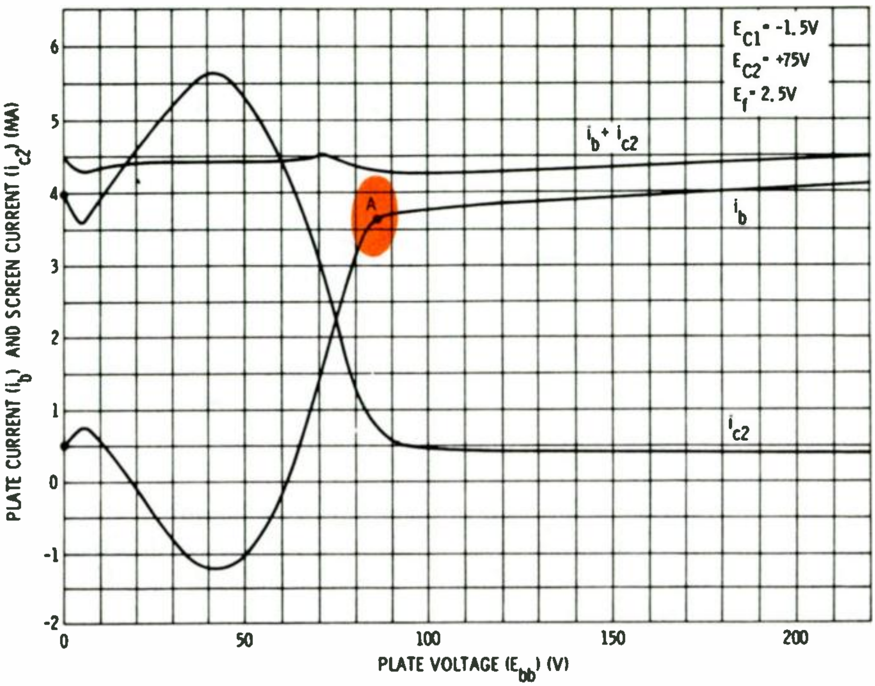


Figure 9 — Space current divides between screen grid and plate.

MUTUAL CONDUCTANCE OR TRANSCONDUCTANCE TEST

Mutual conductance (control grid-to-plate transconductance) is a function of the amplification factor and dynamic plate resistance of a tube. In the measurement of mutual conductance, a small signal is utilized, so that the tube is operated as an essentially linear device. Values of mutual conductance, or transconductance, are measured in mhos, according to the formula:

$$G_m = \frac{\Delta i_p}{\Delta e_g}$$

where,

G_m denotes mutual conductance in mhos,

Δi_p denotes a small change in plate current (ampere units),

Δe_g denotes a small change in grid voltage (volt units).

Because all receiving-type tubes have G_m values much less than 1 mho, it is customary to express G_m in micromhos, or 10^{-6} mhos. A diode does not have a G_m value, and must be tested for emission capability. There are two basic methods of measuring G_m values. The grid-shift method is a DC or static test, and employs a push-switch that changes the control-grid by a reference amount, such as 0.5 volt. In turn, the change in plate current is indicated by a DC meter. This method was formerly used extensively, particularly in laboratory-testers, but has been supplanted by the dynamic G_m test: a small AC signal is applied to the control grid, and the resulting AC plate current is indicated by an electrodynamometer.

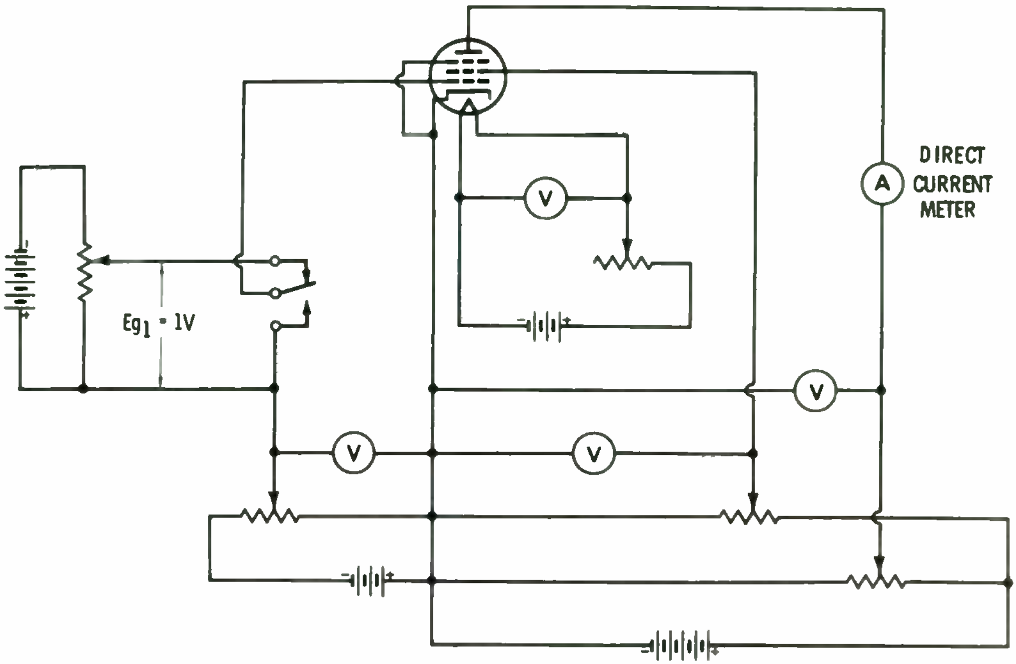
The dynamic method is more

practical for service-type testers because it is simpler to use, and the plate meter can be calibrated in micromho values. The fundamental test configurations employ DC voltages on the tube electrodes; however, many service-type G_m testers are arranged to apply AC voltages to the tube electrodes. Many mechanical arrangements are used by various manufacturers. For example, Figure 10 illustrates the card-type G_m tester. Other arrangements employ lever switches, push-button switches, potentiometers, and various combinations of these. Quite a few G_m testers feature a multiplicity of sockets with a minimum of controls. In all cases, the result is the same; a small AC signal is applied to the control grid of the tube, with the AC plate-current flow indicated by a meter.

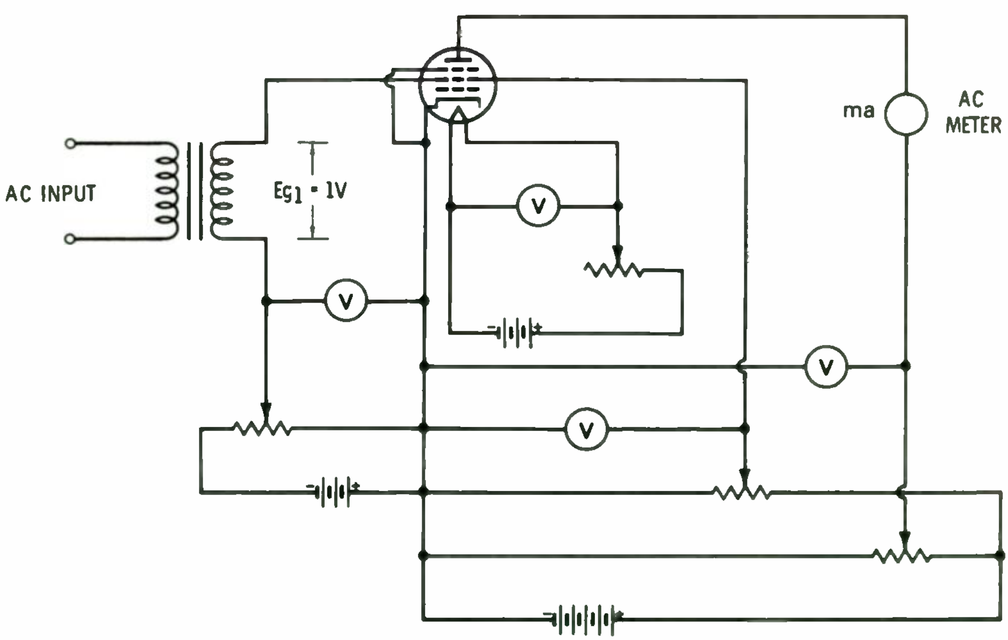
Figure 11A depicts the fundamental *static* G_m test arrangement,

Courtesy Hickok Electrical Instrument Co.

Figure 10 — Card-type mutual-conductance tube tester.



A - Static.



B - Dynamic.

Figure 11 — Basic static and dynamic Gm test circuit.

and Figure 11B depicts the fundamental *dynamic* G_m test arrangement. An electrodynamometer type of AC meter has a certain advantage over a rectifier-type instrument because it is a true rms meter. An electrodynamometer reads accurate rms values of current, regardless of waveform distortion. If the line voltage should not be a true sine wave (as is often the case in heavily industrialized areas), the tester will nevertheless indicate correct current values. However, electrodynamometers (Fig. 12) are comparatively expensive and are used chiefly in laboratory equipment.

The plan of a comparatively elaborate service-type G_m tester is shown in Figure 13. DC voltages are applied to the tube electrodes, and a small 5-kHz sine wave voltage is applied to the control gird. To obtain accurate G_m indication, the plate circuit is designed to have minimum impedance, and, in the ideal test situation, the plate-cathode circuit would have zero impedance. Any plate-circuit impedance adds to the apparent value of the tube's dynamic plate resistance. In order to provide low impedance and also to separate the AC and DC components of plate current, transformer coupling may

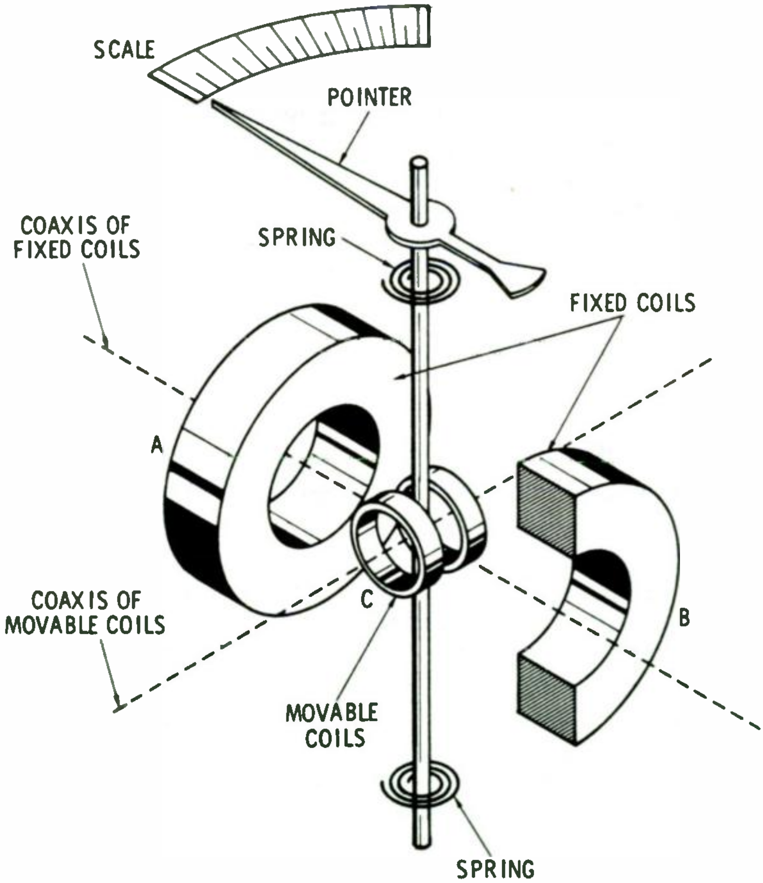


Figure 12 — Plan of electrodynamometer instrument.

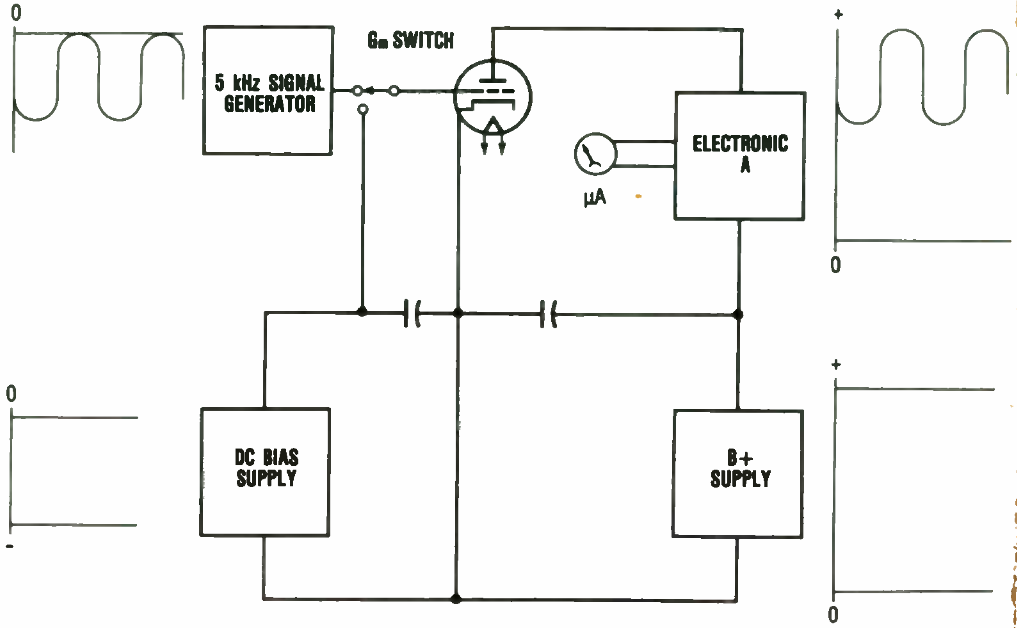


Figure 13 — One form of an accurate Gm test arrangement.

be employed between the meter and the test circuit. A self-checking feature of some G_m testers consists of a switch arrangement to check the meter reading when it is switched across a precision resistor in the grid-driving circuit. Thereby, the amplitude of the drive signal can be set accurately.

G_m Tester Circuits

A complete circuit for a high-performance G_m tester is shown in Figure 14. Overload warning is provided by lamp I1. This lamp lights if the tube under test has a short-circuit that would slam the meter on a G_m test. Therefore, if the warning lamp glows, the tube must be rejected without further tests. As in most tube testers, a line test is provided. This permits the operator to adjust the line voltage to standard value, so that correct test voltages are supplied. The 5-kHz grid-drive signal is provided by a built-in oscillator (V1). A standard noise test is provided; this requires a pair of earphones that is plugged into the noise-test jacks. Auxiliary circuitry provides for tests of pilot lamps and ballast resistors. The leakage tests and filament-continuity tests employ neon-bulb indication. Gas or grid-emission current is indicated on the meter. A roll chart is provided in the instrument for control settings of each tube under test.

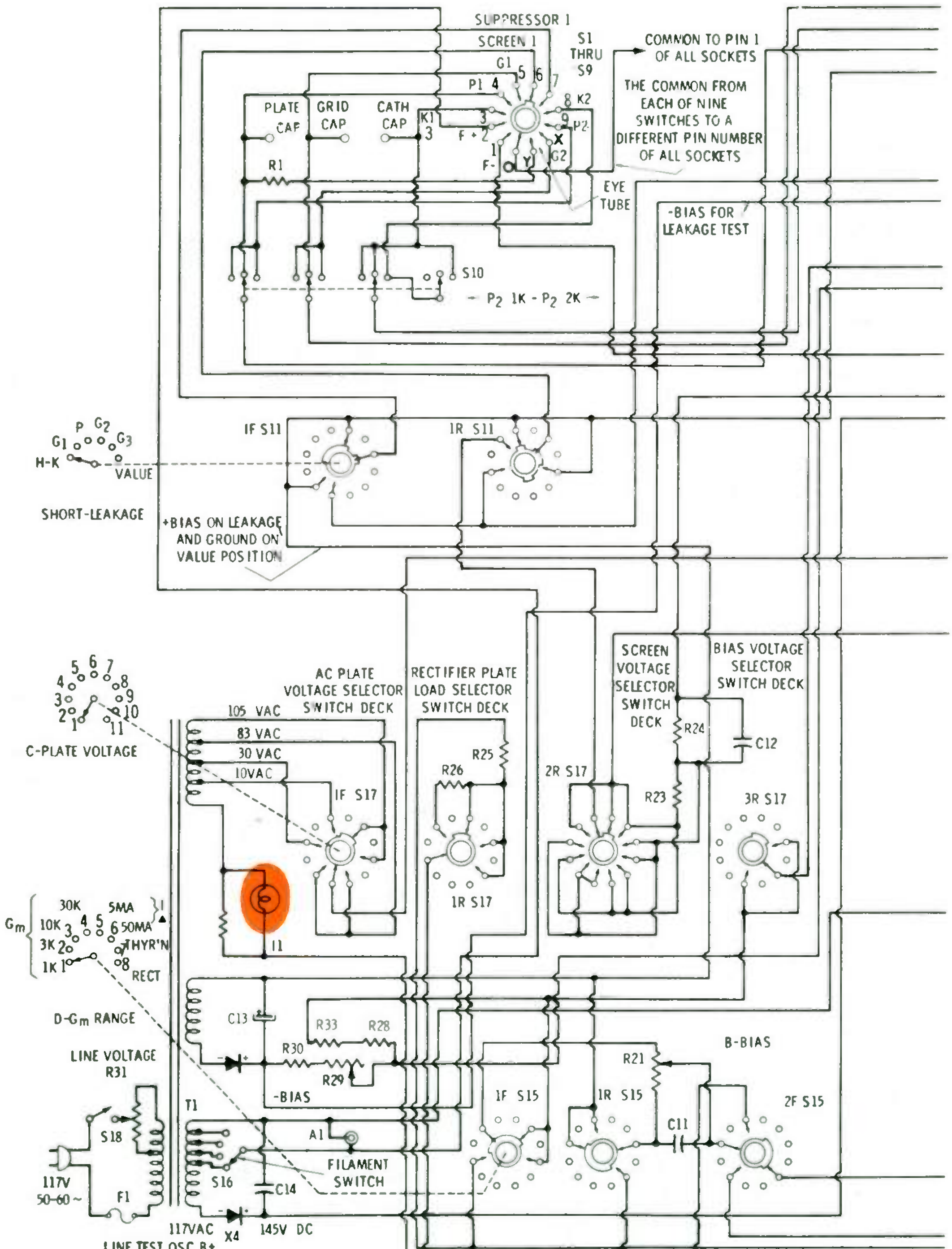
Figure 15 shows another widely-used G_m test configuration. A mercury-vapor rectifier tube is used to develop plate-supply voltage, and a vacuum-tube rectifier is used to develop grid and screen supply voltages. T_a is the tube under test, T_1 rectifies the plate-supply voltage, and T_2 rectifies grid and screen supply voltages. Note that the supply voltages are pulsating direct current. Voltages E_1, E_2, and E_3 are obtained from windings on the same power transformer, and are in phase with each another. Let us consider the circuit action with grid-signal voltage E_5 absent. During the half-cycle that P_1 is positive, current flows via P_1-K_2-S_1-Pa-K_1-B-D-R_1-E to P_1. A portion of this current is shunted through R_2 and meter M. Meter current flows from F to E, and tends to cause the pointer to deflect to the left. During the half-cycle that P_2 is positive, current flows via P_2-K_2-S_1-Pa-K_1-B-D-R_2-F-P_2. A portion of this current is shunted through R_1-M. Meter current flows from E to F, and tends to cause pointer deflection to the right. The pointer remains motionless because of its inertia.

Next, let us consider the circuit action in Figure 15 with the grid-signal voltage E_5 applied. When P_1 is positive, point C is negative with respect to B. Thereby, grid G is driven more negative, reducing the plate-current flow. Meter current from F to E is also reduced. When P_2 is positive, point C is positive with respect to B. Thus, the grid becomes less negative, which increases the plate current. Meter current from E to F is increased. Since the up-scale deflecting force is greater than the down-scale deflecting force, the pointer deflects up-scale. This unbalance of currents is proportional to the mutual conductance of the tube; therefore, meter M can be calibrated in micromhos. Two grid-signal amplitudes are provided, such as 1 volt or 5 volts. Power-output tubes are checked at high grid-drive, in order to indicate power-output capability. If a low G_m reading is obtained at high grid drive, we know that the tube is being driven into saturation and has subnormal power-output capability.

G_m tube testers are often designed with many sockets, as illustrated in Figure 16 to minimize the number of controls that are required. The array of test sockets provides the same basic operating simplicity as punch cards. Many tube testers of this type provide a life test, in addition to the conventional tests. A life test is made by pressing a button that reduces the heater or filament supply voltage by 10 percent. If the G_m reading falls, we know that the tube has limited emission capability, and that it cannot be expected to provide extensive future service. This test is also useful to weed out tubes that are used in series heater strings. Since heaters have a resistance tolerance, it is possible that a tube in a series string may be required to operate at 10 percent below normal heater voltage.

THYRATRON TEST CIRCUIT

Some tube testers also provide a test for thyratron tubes. A typical test configuration is shown in Figure 17. A DC milliammeter is connected in series with the anode of the thyratron under test. AC voltage is applied to the anode. To test the thyratron, the DC bias is increased until the tube suddenly ceases to conduct. This is the cutoff point of the tube. Normal cutoff voltages are specified for various thyratrons on the roll chart. Note that the anode must be supplied with AC voltage in this test. The



HEATER VOLTAGE FOR V1 & V2 ARE CONNECTED ON THE 5V FILAMENT TAP. ALL LAMPS ARE CONNECTED BETWEEN THE .63 & 6.3 TAPS ON THE FILAMENT WINDING.

▲R19 & S14 ARE MECHANICALLY CONNECTED.

Courtesy Triplett Electrical Instrument Co.

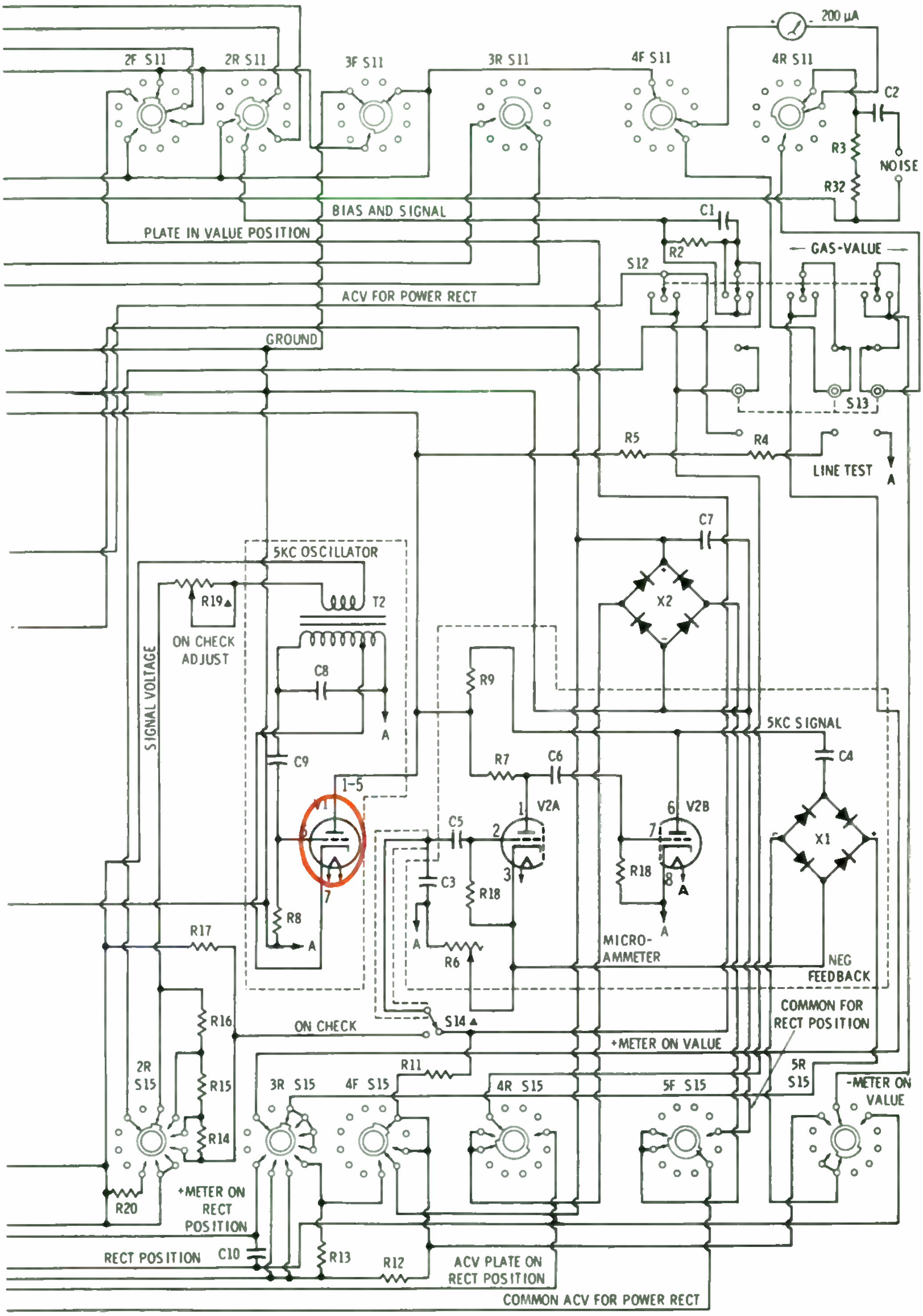
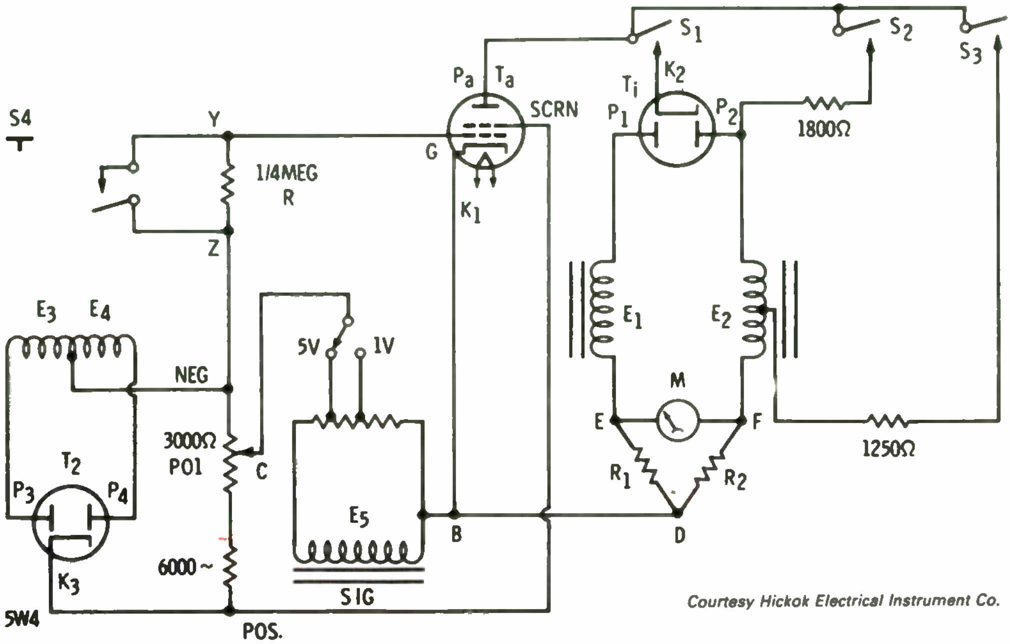
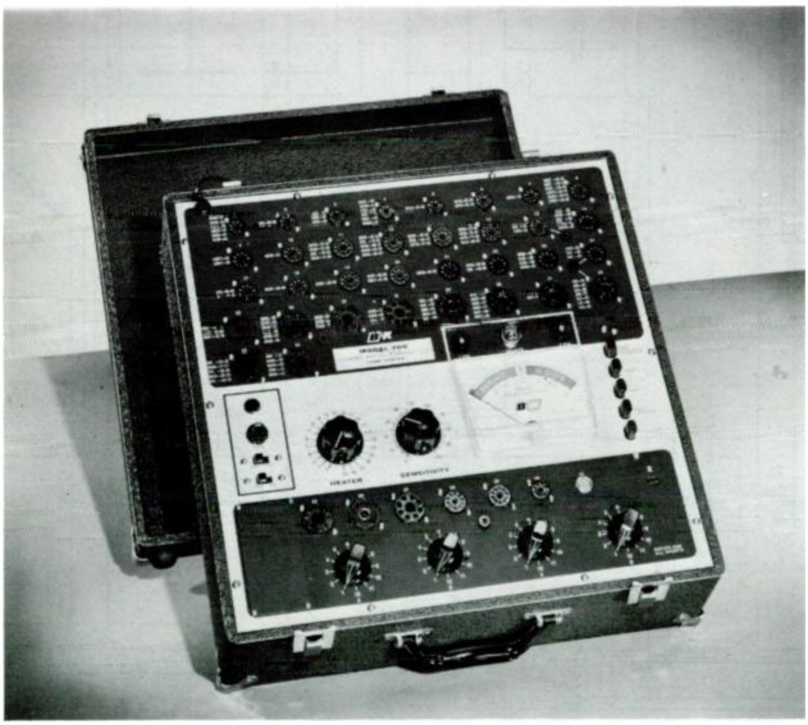


Figure 14 — Schematic of an elaborate Gm tester.



Courtesy Hickok Electrical Instrument Co.

Figure 15 — Widely-used Gm test arrangement.



Courtesy B & K Mfg. Co.

Figure 16 — Gm tester with minimum number of controls.

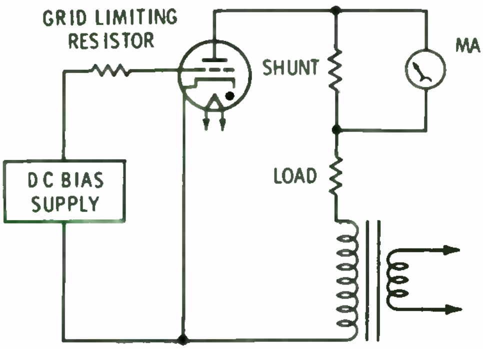


Figure 17 — Typical thyratron test circuit.

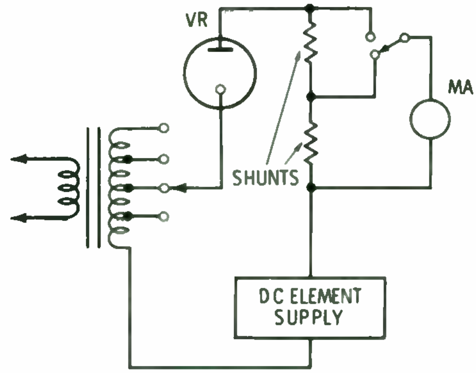


Figure 18 — Typical voltage regulator test circuit.

reason for this is that although the grid can initiate conduction, it loses control after conduction starts. Therefore, the plate must be supplied with a voltage that rises to a peak and then drops to zero. By driving the plate alternately positive and negative, the thyratron will definitely cease conduction when the grid-bias voltage is raised to its critical negative value.

VOLTAGE REGULATOR TUBE TEST

Service-type tube testers sometimes provided facilities for testing voltage-regulator tubes. An AC voltage with a DC component is applied to the anode, as depicted in Figure 18. The peak voltage is increased in steps to the point at which the tube suddenly starts to conduct. This is called the striking voltage of the regulator tube. Minimum striking voltages for various voltage-regulator tubes are specified on the roll chart. Although a striking-voltage test is not conclusive, it gives a good basic indication of the tube's condition. A failing regulator tube or thyratron often develops excessive internal resistance. This condition is checked by connecting a scope across the tube while it is conducting. Excessive internal resistance shows up as a waveform with a sloping, rather than a flat, top and with an overshoot pip at the end of the leading edge.

TUNING-EYE TUBE TEST

Figure 19 shows a typical eye-tube test circuit. A high plate-load resistance, typically 1 megohm, is used. This makes the plate voltage vary substantially as the grid bias is changed. The bias voltage is set to the value specified on the roll chart, and the target shadow is observed to determine the control action of the tube.

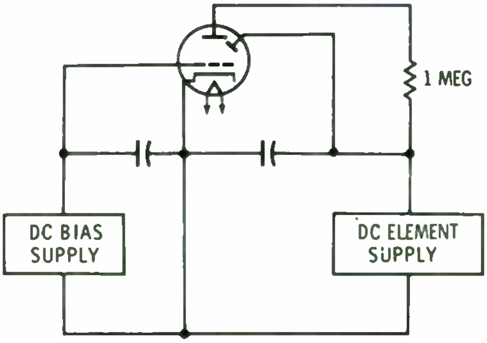


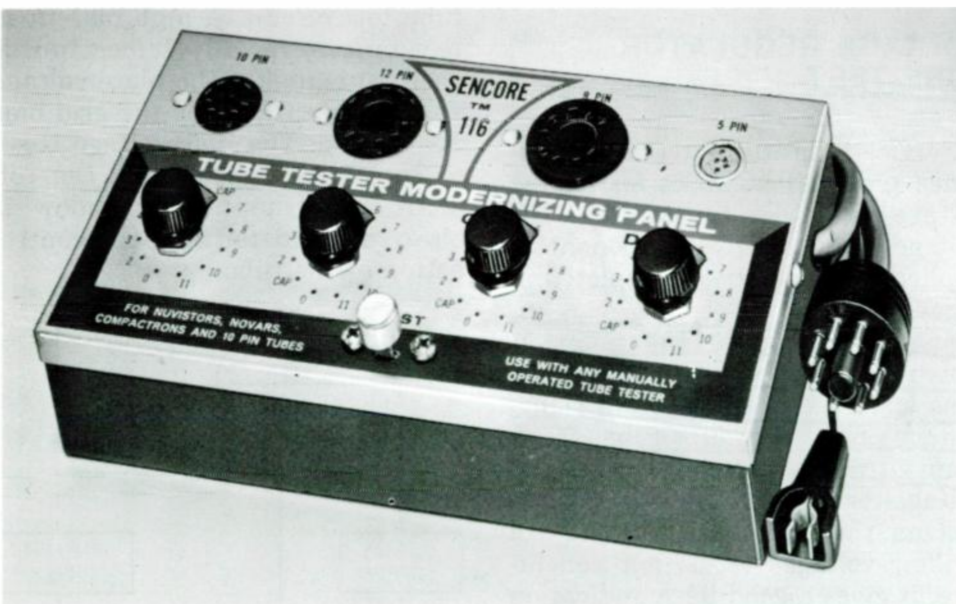
Figure 19 — Typical eye-tube test circuit.

ACCESSORIES

To meet the problem of new tube types, manufacturers often provide dummy tube sockets on tube testers. As new tubes become available, supplementary data is issued with instructions for wiring in a dummy socket. However, this provision cannot take into account new basings that may appear. Therefore, new sockets to accommodate novel basings are provided in the form of external adapters, as illustrated in Figure 20. As external adapters are made available, supplementary test data is also issued.

Picture-tube testers are designed both as individual instruments and as an auxiliary function of a receiving-tube tester. They are classified as emission or beam-current types. An emission type measures total cathode emission, while a beam-current type measures the electron flow that passes through the aperture in the control grid to the screen. Since only the central area of the cathode contributes to beam current, a test of this type is more conclusive. Figure 21 illustrates the formation of the beam current.

A typical configuration for a beam-current picture-tube tester is shown in Figure 22. Shorts and leakage tests are made in the same manner as for a receiving tube. A neon-bulb indicator indicates leakage for any element, according to the switch setting. In the beam-current test, an adjustable negative bias is applied to the control grid. The beam current is collected by subsequent electrodes, and indicated on a meter scale. Beam current is measured at three successive values of grid bias. This provides a test



Courtesy Sencore, Inc.

Figure 20 — Tube tester adapter.

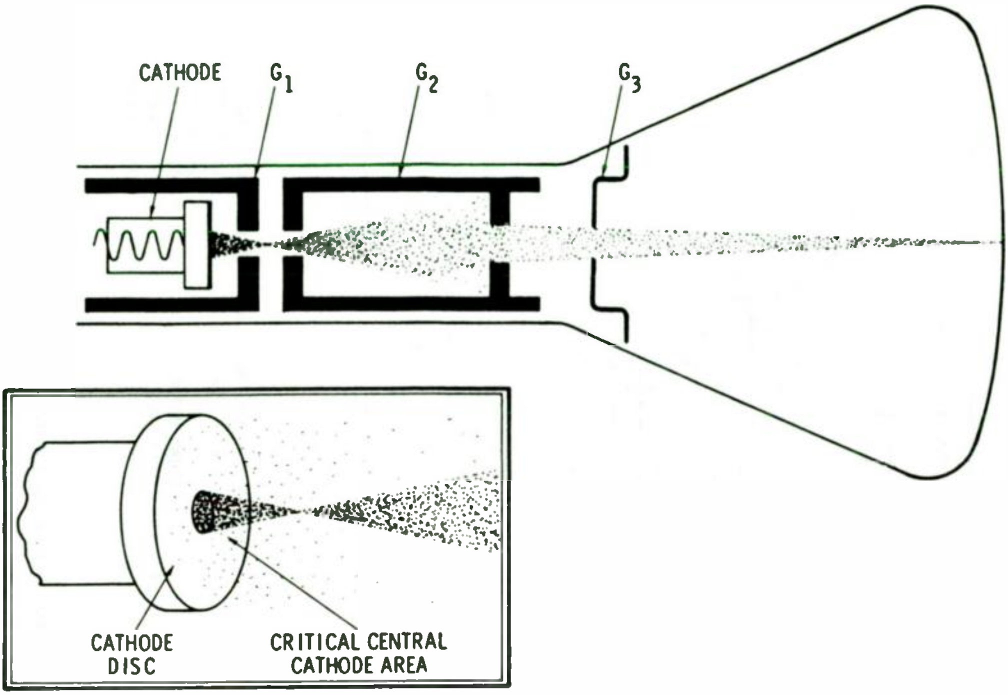


Figure 21 — Electron distribution from CRT cathode.

for grid control action. Individual tests are provided for the three guns in color picture tubes. 10 A rejuvenating function is provided, which will sometimes bring a weak tube up to normal beam current.

Some tube testers are combined with transistor testers, as illustrated in Figure 23. Other tube testers, such as shown in Figure 24, have auxiliary VOM functions. Another combination instrument comprises tube and transistor test functions with a built-in VTVM. Such combination instruments may be designed in comparatively compact form, so that they are easily portable for use on outside service calls. In the past, most of the elaborate tube testers provided VOM functions with a sensitivity of 1,000 ohms-per-volt, or 10,000 ohms-per-volt. Modern tube testers that have VOM functions provide a sensitivity of 20,000 ohms-per-volt. Those with VTVM functions have a typical input resistance of 11 megohms on all DC voltage ranges.

SUMMARY

Tube testers determine whether a tube is good or bad. A tube is considered bad if it fails to perform its intended function in the circuit. Although a tube may pass the complete check on a tube tester, it still might not work in the circuit. Certain circuits require a combination of high performance characteristics that are impossible to check on the tester.

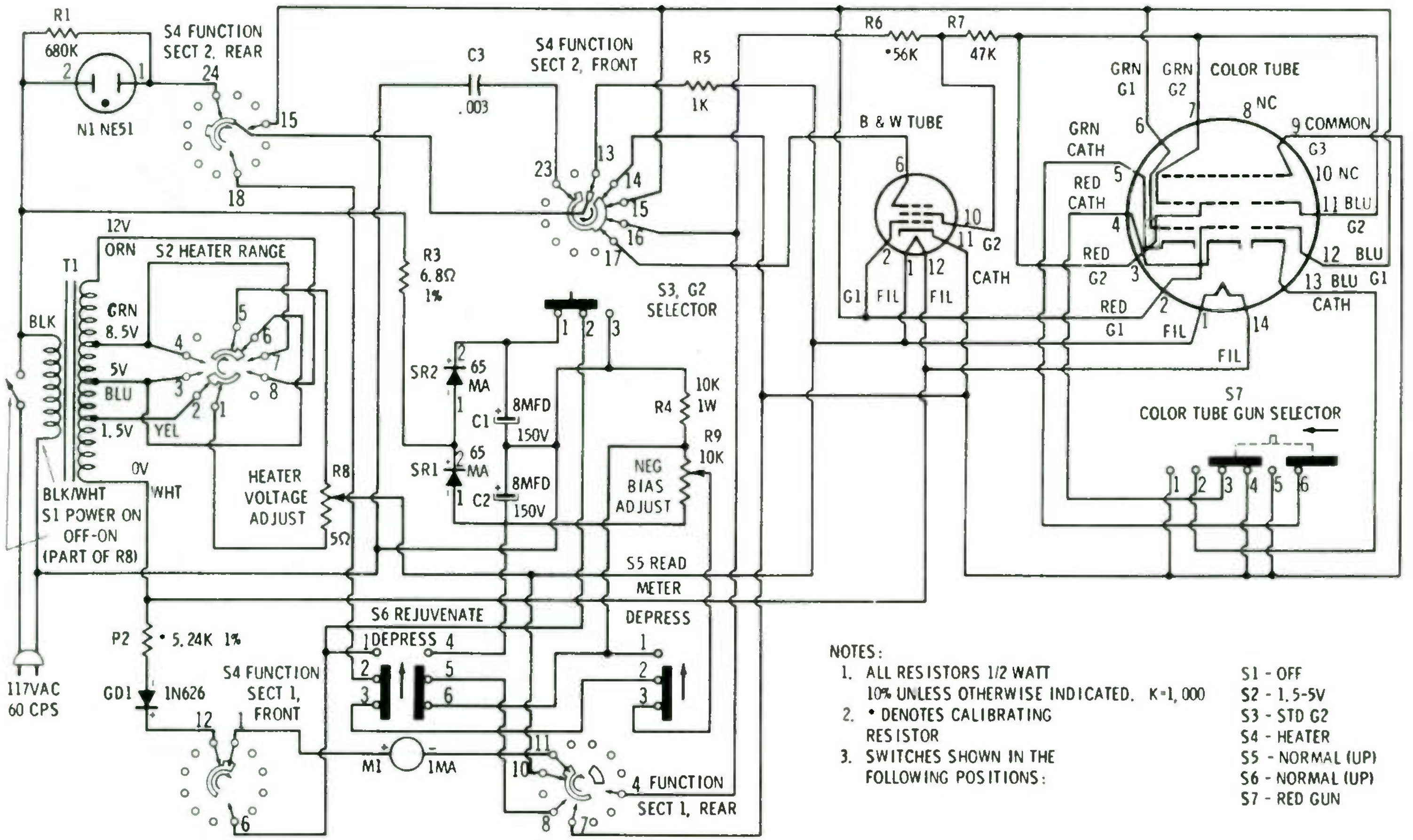


Figure 22 — Typical picture-tube tester circuit that also contains a rejuvenating control.

The designs of testers range from those containing simple filament checking circuits to the ones that indicate shorts, leakage, grid and cathode emission, mutual conductance and power output. The more expensive tube checker usually has a provision for a simple test of a transistor and a solid state diode. They may also have the capability of testing special tube types, such as voltage regulator tubes and cathode ray tubes.

Courtesy Electronic Instrument Co.,Inc.

Figure 23 — Combination tube and transistor checker.

Courtesy B & K Mfg. Co.

Figure 24 — Tube tester with VOM functions.

TEST

Lesson Number 57

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-057-1.

1. **A tube under test should first be checked for**
   A. shorts.
   B. emission.
   C. high frequency.
   D. power output.

2. **An emission tester for vacuum tubes will**
   A. provide a good test of a tube.
   B. not provide a complete test of a tube.
   C. use the control grid to control the flow of plate current.
   D. usually produce flourescence on the interior of the glass envelope.

3. **Diodes that are used as power rectifiers are tested**
   A. to locate the cathode hot spots.
   B. to obtain a blue glow inside the tube.
   C. at their maximum rated values of plate current.
   D. to determine whether they are amplifying properly.

4. **A power output test of a tube will have**
   A. only the grid emission checked.
   B. only the plate current indicated.
   C. only DC voltages on the plates, and only AC on all grids.
   D. DC voltages on the screen grid and plate, and an AC voltage driving the control grid.

5. The most accurate prediction of tube life is provided by the
- A. screen-grid knee test.
- B. leakage test.
- C. mutual-conductance test.
- D. basic emission test.

6. Mutual conductance, also known as transconductance,
- A. gives information about the grid voltage.
- B. denotes a small change in plate current.
- 9 C. is an indication of diode emission.
- D. is usually expressed in mhos on the meter scale in tube testers.

7. The effect of a defective socket on a tube tester can be overcome by
- A. rocking the tube in its socket.
- 5 B. inserting a tube saver in the tube tester and then checking the tube.
- C. comparing it with another tube of the same type that is known to be good.
- D. none of the above.

8. A high grade tube tester
- A. is always accurate.
- B. can always give a complete review of the condition of a tube.
- C. should only indicate the transconductance value of a tube.
- D. is somewhat limited in its use, because it cannot duplicate every operating characteristic of a vacuum tube under all operating conditions.

9. A voltage regulator tube is tested to determine its
- A. striking voltage.
- 17 B. lowest operating voltage.
- C. minimum plate current.
- D. none of the above.

10. The rejuvenating function included in most picture-tube testers
- A. measures the cathode emission.
- B. measures the beam current.
- 19 C. will sometimes bring a weak tube up to normal beam current.
- D. measures the leakage current.

Notes

Notes

Notes

Portions of this lesson from
Know Your Tube and Transistor Testers
by Robert G. Middleton
Courtesy of Howard W. Sams, Inc.

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

FOLLOWING ADVICE

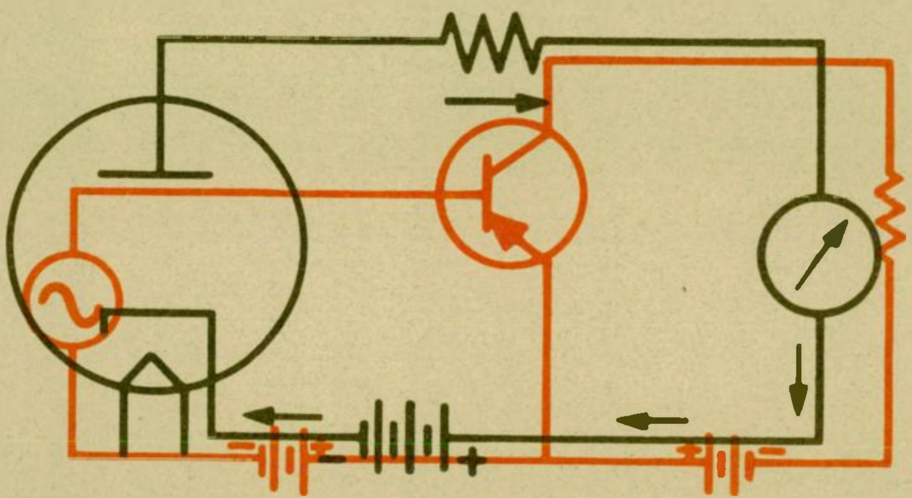
Some men have what amounts to genius at seeing just what they must do to make a success of their lives. So they do it, and are successful. They teach other men to do the things necessary to succeed and those men also become successful. What is fascinating about this is that success is attainable for all . . . who are willing to work for it.

Follow the good advice given by successful men, put this advice to work, and you can enjoy the same success.

S. T. Christensen

LESSON NO. 58

REVIEW FILM OF LESSONS 54 THROUGH 57



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-058

407

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 4/73
Reprinted July 1974

REVIEW FILM TEST

Lesson Number 58

The ten questions enclosed are review questions of lessons 54, 55, 56, & 57 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and Film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER: YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

Lesson Number 58

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having the Test Code Number 52-058-1

1. **A signal tracer is similar to a**
   A. radio transmitter.
   B. signal generator.
   C. radio receiver
   D. none of the above.

2. **Defective AVC in an AM receiver causes**
   A. distortion.
   B. high level hum.
   C. the receiver to jump frequency.
   D. loss of output.

3. **The Hartley circuit is used in** RF sig gen
   A. an audio amplifier.
   B. an oscillator.
   C. a VTVM.
   D. an oscilloscope.

4. **Zero beating is a method used to**
   A. test an audio amplifier.
   B. calibrate a VTVM.
   C. calibrate an oscilloscope.
   D. calibrate a signal generator.

5. Most RF signal generators have
- A. straight line frequency calibration.
- B. linear frequency calibration.
- C. non-linear calibration.
- D. an irregular calibration.

6. Harmonics of a signal generator can be used for
- A. distortion measurements.
- B. calibration of the fundamental frequency.
- C. testing transistors.
- D. determining Beta.

7. The Wien-bridge circuit
- A. uses inductance.
- B. is used to measure capacity.
- C. is used in an HF oscillator.
- D. is used in an AF oscillator.

8. DC tests of a transistor are only good for transistors used as
- A. AF amplifiers
- B. RF oscillators.
- C. IF amplifiers.
- D. all of the above.

9. The simplest type of tube tester measures
- A. Gm.
- B. emission.
- C. filament continuity.
- D. element shorts.

10. In an emission tester, the tube operates as
- A. a diode.
- B. an audio amplifier.
- C. an RF oscillator.
- D. none of the above.

Notes

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"Serving America's Needs for Modern Vocational Training"

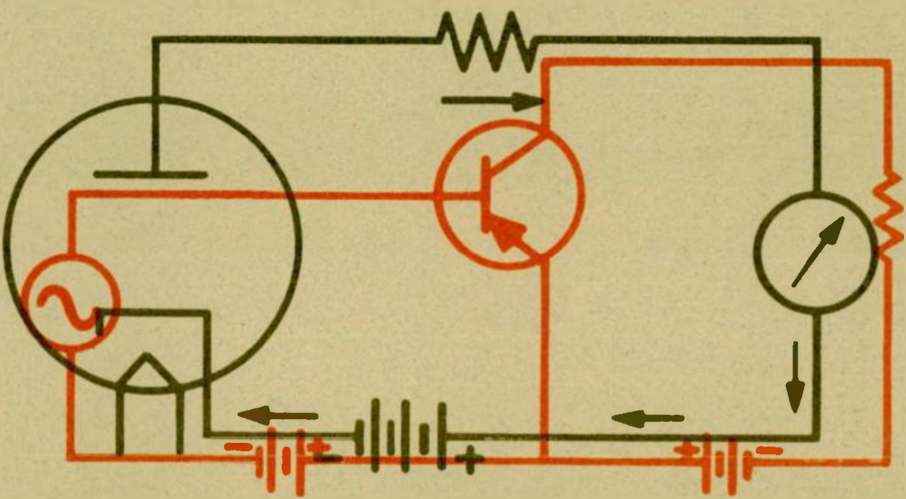
PLANNING

Did you ever hear the saying "even the best made plans can change"? Chances are you have, and probably even experienced it yourself. Well, you're not alone. It's happened to most of us, but that should not discourage you from continuing to make plans. Without them, you drift and cannot efficiently run your everyday activities. Oh, maybe you can get by for awhile, but not long. Most plans stay intact and can help you achieve the everyday tasks that confront you. So start now . . . plan today for tomorrow's activities.

S. T. Christensen

LESSON NO. 59

OSCILLOSCOPES



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-059

407

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CONTENTS

OSCILLOSCOPES

INTRODUCTION

The modern oscilloscope is the most versatile tool of the electronic technician. It has a unique ability to accurately display complex waveforms. Any recurrent waveform can be frozen on the display screen to appear motionless for detailed study. A scope can be calibrated to measure voltage or current. When the scope is synchronized, a known frequency can be used to measure an unknown frequency.

Modern TV receivers were all developed from the basic scope tube. The scope is now the important instrument to keep these receivers in good operating condition.

This lesson will concentrate on the understanding and the applications of conventional service-type scopes. It is important to remember that these instruments are merely one type of a large variety of oscilloscopes. For example, while a better grade service-type scope can display a signal up to about 4.5 MHz, some elaborate industrial scopes display frequencies up to 500 MHz.

Scopes are also used in the medical field and have essentially the same tube as the service scope, but they use a different screen material. The doctor's interest is in the neurological waveforms of the patient; these have very low fundamental frequencies. Generally, they are less than two hertz. To display these low frequencies, the scope tube must have a long persistance fluorescent screen as against a medium persistance screen in the service scope.

More than thirty different screen phosphors are available and range in persistance and color.

HOW TO ADJUST AN OSCILLOSCOPE

Oscilloscopes are not difficult to adjust, although they do have a large number of controls. Even the simplest scopes have about a dozen knobs and switches. However, if the action of each control or switch is taken step by step, the instrument soon loses its mystery. All service scopes are AC operated.

To turn the scope on, set the power switch to its "on" position. This switch may be an individual control, or it may be combined with an operating control. When power is applied to the scope circuits, a pilot lamp glows, or, in some cases, an edge-lighted graticule (calibrated screen) is illuminated.

Intensity-Control Adjustment

After a brief warm-up period, a spot or line may appear on the screen. If not, turn up the intensity control. Do not advance it more than is necessary, however, because the screen of the cathode-ray tube can be burned, particularly if the electron beam is forming a small stationary spot on the screen.

If a spot or line does not appear when the intensity control is turned up, either the horizontal- or vertical-centering control may be at the extreme end of its range. This can throw the spot or line off-screen. Therefore, begin the operating procedure by adjusting each centering control to its mid-range.

Centering-Control Adjustment

The action of the centering control is seen in Figure 2. The spot

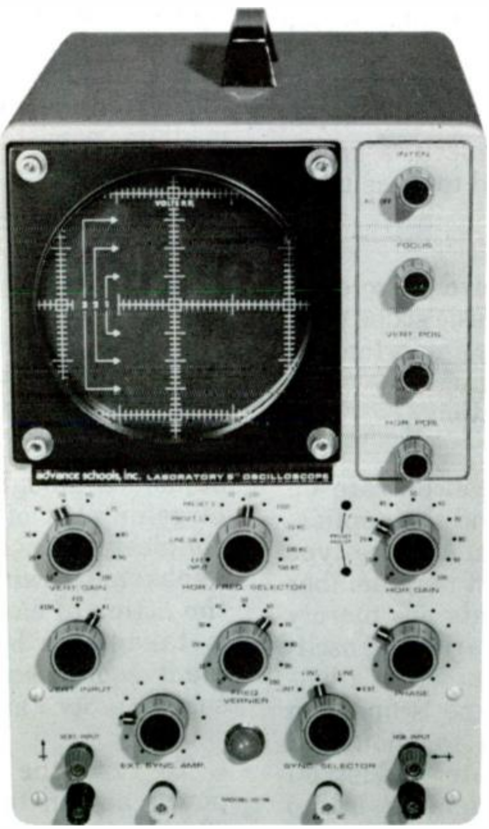


Figure 1 — Front panel view of an oscilloscope. (Courtesy of Heath Co.)

moves up and down as the vertical-centering control is rotated back and forth. Similarly, the spot moves left and right as the horizontal-centering control is rotated back and forth. In theory, any desired pattern could be traced out on the screen by turning the centering controls. This is a simple manual analogy to the pattern development which takes place automatically when the electronic circuits of a scope are energized.

In practice, of course, patterns are not traced out in this manner. The centering controls are set to position the beam on the screen, and are not readjusted unless particular test conditions make this desirable. Some types of patterns may not appear centered on the

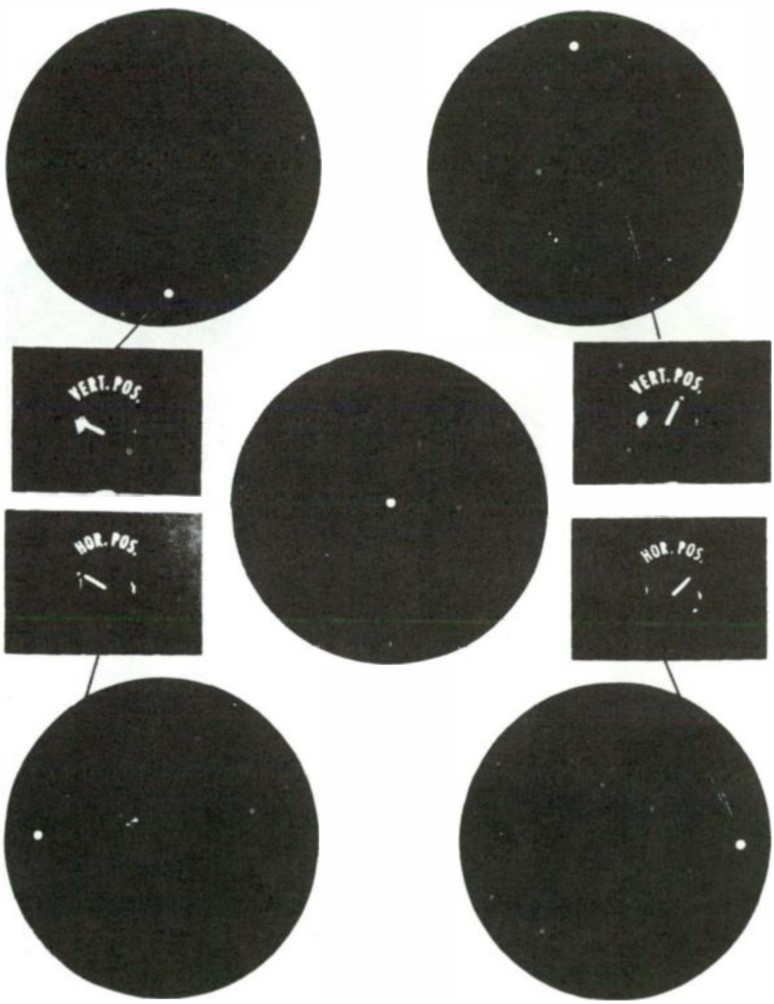


Figure 2 — Action of positioning (centering) controls.

screen unless the centering controls are readjusted, for reasons that will be explained later.

Focus-Control Adjustment

Figure 3 shows how the appearance of a spot changes on the scope screen as the focus control is turned. The focus control is adjusted for the smallest spot possible. In most scopes, the intensity and focus controls interact. Therefore, the focus control may need to be readjusted if the intensity-control setting is changed.

The reason for this interaction is apparent from Figure 4. The focus control varies the DC voltage applied to anode 1 of the CRT, and the intensity control varies the voltage on the cathode. The electrostatic flux lines thus produced between the electrodes form a "lens" which focuses the electron beam. If the intensity voltage is changed, the focus voltage must be changed also, to maintain correct lens formation.

Note the astigmatism control in Figure 4. It varies the DC operating voltage of anode 2. In some scopes,

Figure 3 — Action of focus control.

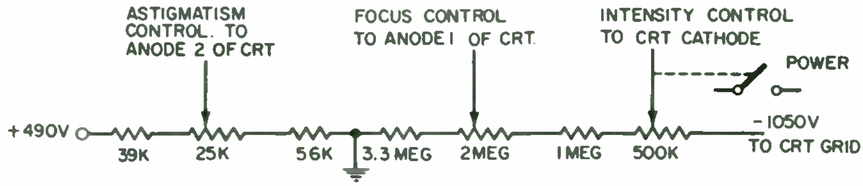


Figure 4 — Focus and intensity functions.

this voltage is fixed. In other scopes, an astigmatism control is provided but may be located in the instrument cabinet. The astigmatism control provides uniformity to the focus control, so that the pattern can be focused properly in all portions of the screen. The astigmatism control interacts to some extent with the focus and intensity controls.

Horizontal-Amplitude and Function-Control Adjustment

The horizontal-amplitude control (sometimes called the horizontal-gain control) adjusts the width of the pattern. If the control is turned to zero, a spot is displayed on the screen. As the control is advanced, the spot spreads out horizontally into a trace. If the trace does not appear, check the setting of the horizontal-function control. If this control is set to the "horizontal-input" position, little or no trace length will be obtained. This position is for the application of external signals. Set the control to + or − Sync, for ordinary displays of waveforms on internal-sawtooth sweep. When the function control is in one of these positions, an internally generated sawtooth-voltage signal is applied to the horizontal-deflection plates of the cathode-ray tube. This signal deflects the electron beam horizontally.

4

Since a sawtooth voltage is linear, the spot moves uniformly in time from left to right across the screen. During the brief retrace interval, the spot quickly returns to the left side of the screen. Because of this linear, or uniform, motion of the spot, sawtooth deflection is called a *linear time base.* In other words, when sawtooth deflection is used, each inch of horizontal travel takes place in the same time interval. This permits the display of voltage waveforms as a function of time.

Application of a 60-Hertz Test Voltage

All scopes have some provision for the application of a vertical-input signal. If a 60-Hz test voltage is applied to the vertical-input terminals, a sine-wave pattern can be displayed on the scope screen. A suitable test voltage can be obtained by connecting the vertical-input terminals between the heater line and ground in a radio or TV receiver. Many scopes have a 60-Hz test-voltage terminal on the front panel, and a lead can be connected from the vertical-input terminal to the test-voltage terminal.

A sine-wave pattern may or may not appear when the test voltage is applied. This depends on the setting of certain operating controls. For example, if the horizontal-deflection rate is incorrect, only a blur may be displayed. Practically all scopes have a coarse and a fine (vernier) sawtooth frequency control. The coarse control is a rotary step switch; the vernier control is a potentiometer. The two are also called the sweep-range control and the range-frequency control.

Set the step control to a position which includes 60 Hz. Adjustment of the fine control "fills in" the step and permits the sawtooth oscillator to operate at 60 Hz. Rotate the control to see whether a single-cycle display appears on the screen. Possibly no other adjustments will be required, and a pattern as detailed in Figure 5 may appear. Note that the displayed cycle is not quite

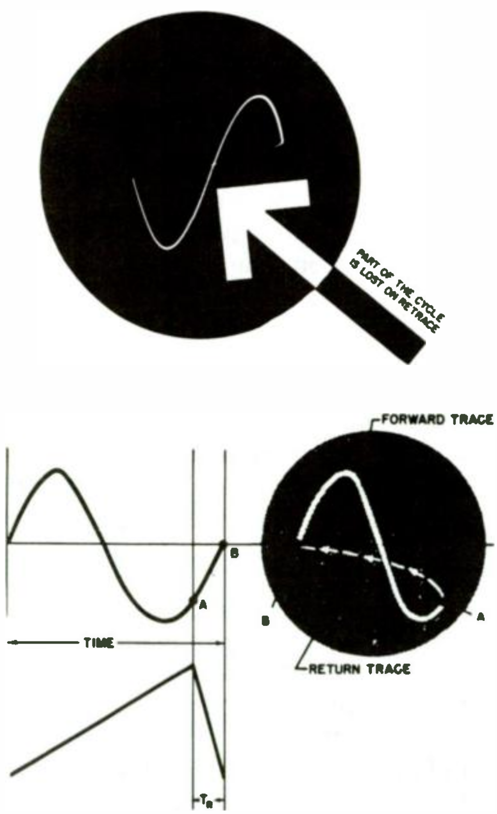


Figure 5 — Details of a single-cycle display.

complete. A small portion is "lost" on retrace because the sawtooth deflection voltage does not drop to zero instantly during retrace time. The lost portion of the display is often seen as a visible retrace line in the pattern.

At this point, the required adjustment of the vernier sawtooth control may be quite critical. Perhaps the single-cycle display can be stopped only for an instant. Then it "breaks sync," and a blurred pattern reappears. On the other hand, the pattern may lock tightly, but appear broken into fragments. The first difficulty is due to the sync control's being set too low. The second difficulty is caused by the sync control being set too high. In either case, the pattern is locked improperly by the sync control. The proper method for adjusting the sync control is to advance the control sufficiently to lock the pattern, but not so far that operation of the sawtooth oscillator is disturbed.

A pattern like the one illustrated in Figure 6 is sometimes confusing. Such a pattern is displayed when the sweep frequency is set to twice the signal frequency. For example, if the signal frequency is 60 Hz, the pattern shown in Figure 6 is obtained when the sweep frequency is set to 120 Hz. On the other hand, when the sweep frequency is set to one-half of the signal frequency, two cycles of the signal will be displayed, minus a small portion of the waveform that is lost on retrace. (See Figure 7.)

Pattern Size vs. Intensity Control Adjustment

Now that a sine-wave pattern is displayed on the screen, the trace appears much dimmer than the former small spot or horizontal line. If the sine-wave pattern fills most of the screen vertically, it will appear quite dim compared with a

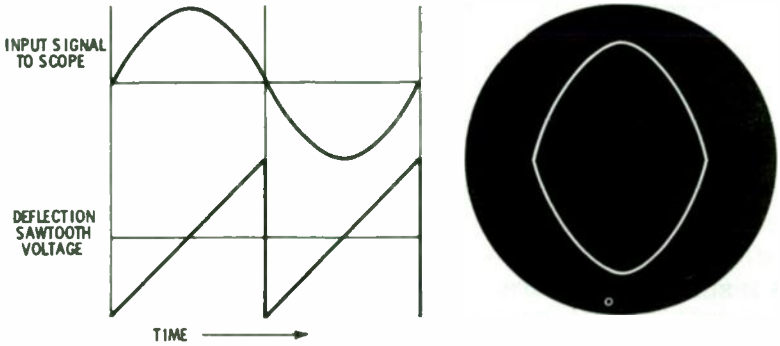


Figure 6 — Display of sine wave when the sweep frequency is double the signal frequency.

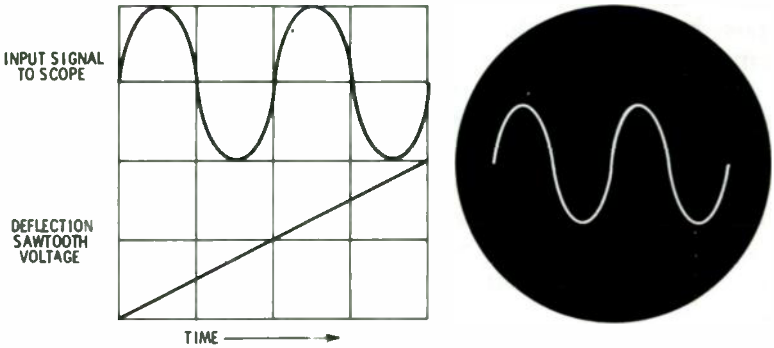


Figure 7 — Display of sine wave when the sweep frequency is one half the signal frequency.

simple spot. The reason is that the electron beam has a much longer path to trace out; consequently, each point along the trace receives much less energy. Therefore, it is necessary to turn up the intensity control in order to make the wave pattern more clearly visible. However, this usually changes the focus also, and in some scopes, the pattern tends to "bloom".

If the brightness of the pattern is not satisfactory, check the ambient light in the shop. High-level illumination from a window may be "washing out" the display. Move the scope or place a light hood around the scope screen.

A sine-wave pattern (or any other pattern) can be shifted vertically and horizontally on the screen by adjusting the centering controls, as was discussed previously in the cases of the spot and the line. As the scope warms up, the sine-wave pattern may drift vertically, horizontally, or both, and in that case, readjust the centering controls as required.

Vertical Gain Adjustment

Another difficulty may arise at this point. Perhaps the pattern locks satisfactorily, but vertical deflection is insufficiant or excessive. The vertical-gain control, no doubt, is set incorrectly. It is adjusted normally for a pattern height of approximately three-fourths of full screen.

Although the simplest scopes have a single vertical gain control, most scopes have both step and vernier control. If the input voltage is comparatively high, the step control is set to the "low" position, and vice versa. Other step gain controls may have three or four positions. They permit application of a wide range of input voltages, without overloading the vertical amplifier in the scope.

All oscilloscopes have vertical amplifiers. An amplifier is necessary because a cathode-ray tube is comparatively insensitive, and requires approximately 300 volts for adequate deflection. Because it is often necessary to investigate signal voltages as low as .02 volt, a high-gain vertical amplifier is required in practical work.

In the simplest scopes, the vertical-gain control is a potentiometer. This type of control is satisfactory only for low-frequency operation. A simple potentiometer distorts a high-frequency waveform because of its stray capacitances.

An interesting principle of circuit action makes possible a gain-control configuration having both high input resistance and distortionless attenuation. At low frequencies, these requirements are met by a resistive voltage divider, (Fig. 8A) and at high frequencies, by a capacitive voltage divider (Fig. 8B). The resistive divider distorts high frequencies, and the capacitive divider distorts low frequencies. However, when the two configurations are combined, as in Figure 9, all frequencies are passed

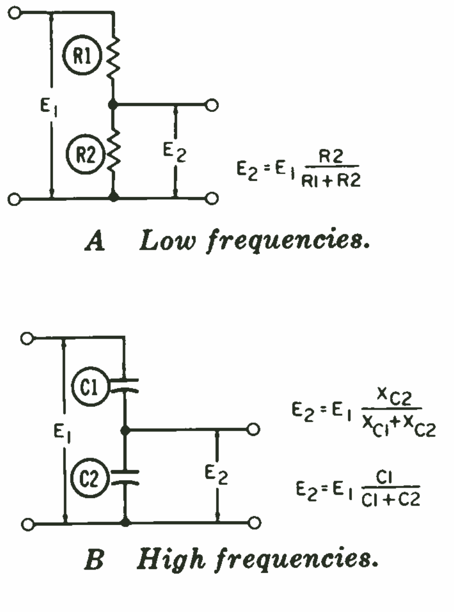


Figure 8 — Voltage dividers for low and high frequencies.

without distortion. Trimmer capacitors C_1 and C_4 are used to balance the high- and low-frequency response. These capacitors are maintenance adjustments and are located inside the scope case.

The step attenuator in Figure 9 has three positions. The input signal is applied across series resistors R_1, R_2, and R_3. The input resistance is 1.5 megohms for any of the three steps. When the step attenuator is set to a tap on the divider network, the output signal is reduced. Thus, the input amplifier is not overloaded, even though the input signal may be quite high. The step attenuator is merely set to a lower position.

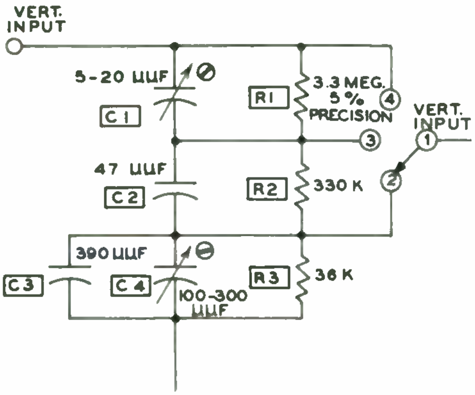


Figure 9 — Compensated step attenuator. (Courtesy of Heath Co.)

A continuous (vernier) vertical-gain control is in the cathode circuit of the input tubes.

The proper settings of step- and vernier-gain controls are of prime importance. In many scopes which have both of these controls, incorrect gain settings will overload the cathode follower and cause the waveform to be clipped (Figure 10). This means that the step attenuator has been set too high, and the vernier attenuator too low. Distortion is corrected by lowering the setting of the step control, and advancing the setting of the vernier control. Clipping is a distortion which can be quite confusing if it is not understood.

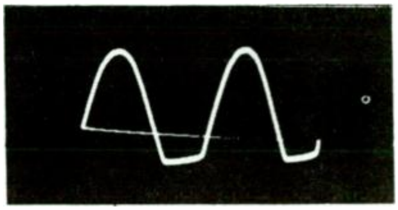


Figure 10 — Sine wave clipped by overloading.

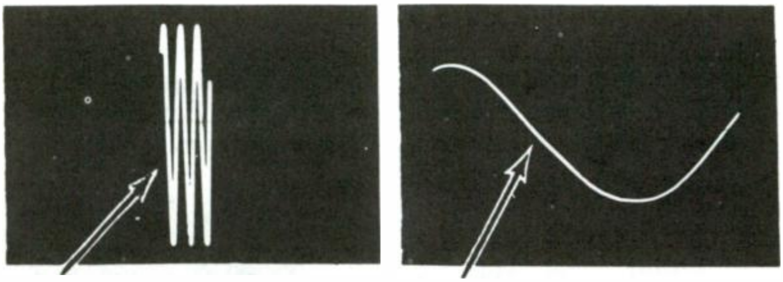
Horizontal Gain Adjustment

Although vertical deflection is satisfactory, the pattern may be excessively compressed or expanded horizontally (Fig. 11). The horizontal-gain control must be adjusted. Less elaborate scopes have a simple potentiometer-type horizontal-gain control only; others have both step- and continuous-gain controls. In most cases, the horizontal-step control is merely a resistive divider network. However, a few service scopes have the same type of compensated step control used in the vertical section. These scopes are somewhat more expensive.

For most test work, good high-frequency response in the horizontal section is not needed. Therefore, the horizontal-amplifier circuit is often simpler than the vertical.

Frequency Control Adjustments

When using the oscilloscope, it is customary to display two cycles of



A Insufficient horizontal deflection. *B Excessive horizontal deflection.*

Figure 11 — Horizontal gain control effect.

the signal on the cathode-ray tube screen. This is done by adjustment of the sawtooth-frequency control. Consider, for example, a 60-Hz signal. When the sawtooth-frequency control is adjusted to 30 Hz, the signal goes through two excursions during one trace interval, and two cycles of the signal are displayed. Similarly, when the sawtooth frequency is adjusted to 20 Hz, three cycles of the signal are displayed.

A typical scope sawtooth oscillator is a free-running oscillator which feeds a sawtooth voltage to the horizontal amplifier. The step frequency control is used to select a pair of capacitors ranging in value from 80 pf to 0.25 mfd. Higher values of capacitance provide a lower sawtooth frequency. The vernier frequency control is a pair of ganged potentiometers. Higher values of resistance provide a lower sawtooth frequency. The vernier control is used to "fill in" between the various positions of the step control. The sawtooth frequency can be adjusted from 10 Hz to 500 kHz.

CALIBRATION AND PEAK-TO-PEAK VOLTAGE MEASUREMENTS

An oscilloscope is a voltmeter which displays instantaneous, peak, and peak-to-peak voltages. It also displays the rms values of some waveforms. The meaning of peak values is evident in Figure 12.

Peak-to-peak voltages are specified in receiver service data. They are usually measured on the scope screen, although a peak-to-peak VTVM can be used. To calibrate a scope for peak-to-peak voltage measurements, its sensitivity for the chosen setting of the vertical-gain controls is determined. A known peak-to-peak voltage is applied to the vertical-input terminals of the scope, and the resulting number of divisions noted for deflection along the vertical axis. Thus, if a 1 volt peak-to-peak signal is applied to the scope and 10 divisions of vertical deflection are observed, the vertical-gain controls are set for a sensitivity of 0.1 volt peak-to-peak per division.

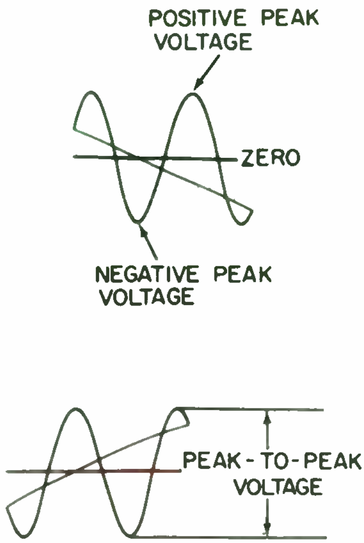


Figure 12 — Meaning of positive peak, negative peak and peak to peak voltage.

In the lesson on Alternating Current, you studied the definition of peak volts. Now, consider the voltage from an ordinary heater string. It has an rms value of 6.3 volts. Because it is a sine-wave voltage,
5 its *peak-to-peak* value is found by multiplying 6.3 by 2.83. Therefore, 6.3 volts rms has an amplitude of 17.8 volts peak-to-peak, which is usually rounded off to 18 volts peak-to-peak in practical work. Thus, if the vertical input of the scope is connected to a heater line, an 18-volt peak-to-peak voltage is being applied to the vertical amplifier. But, the peak voltage would be half or 1.414 times 6.3 volts or approximately 9 volts.

Consider an arbitrary calibration voltage, such as 12 volts peak-to-peak, being applied to the vertical-input terminals. If the vertical-gain controls are adjusted to make the voltage waveform extend over 12 divisions vertically (Fig. 13), the scope will be calibrated for 1 volt peak-to-peak per division. In turn, each major division on the graticule marks off 5 volts peak to peak. In this manner, a scope is calibrated easily for any convenient source of peak-to-peak voltage. Note carefully that a service-type VOM or VTVM reads the rms voltage of sine waves. *The peak-to-peak voltage of a sine wave is 2.83 times the rms reading.*

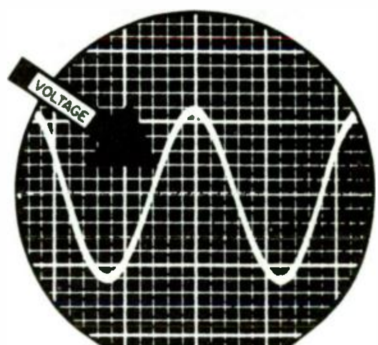


Figure 13 — A vertical excursion of 12 divisions.

COMPLEX WAVEFORMS

Although a sine wave is symmetrical, most waveforms encountered in electronic test work are nonsymmetrical. A pulse waveform, such as the one shown in Figure 14 is nonsymmetrical and, in turn, has a positive peak voltage which is not the same as its negative peak voltage. Nevertheless, once a scope has been calibrated with a sine wave, peak-to-peak
6 voltages of complex waveforms can also be measured on the screen.

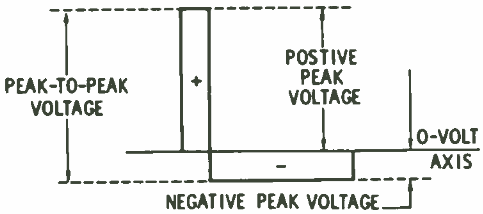


Figure 14 — Pulse-waveform voltages.

A square waveform is a complex symmetrical waveform, and its voltage is measured in peak-to-peak values. Figure 15 shows a square wave which has the same peak-to-peak voltage as the sine wave illustrated; however, the rms voltage of the square wave is different from that of the sine wave. Note carefully that service-type VOM's respond differently to these two waveforms, even though they have the same peak-to-peak voltage. A VOM indicates the true rms voltage of the sine wave, but does not indicate correctly when a square wave is measured.

A peak-to-peak reading VTVM indicates, of course, the true peak-to-peak voltage of any type of waveform. Once the sensitivity of a scope is adjusted for a certain number of volts per division, peak volt-
6 ages can be measured as easily as peak-to-peak voltages.

LISSAJOUS PATTERNS

A Lissajous (lee-so-zoo) pattern is a simple circular pattern formed by a sine-wave voltage. Such patterns are produced by feeding sine-wave voltages to both the vertical and horizontal amplifiers. Because many scopes have a 60-Hz sweep position on the function switch, such patterns can be made readily by utilizing this function. When any 60-Hz sine-wave voltage is applied to the vertical-input terminals, a Lissajous pattern then appears on the scope screen.

The pattern shows the phase of the vertical signal with respect to the horizontal signal. Progressive phases are illustrated in Figure 16. A circular pattern provides a good check for sine-wave purity. Furthermore, if there are harmonics in the 60-Hz voltage applied to the vertical or horizontal amplifier, or both, a perfect circle cannot be obtained. Irregularities are seen instead.

Lissajous patterns can be obtained, of course, at any frequency within the response range of the scope. The principle of pattern development is the same, regardless of frequency. Figure 17 illustrates how in-phase deflection voltages on the vertical and horizontal CRT

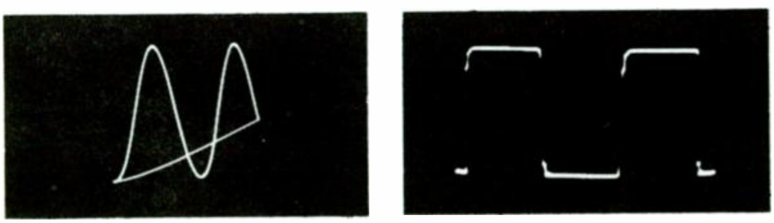


Figure 15 — These waveforms have the same peak-to-peak voltages but their rms ("root means square") values are different.

Figure 16 — Lissajous patterns show phase difference between two sine waves.

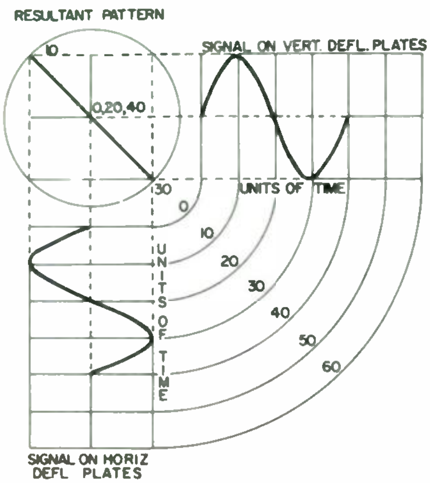


Figure 17 — In-phase sine waves form a straight-line cyclogram.

plates produce a straight line. Similarly, Figure 18 shows how a 90° phase difference produces a circular pattern. When one of the frequencies is double, triple, or quadruple the other frequency, crossover patterns result. If the two frequencies are not integrally related, the pattern is not fixed. Instead the pattern moves through successive phase sequences. By this principle, an oscilloscope may be used to adjust an unknown variable frequency to a known fixed frequency. Inject the unknown frequency into the vertical input circuit and the known frequency into the horizontal. The scope pattern will stand still *only* when the two frequencies are an integral ratio of each other, that is, when the ratios are 1:1, 2:1 . . . 10:1, or 1:3, 5:4 etc. The frequency ratio can be determined by counting the number of loops at the top edge of the screen as compared to the number of loops at the right edge of the screen.

The only limitation to this scheme of frequency comparison is the bandwidth of the scope circuits. With a wide band scope, frequencies up to one or two MHz can be displayed. When using a scope having a 100 kHz bandwidth, patterns cannot be displayed much above 20 kHz.

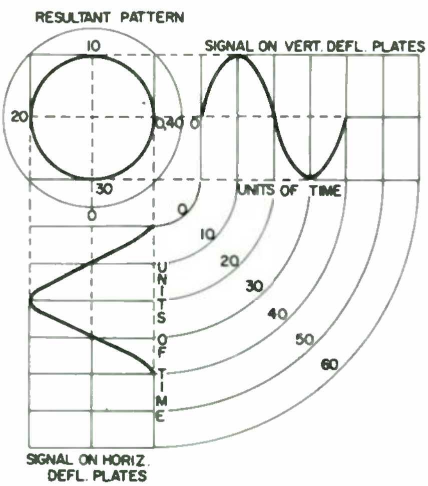


Figure 18 — Sine waves 90 degrees out-of-phase form a circular cyclogram.

PHASE ANGLE MEASUREMENTS

An oscilloscope may also be used to determine the phase angle between two voltages of the same frequency. Feed one voltage to the vertical input and the second to the horizontal input. From the displayed pattern, the phase angle can be estimated as shown in Figure 19.

To determine the exact phase angle between the two voltages, see Figure 20. To convert the arithmetical result to phase angle, refer to a table of sine functions as shown in an earlier lesson.

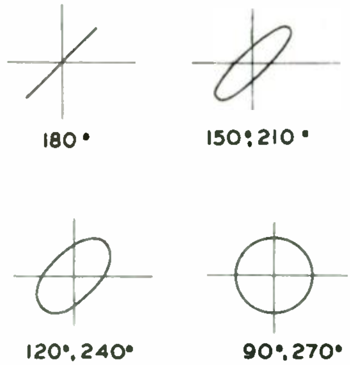
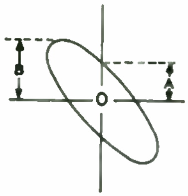


Figure 19 — Phase angle display.

OSCILLOSCOPE PROBES

A scope vertical amplifier has high gain. If unshielded leads are used to connect the vertical amplifier to a circuit under test, the connection leads will pick up extraneous hum and noise that will mask the desired signal.

Since the vertical input terminals of a scope present a fairly high resistance shunted by a relatively



$$\sin \theta = \frac{A}{B}$$

Figure 20 — Exact phase angle.

small capacitance (1 to 3 megohms shunted by 10 to 25 pf), a special type of cable system must be used. This cable system consists of a shielded probe and a length of coaxial cable. Within the probe are two resistors and a variable capacitance, as shown in Figure 21.

Most scopes' vertical inputs average about 1.5 megohms. Since the probe should present to the circuit under test the least possible loading, resistor R1 must be a high value. If R_2 is chosen at 1.5 megohms and the scope input is 1.5 megohms, R_1 must have a value nine times 750,000 ohms or 6.75 megohms. Generally, the coaxial cable is RG-58/U whose capacitance is 28 pf per foot. Assume that a three-foot length of cable is used. The cable capacitance is 84 pf plus the scopes' input capacitance of 17 pf, or a total of 101 pf. Since the resistor ratio was chosen at 9:1 to provide a 10:1 voltage ratio, the capacitance ratio must also be the converse of 1:9 or 9:1. Thus, C_1 is 10.2 pf.

In almost any assembly or grouping of electronic components, there are stray capacitities which are impossible to eliminate. By using a

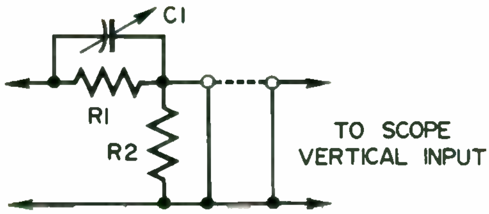


Figure 21 — A 10:1 divider probe.

variable capacitor for C_1, it can be adjusted to compensate for the stray capacity.

The best method of probe adjustment is to drive the probe with a fairly high frequency square wave (10 to 20 kHz) and observe the waveform on the scope. By adjusting C_1 the waveform can be adjusted to an exact square wave. Note that the probe circuit is the same basic circuit as the compensated attenuator as shown in Figure 9.

A second type of probe to use with an oscilloscope is nothing more than an inexpensive solid state diode. The diode is connected as an RF demodulator whose AF output is fed to the vertical input of the scope. (See Figure 22.) This RF probe is useful for signal tracing of an AM modulated carrier whose frequency is many times greater than the vertical response of the scope. For example, a TV picture carrier is an AM modulated signal. However, in a TV receiver, it is converted from its signal channel to an IF frequency of 41 to 45 MHz by the TV tuner. With the probe shown in Figure 22, the carrier's video modulation is recovered and displayed on the scope. Remember, that in order to display video modulation, the scope must have a vertical frequency response to 4 MHz.

RADIO-RECEIVER TROUBLESHOOTING

Signal-tracing is one of the principal troubleshooting methods used in radio-receiver servicing. Although ordinary signal tracers are quite useful, they fall far short of the oscilloscope's information capability. A scope is the best radio signal tracer, because it gives both distortion data and exact amplitude measurements. Scope patterns show where distortion originates, and indicate the type of distortion present, which in turn helps to pinpoint the defective component. Accurate gain measurements can also be made, and these measurements cannot be approximated by an ordinary signal tracer.

Only AM receiver troubleshooting is covered in this lesson. Test signals for AM radio troubleshooting should be supplied by an AM generator. Broadcast signals are difficult to work with because of their transient characteristics.

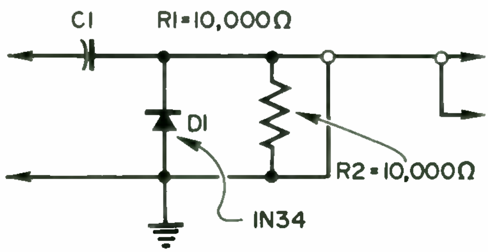
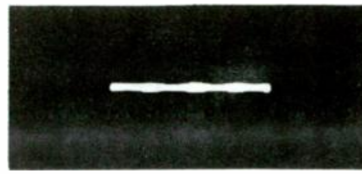
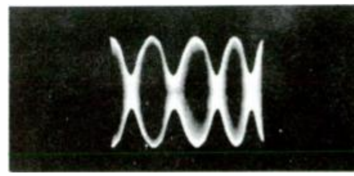


Figure 22 — An RF probe.

Conventional AM radio chassis can be serviced with any scope which is adequate for black and white TV work. The highest signal frequency of interest is 2.06 MHz. This is the frequency generated by the conversion oscillator when the receiver is tuned to 1605 kHz. The oscillator 16 frequency is always on the high side of the signal. Since most AM receivers use a 455-kHz IF frequency, the sum of the signal frequency and IF frequency equals 2060 kHz. A high-frequency probe must be used with the scope in order to avoid objectionable circuit loading and detuning, as illustrated in Figure 22.



A Input.



B Output.

Figure 23 — Basic gain display.

GAIN MEASUREMENTS

An uncalibrated scope can be used for gain measurements, because the gain figure is merely a ratio. Connect the output from an AM signal generator to the antenna input terminals of the receiver, or connect the output of the generator to a small coil that is then coupled to the loop antenna. When the high frequency probe of the scope is transferred from the grid to the plate terminal of an IF stage, for example, the comparative heights of the two displays give a measure of stage gain, as seen in Figure 23.

This is a basic display, but it is difficult to work with because the first waveform of the scope is utilized accordingly. A simple example is this: if the first waveform has the same amplitude as the second waveform when the decade control is advanced one step for the first test, the stage gain is 10. The gain of a stage in normal operation depends on the AVC bias voltage, and this in turn depends on the signal level. Hence, the AVC system should be temporarily disabled by 9 using a clip lead to ground the circuit. The term AVC is interchangeable with AGC (Automatic Gain Control).

It is important to be accurate in making gain measurements, and not to use a probe with an excessively high capacitance. This detunes an IF transformer and also makes the gain figure incorrect. Also, do not overload the receiver with a high input signal from the generator. The signal will be clipped, and a false gain figure will be obtained. The normal gain for an IF stage cannot be calculated easily, and reference should be made to the receiver service data or to a comparative check in a normally operating receiver.

The difficulty in making gain calculations is seen from an inspec-

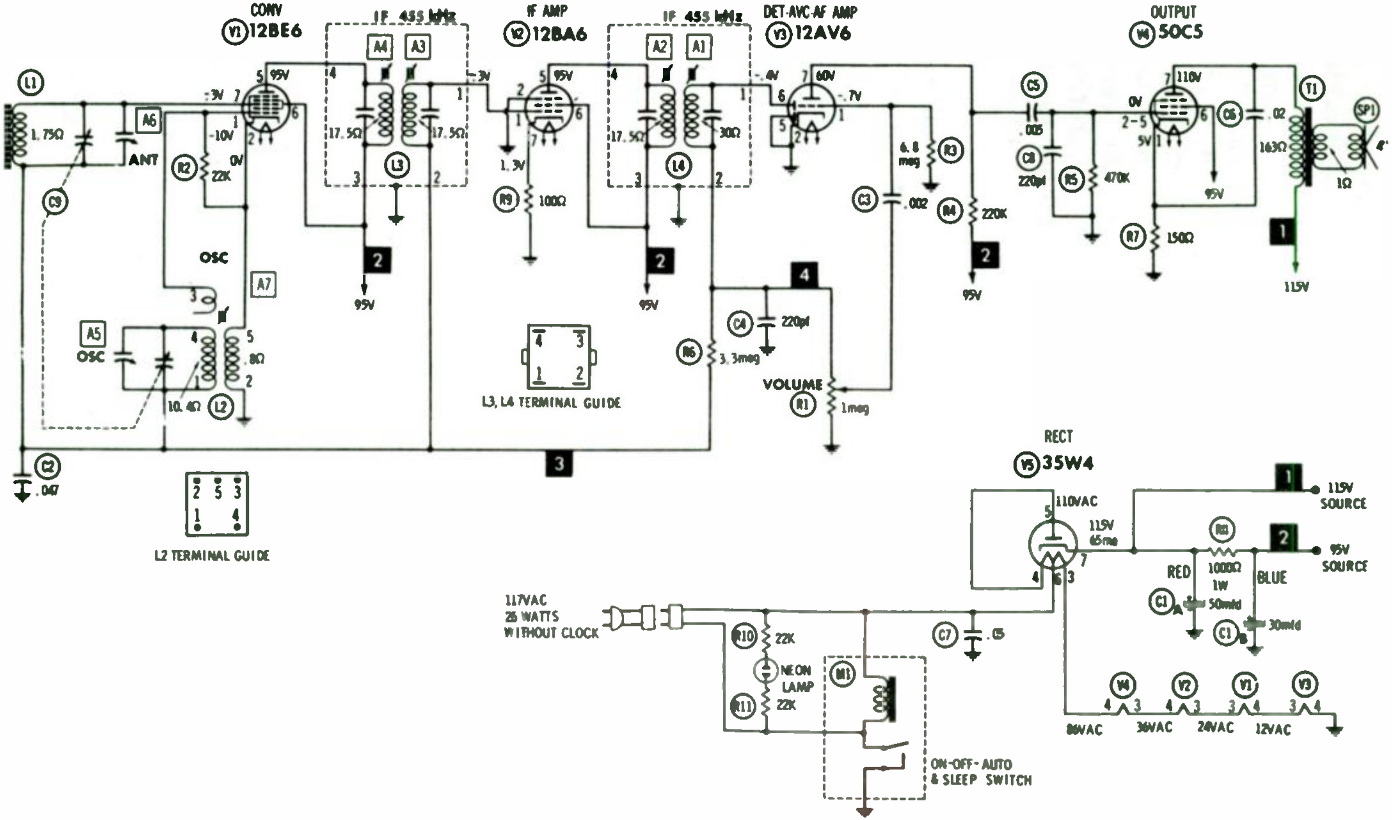


Figure 24 — Typical AM radio receiver circuit.

tion of the circuit diagram in Figure 24. Although the tube type is known, its mutual conductance depends on the AVC clamp voltage. This information can sometimes be obtained from a tube manual, but the plate-load impedance into which the tube works can be determined only with lab-type equipment. Reliance must be placed, therefore, on service data for the particular receiver configuration, or on comparative data obtained from a similar receiver which is operating normally.

TYPE OF TEST SIGNAL

An amplitude-modulated test signal is illustrated in Figure 23. Modulation is necessary when using an ordinary signal tacer, but an unmodulated (CW) signal can be used when checking through the RF and IF circuits with a scope.

A CW signal is, of course, not suitable for checking the circuit past the detector, even if a DC scope is used. Although the detector generates a DC output voltage in response to a CW signal, this output is blocked by the audio coupling capacitor. Therefore, an amplitude-modulated signal must be used in these tests. A modulation depth of 30 percent is standard, but is not necessary.

The shape of the modulation envelope may change greatly as the generator is tuned through the receiver passband. Make certain to "center" the generator in the passband for a low distortion audio signal in the AF amplifier.

OSCILLATOR DEFECTS

The applied test signal is of no concern when checking the oscillator because it is a self-generating circuit. If the oscillator is not dead, a sine wave should be present, regardless of whether or not an input signal is present. The normal amplitude of the oscillator output may be given in the receiver service data, or a comparative test can be made in another receiver with the same tube lineup as the receiver under test.

A defective oscillator circuit occasionally has an output signal of normal amplitude, but is off-frequency, making the receiver appear to be dead. This is a particularly difficult trouble condition when appreciable preselection is used in the receiver. It is a simple matter, however, to measure the oscillator frequency with a scope. Observe the number of peaks in the oscillator waveform. Then, apply the signal generator output directly to the scope, and tune the generator for the same number of peaks. The reading on the generator dial is then the same as the oscillator frequency. In normal operation, the oscillator frequency will differ from the RF input frequency by 455 kHz. In most receivers, the oscillator frequency is higher than the signal. (Signal frequency plus the IF frequency equals the oscillator frequency.) Even though the receiver dial may not be highly accurate, this procedure serves as a rough guide in evaluating oscillator operation.

For a more accurate determination, apply an RF signal from the generator to the receiver, and connect the scope probe to the preamplifier output. Then tune the generator for maximum scope deflection. If the circuit is operating properly, the reading of the generator dial will differ 455 kHz from the oscillator frequency.

If the oscillator frequency measures incorrectly (usually too high), look for an open capacitor in the circuit. A defective oscillator coil is a less frequent trouble cause, but is a possibility. To summarize, a preliminary scope test of the oscillator in case of a "dead receiver" complaint can often save considerable time.

TESTING AUDIO AMPLIFIERS

A wide variety of useful tests can be made in audio equipment with a scope. Such equipment ranges from the simple audio amplifiers used in table-model radios, through commercial-sound installations, to high-fidelity amplifiers. The vertical and horizontal amplifiers in service-type scopes are seldom capable of Hi-Fi response. It might, therefore, be supposed that accurate checks of distortion could not be made. It is a general rule that test equipment must have performance characteristics equal to or better than the device under test. There are, however, certain exceptions which are made possible by suitable test techniques.

LINEARITY CHECKS

Amplitude nonlinearity is a basic cause of distortion in audio amplifiers. In order to make a linearity test with a scope, first determine the linearity of the scope itself. This provides a reference pattern for use in evaluating the linearity of an audio amplifier. Connect the output from an audio oscillator to both the vertical- and horizontal-input terminals of the scope, as shown in Figure 25. (The waveform of the audio oscillator is of no concern here.) Now set the audio oscillator frequency to approximately 400 Hz. A diagonal-line display appears on the scope screen.

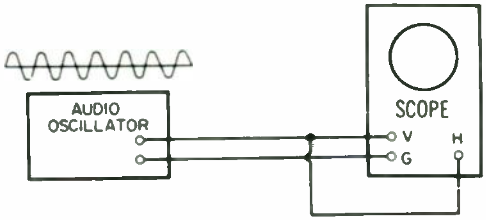


Figure 25 — Check of scope linearity.

If the scope amplifiers are linear, a perfectly straight line will be displayed. If the amplifiers are not linear, the line may have some curvature, as in Figure 26. For an accurate evaluation, place a straightedge along the pattern. This is the reference pattern used in the following test. Connect the equipment as shown in Figure 27. Load resistor R must have an adequate wattage rating, and its resistance should equal the recommended load impedance for the amplifier. The amplifier should be driven to its maximum rated power output. Power output is determined by measuring the AC voltage across R. The voltage is measured in rms units with an ordinary VOM. The power in watts is equal to E^2/R.

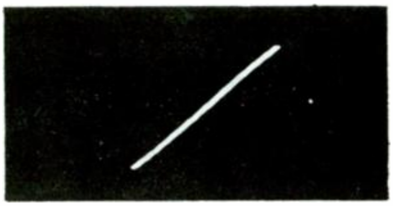


Figure 26 — Reference linearity pattern.

Now, observe the pattern on the scope screen. If it is exactly the same as the reference pattern, the amplifier under test is linear. On the other hand, more or less nonlinearity is indicated by more or less departure from the reference pattern. If the amplifier under test has good performance characteristics, there may be some doubt whether or not the scope pattern really shows any departure from reference. In fact, very small amounts of nonlinearity are difficult to evaluate with certainty.

An amplifier which has substantial nonlinearity at high power output usually shows less nonlinearity when the power output is reduced. Any amplifier develops increasing nonlinearity as the power output is increased. Objectionable nonlinearity at rated power output can be caused by incorrect grid bias, low plate or screen supply voltages, defective transformers, off-value resistors, or open bypass capacitors. Leaky coupling capacitors change the normal grid bias on a tube. Leaky or shorted cathode bypass capacitors change the normal cathode bias. If a coupling capacitor is low in value, the preceding stage must be overdriven to obtain rated power output, with resulting nonlinearity. An open capacitor in a feedback network causes amplitude nonlinearity.

PHASE SHIFT IN AUDIO AMPLIFIERS

Unless the amplifier is defective, it is highly unlikely that you will observe any phase shift in the pattern at 400 Hz. Phase shift in the amplifier under test causes the line pattern to open into an ellipse. The proportions of the ellipse indicate the amount of phase shift. Some key patterns are illustrated in Figure 16. Amplifier defects resulting in phase shift include: low-value coupling, decoupling, and bypass capacitors; defective transformers; or a defect in the feedback circuit.

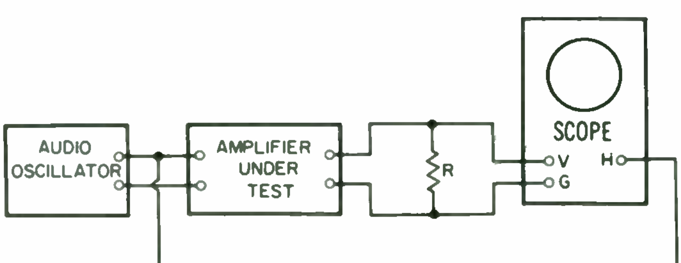


Figure 27 — Amplifier linearity check.

Any amplifier, including the scope amplifiers, will exhibit phase shift at some limiting upper frequency. Here, stray circuit capacitances begin to become significant. The stray capacitances have a partial bypassing effect around plate-load resistors in particular, causing the load to become noticeably reactive at the high test frequency. Phase shift is always the result of reactance. Unless amplifiers are DC coupled, they also exhibit phase shift at some limiting low frequency. This occurs because the values of coupling, decoupling, and bypass capacitors are insufficient to maintain negligible reactance at the low test frequency.

In case of simultaneous amplitude nonlinearity and phase shift, a distorted ellipse is displayed. The ellipse appears more or less flattened, skewed, or egg-shaped, with one end more "open" than the other. In Hi-Fi amplifiers, nonlinearity is more objectionable than phase shift, because listeners detect nonlinear distortion more readily than phase shift in the audible output. The better Hi-Fi amplifiers are designed, however, to minimize phase shift.

When the positive peaks of a sine wave are clipped or compressed (Fig. 28), even harmonics are generated. The waveform is unsymmetrical. If both positive and negative peaks are clipped equally, the resulting waveform is symmetrical, and odd harmonics are generated. Again, if positive and negative peaks are clipped unequally, both odd and even harmonics are developed. Any change in the shape of a sine wave, no matter how gradual, and regardless of the portion of the wave affected, generates harmonics.

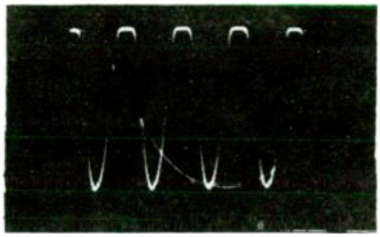


Figure 28 — Severe even-harmonic distortion of a sine wave.

Parasitic oscillation is identified easily in scope tests. It causes a "bulge" on the waveform, usually at the peak. (See Figure 29.) The bulging or ballooning interval consists of a high-frequency oscillation, generally occurring on the peak of drive to a tube which is being driven into grid current. When the grid is being driven positive, the grid input resistance falls to a comparatively low value. Stray reactances in leads and transformer windings can then "see" a high Q which permits a brief interval of high-frequency oscillation. Parasitic oscillation is commonly controlled by connecting small resistors in series with the grid and plate leads at the socket terminals.

Notch distortion, if appreciable, can also be seen in a scope pattern. This difficulty occurs principally in push-pull amplifiers which are incorrectly biased. This distortion is exhibited as irregularities in the

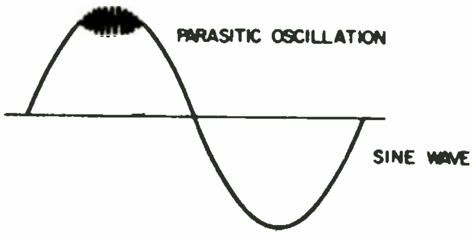


Figure 29 — Appearance of parasitic oscillation on a sine wave.

shape of the sine wave in passing through the zero axis. Notch distortion is aggravated by high-level drive. Any push-pull amplifier develops this type of distortion when driven too hard. If the distortion occurs at rated power output, check the bias voltages at the push-pull tubes. If the bias is correct, check for low plate or screen voltages.

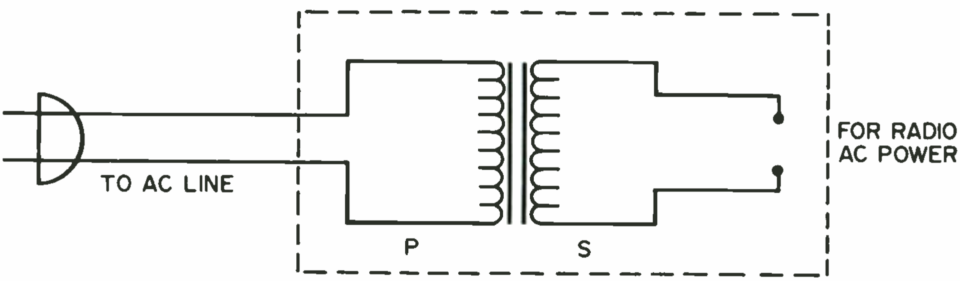
SAFETY WARNING

Many lower-priced consumer electronic products that operate from 120 volt AC power lines are described as "transformerless." This means that the electronic circuit is directly connected to the AC power line and is not isolated by a transformer. When plugged into the power line, even when the AC power is turned off, one side of the AC line of these transformerless receivers is directly connected to a portion of the electronic circuit.

Most transformerless or AC-DC AM tube receivers require about 35 watts of AC power for operation, while the AC-DC AM-FM receiver requires about 60 watts of power. Transistorized models require considerably less, and range from about 10 to 20 watts in power rating. Some black and white TV receivers are transformerless, and their power consumption may be as high as 250 watts.

When working on a transformerless product that is plugged into an AC power socket, one of the two safety procedures listed below should always be followed:

1. Use a 1:1 power line isolation transformer between the receiver and the power outlet.



SECONDARY TURNS = PRIMARY TURNS
OR
OUTPUT VOLTAGE = INPUT VOLTAGE

Figure 30 — Isolation transformer.

Ground the metal chassis of the radio to the power line metallic conduit or BX housing. (See Figure 30).

2. Construct and use the "Safety Tester" as detailed in Figures 31 and 32.

REMEMBER, any voltage over 24 volts is considered to be a hazard to life.

In the United States, one wire in all single phase (two or three wire service leads) is solidly grounded. This neutral lead may or may not be grounded where the electric service enters the house or business structure, but it is certain to be grounded at the utility pole that supports the distribution transformer.

Most electrical inspection codes of cities require that the neutral power lead also be grounded to a cold water pipe in the structure. Codes also require that metallic conduit or BX housing the power leads also be grounded to the cold water pipe at one point. The conduit must not be used to replace or substitute for the neutral power lead. White is the standard color for the neutral lead. The "hot" lead is usually black but may be red or green.

Because of the effective grounding practices of utility companies, be extremely cautious not to touch the "hot" side of the line. Your body can readily complete a circuit path from your hand to your feet for an electric current *that can kill.* Shoes, plastic floor tiles, damp wood or concrete are all poor insulators.

Always inspect the chassis of an electronic unit to determine if it

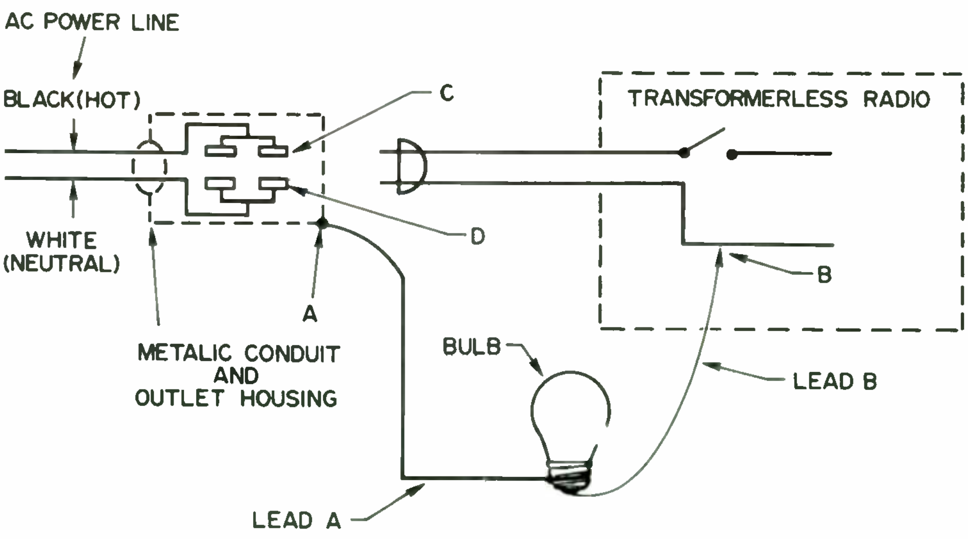


Figure 31 — Safety tester. circuit instructions.

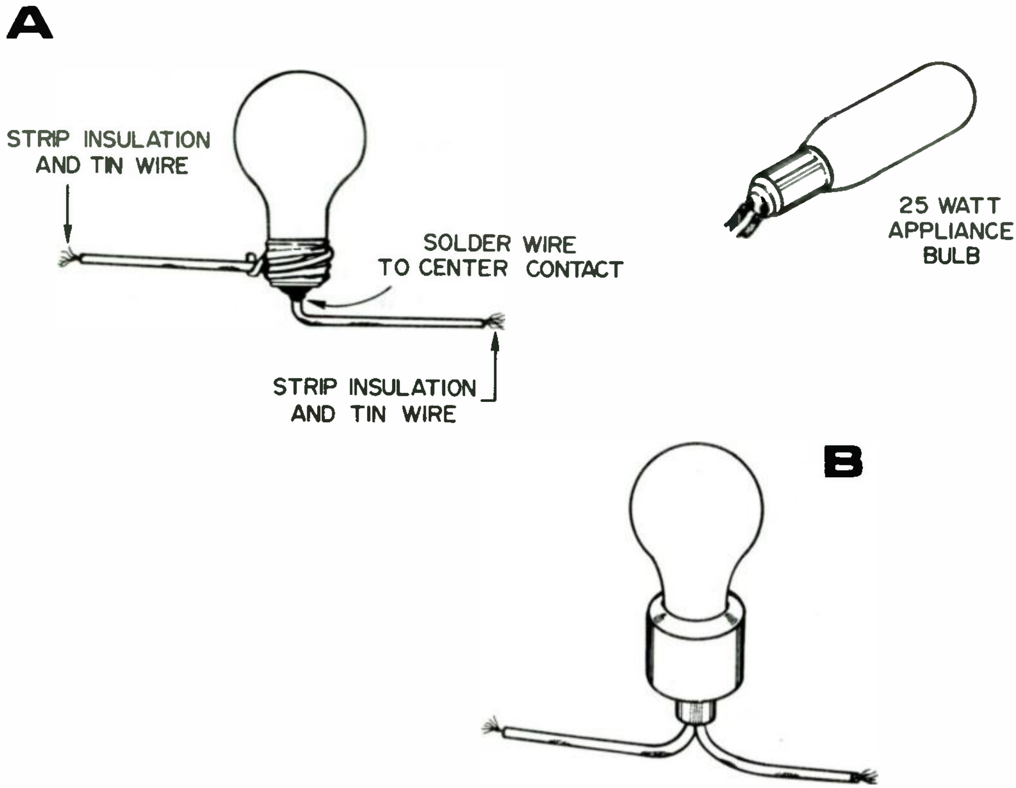


Figure 32 — Make a safety tester.

will create a shock hazard to you when it is plugged into the power line. Inspect the circuit to determine if it is isolated from the AC power line. *If in doubt, use an isolation transformer or a Safety Tester.*

SUMMARY

In this lesson, you have learned the basic adjustments of a service-type oscilloscope. You have learned the difference in magnitude of peak volts vs. peak-to-peak volts.

The method of calibrating a vertical amplifier system of the scope from a known 60 Hz voltage has been detailed.

The generation of Lissajous (Lee-so-zoo) patterns have been explained, and the use of these patterns for phase and frequency measurements have been detailed. Earlier lessons described attenuators; in this lesson, compensated attenuators as used in scope vertical amplifiers are studied.

The need for, the circuits of, and the applications of probes for oscilloscopes have been explained in detail. All of the foregoing information is important to aid you in quickly and efficiently troubleshooting an electronic system.

To increase your ability to troubleshoot, additional material has been presented. This material illustrates the versatility of an oscilloscope in analyzing AM receivers and audio amplifiers.

In the closing portion of this lesson, electrical safety was stressed. A shock hazard is present in any system that is plugged into a power outlet when the protective cover or cabinet is opened or removed. It is important to remember that it's your life—protect it—use caution when working on AC operated equipment.

TEST

Lesson Number 59

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-059-1.

1. An oscilloscope can measure
A. voltage.
B. frequency.
C. gain.
D. all of the above.

2. A compensated step attenuator is used in
A. a VTVM.
B. an AC voltmeter.
C. a peak reading meter.
D. a wide band oscilloscope.

3. To view an AM modulated carrier signal on an oscilloscope, _______ is needed.
A. an AF demodulator probe
B. a low-capacitance probe
15 C. a step attenuator probe
D. an RF demodulator probe

4. The sawtooth waveform produced in an oscilloscope is applied to the
A. vertical deflection plates of the CRT.
5 B. CRT cathode.
C. horizontal deflection plates of the CRT.
D. CRT filament.

5. RMS voltage can be converted to peak-to-peak voltage by multiplying the RMS voltage by

A. 3.16
B. 1.4
11 C. 2.83
D. 0.707

6. Voltage of a complex waveform can only be measured with

A. a signal tracer.
11 + 12 B. a calibrated oscilloscope.
C. an RMS VOM.
D. a calibrated signal strength meter.

7. A circular scope display can be obtained from

13 A. two sine waves having 90° phase difference.
B. two sine waves in phase.
C. a sine wave plus a sawtooth wave.
D. two sine waves differing by 180°.

8. In a super heterodyne receiver, the oscillator frequency is generally

A. higher than the signal frequency.
16 B. lower than the signal frequency.
C. equal to the IF frequency.
D. equal to the signal frequency.

9. When performing gain measurements on an RF or IF system,

A. the AVC voltage can be disregarded.
16 B. the AVC voltage should be disabled.
C. a VTVM should be connected to the AVC circuit.
D. the AVC voltage must be present.

10. Electric utility power systems have

A. poor grounding.
23 B. excellent grounding.
C. no grounding.
D. grounding only at the customer's meter.

Notes

Notes

Notes

Portions of this lesson from
Troubleshooting with the Oscilloscope
by Robert G. Middleton
Courtesy of Howard W. Sams, Inc.

"School Without Walls"
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THE ANGRY CUSTOMER

Four simple rules followed by one service manager in his handling of an angry customer are:

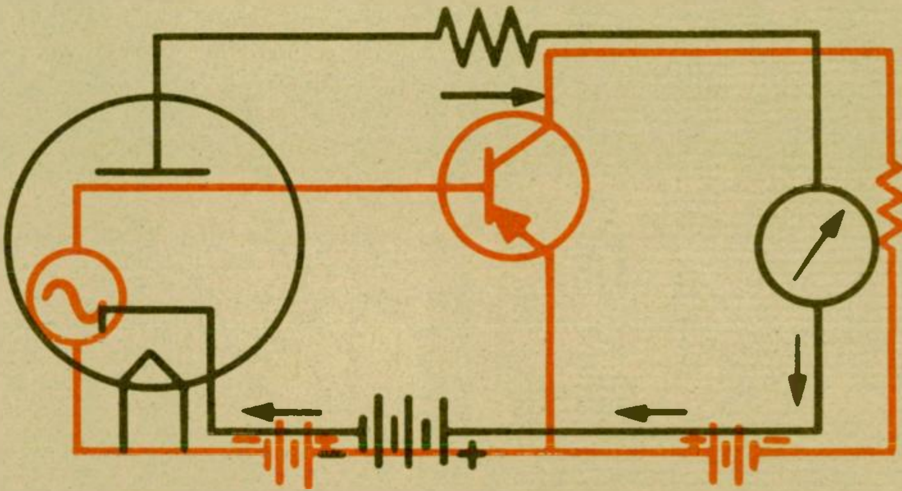
1. Let him talk, "blow off steam," without interruption.
2. Don't lose your cool. Keep your self control at all times.
3. Check out all statements and qualify any existing confusion in your own mind.
4. Take appropriate action to correct the problem.

If you're wrong, say so. If you're right, defend yourself.

S. T. Christensen

LESSON NO. 62

AM RADIO RECEIVERS PART 2



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE NO. 52-062

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CONTENTS

AM RADIO RECEIVERS PART 2

INTRODUCTION

In this lesson we will continue our discussion of AM receivers from Part 1. We will begin with tube-type audio amplifiers, which were discussed only briefly in Part 1. Transistor audio amplifiers will then be examined. They will be covered in relation to those used in current radios, whereas tube-type amplifiers will be related primarily to basic circuits.

TUBE-TYPE AUDIO AMPLIFIERS

The audio section shown in Figure 1 is typical of the ones used in millions of home table radios manufactured over a period of forty or more years. It is called a two-stage amplifier because two stages are used. It is also called single-ended because only one tube is used in the output stage. The input stage is a triode voltage amplifier that receives audio signal voltage from a previous stage and boosts it to a higher level. The higher level audio signal is then used to drive the power amplifier.

The power amplifier is either a power pentode or a beam power tube. Its function is to provide voltage and current to operate the loudspeaker.

3

An input capacitor (C_1 in Figure 1) is used to couple audio signals to the grid of V_2 while blocking any DC voltages present at the output of the previous stage.

4

One of the two commonly used forms of bias may be used to set the operating point of V_1. If resistor R_{aux}. is inserted, the tube is said to be cathode biased. This form is less common than another type that uses a large value grid resistor (R_1 in Figure 1). Electrons attracted to the grid accumulate due to the high resistance path through R_1 and establish a negative potential on the grid. The balance of the amplifier is conventional circuitry. Capacitor C_3 may or may not be included. It bypasses the cathode resistor for the output tube, eliminating negative feedback and a reduction in gain due to this resistor.

PHASE INVERTERS

A phase inverter is a circuit or device that changes the phase of a signal by 180°. One type of phase

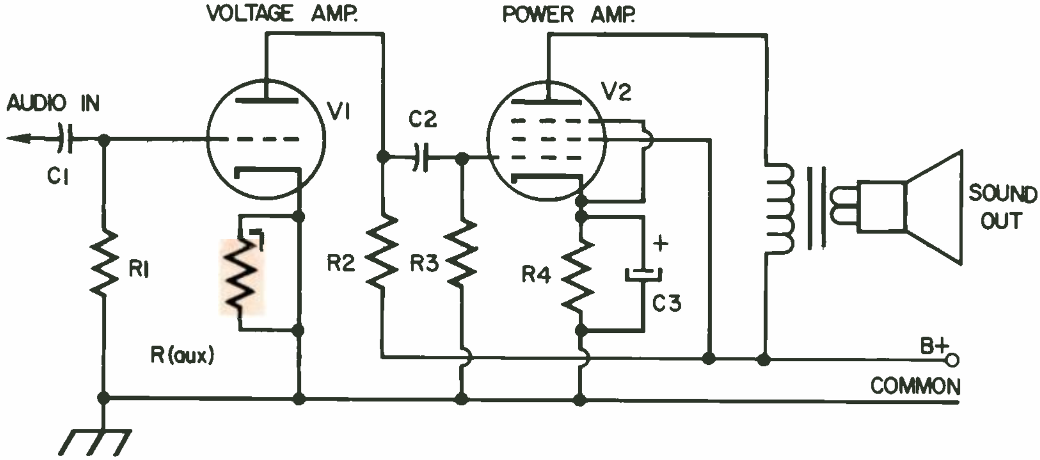

Figure 1 — Two-stage audio amplifier.

inverter is the transformer, with which the instantaneous polarity of the load may be reversed with respect to the source by reversing either the connections of the secondary leads to the load or the primary leads of the source. A conventional electron-tube amplifier (untuned and RC coupled) also produces an output of opposite polarity to the input; if no gain is desired, various methods may be employed to produce unity gain. Either single- or two-tube amplifiers may be used to convert one input waveform into two output waveforms of opposite polarity. Such amplifiers are called PHASE SPLITTERS or PARAPHASE amplifiers.

Transformer Phase Inverter

In operation, all transformers produce across the secondary an induced EMF that is opposed to the change in flux producing it. The instantaneous polarity of the actual output voltage across a load depends on how the leads from the secondary are connected.

Figure 2 indicates phase inversion of square waves and sine waves. With square waves, the polarity has simply been inverted. This is also true for sine waves, but in this case it may be more convenient to refer to the inversion as a 180° phase shift—in effect, the same result as if the waveform had been moved along the time axis 180°. If no change in voltage is desired, a 1-to-1 turns ratio is employed.

A transformer with a center-tapped secondary, as shown in Figure 5, is used in class-B push-pull amplifiers. This type of transformer phase inverter has limited application because of distortions and losses inherent in transformers. For example, the loss in voltage through leakage reactance is greater for higher frequencies than it is for lower frequencies. The shunting capacitance effect and hysteresis losses also increase with frequency. In many circuits where harmonics must be transmitted unattenuated and undistorted, the transformer phase inverter is re-

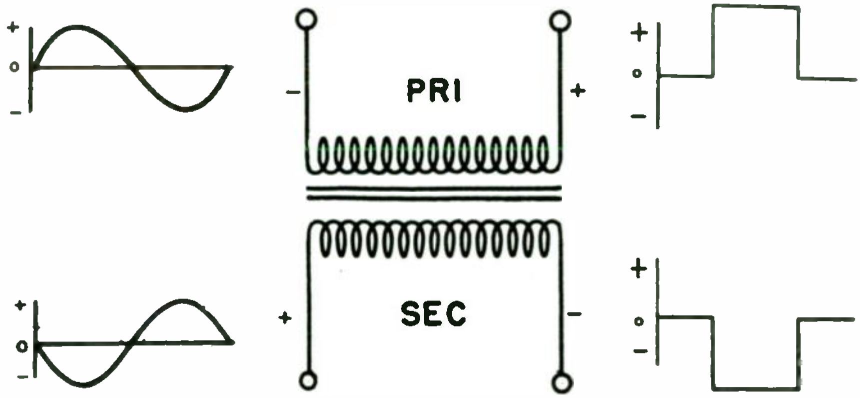

Figure 2 — Transformer phase inversion.

placed with a circuit that performs phase inversion without the use of transformers.

Single-Tube Paraphase Amplifier

6 A form of single-tube paraphase amplifier is shown in Figure 3. The values of resistors R_2 and R_3 are the same. Therefore, the voltage drop across both of them is the same, since the same plate current flows through both. The instantaneous polarities, however, are exactly opposite because at the instant a positive-going signal is applied to the grid, point X becomes less positive with respect to ground and point Y becomes more positive. These signals, with the polarities indicated in the figure, are impressed across

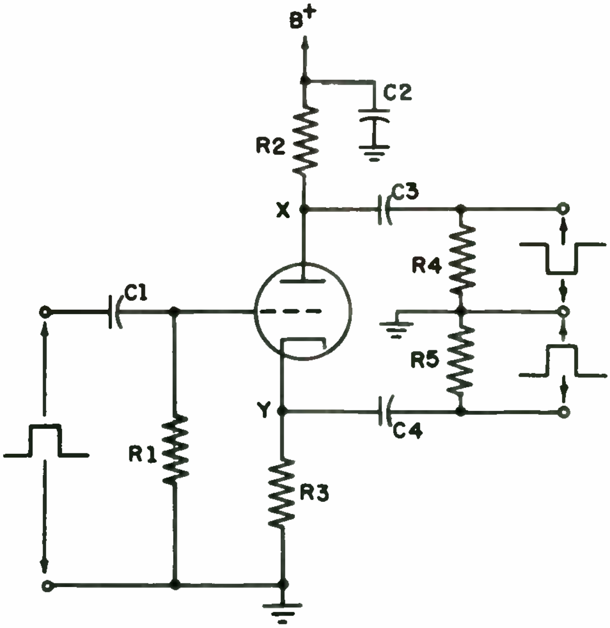

Figure 3 — Single-tube paraphase amplifier.

load resistors R_4 and R_5 through blocking capacitors C_3 and C_4. C_2 is the plate supply bypass capacitor.

In actual practice, this basic type of single-tube paraphase amplifier may be modified to avoid some of the degenerative action due to the unbypassed cathode resistor or it may be compensated to permit a better frequency response.

Two-Tube Paraphase Amplifier

A 2-tube paraphase amplifier is shown in Figure 4. Tube V_1 operates as a conventional amplifier having normal gain, and V_2 operates as a phase inverter, the input of which is reduced to the same value as the input of V_1. Thus V_2 amplifies the signal as much as V_1 and the output is essentially symmetrical about the zero-voltage reference line.

A positive-going signal on the grid of V_1 causes an increase in plate current and a reduction in positive plate potential at point X. This reduction in positive potential is transmitted as a negative-going signal through coupling capacitor C_4 to resistors R_6 and R_7. The grid input of V_2 is tapped off between resistors R_6 and R_7 to feed the proper magnitude of negative-going signal to V_2. For example, if V_1 and its associated circuit has a voltage gain of 50, the resistance of R_7 should be one-fiftieth of the total value of R_6 plus R_7. At the instant a positive-going signal is applied to the grid of V_1, a negative-going signal is thus applied to the grid of V_2. The positive potential at point Y is increased, and a positive-going signal is applied to resistor R_8, through coupling capacitor C_5. At the same time, the negative-going signal appears across resistors R_6 and R_7.

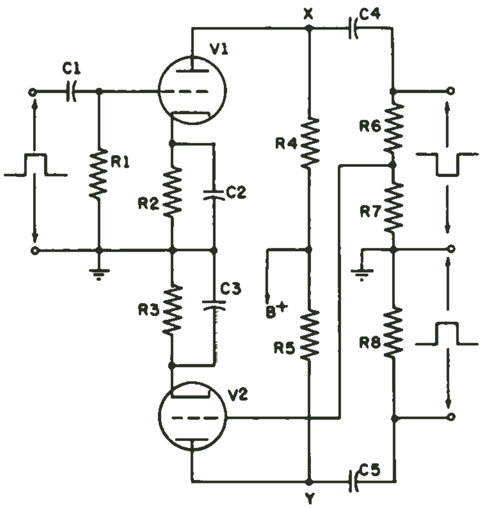

Figure 4 — Two-tube paraphase amplifier.

If the operating conditions of the two tubes are carefully chosen and the circuits are properly adjusted, the two amplified output signals should be essentially undistorted and of opposite instantaneous polarity. In actual practice this method presents some difficulty because the adjustments are critical. However, it is widely used as a means of driving class-A push-pull audio power amplifiers.

PUSH-PULL POWER AMPLIFIERS (VACUUM TUBE)

There are several advantages of a push-pull amplifier as the output stage of an audio-frequency amplifier. Second harmonics and all evenly numbered harmonics are eliminated. Hum from the plate power supply is eliminated because ripple components in the two halves of the primary of the output transformer counteract each other in the output.

Plate-current flow through the two halves of the primary winding is equal and in opposite directions. Therefore, there is no DC core saturation and the low-frequency response is improved.

Regeneration is also eliminated because signal currents do not flow through the plate-voltage supply when the circuit is operated as a class-A amplifier.

The voltage amplifier driving the push-pull power amplifier may be either resistance- or transformer-coupled to the power stage. If the power amplifier is operated class A or class AB, resistance coupling is used because it affords a better frequency response. A phase-inverter tube (discussed later) or section of a tube must be used in connection with the resistance-coupled driver to provide the correct phase relation at the input of the push-pull stage.

When the power tubes are operated class B, an input transformer employing a stepdown turns ratio is commonly used. The transformer not only supplies the grid current necessary for class-B operation, but at the same time permits an instantaneous signal voltage of the correct polarity to be applied to the grids of the two power tubes.

Class-B power amplifiers draw practically no plate current when no signal is applied, and plate efficiency is much higher than that of class-A amplifiers. They are subject, however, to third-harmonic distortion, and the operating conditions are critical.

Transformer-Coupled

7

A transformer-coupled, push-pull amplifier is shown in Figure 5. Class A operation is assumed.

When no signal voltage is applied, equal plate currents flow through each tube. Equal currents also flow through each half of the primary of the output transformer toward the center tap. The magnetomotive forces resulting from the currents are equal and opposite and therefore cancel, leaving no magnetic field because of the DC component of the plate current. This cancellation effect is a big advantage over the single-tube output in which direct current flows continuously through the primary winding.

A signal voltage across the secondary of the input transformer, T_1, will at a given instant have polarities as indicated. This voltage will be divided equally between tubes A and B. The push-pull arrangement thus requires, and will handle, twice the input voltage of a single tube under similar operating conditions. The grid of tube A is positive with respect to the center tap at the instant the grid of tube B is negative. Plate current increases in tube A and decreases a proportionate amount in tube B.

The increase in current flowing down through L_{p1} and the decrease in current flowing up through L_{p2} constitute two magnetomotive forces that combine additively to produce an output voltage in the secondary that is proportional to the sum of these two components.

Second harmonics are eliminated in push pull output. The dynamic i_p-e_g curve for tube B is inverted with respect to that of tube A. Thus, when the input signal swings the grid voltage of tube A in a positive direction it is swinging the grid voltage of tube B the same amount in a negative direction.

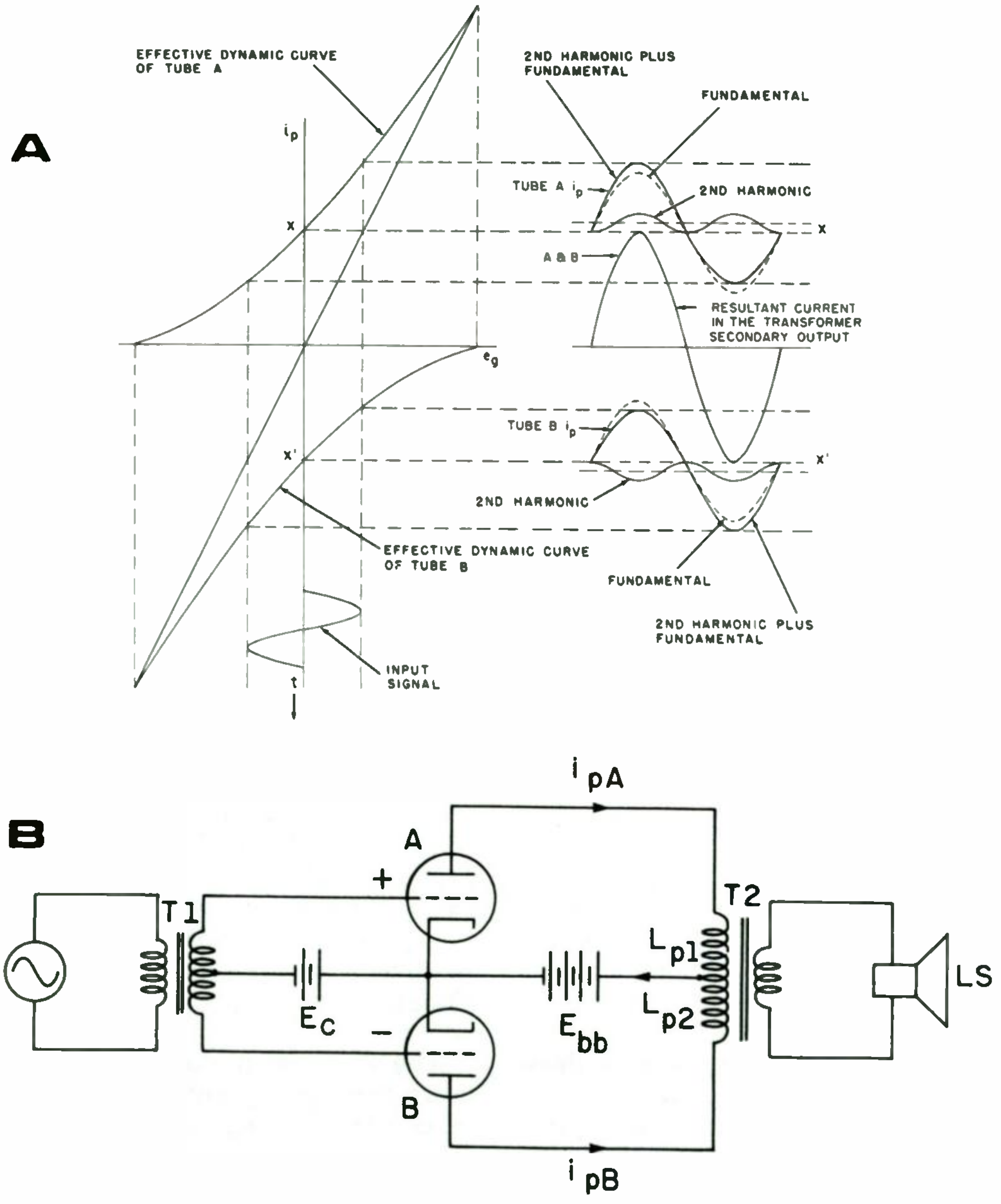

Figure 5 — Transformer-coupled push-pull amplifier.

Plate current in tube A increases as plate current in tube B decreases. The plate current swing about the X-X axis for tube A is not symmetrical because the tube is operating on a nonlinear portion of the i_p-e_g characteristic curve. The same condition is true of the plate current swing about the X′-X′ axis for tube B.

The plate-current curves of each tube may be resolved into a fundamental and second harmonic. The axis of the fundamental and its second harmonic is displaced from the axis of the original plate current curve by an amount equal to the peak value of the second harmonic. Combining the fundamental components of both tubes gives an output of twice the amplitude of one tube. However, when the second harmonics are combined, the resultant is zero because they are equal in amplitude and 180 degrees out of phase. The fundamental output current has the same waveform as the input voltage.

TRANSISTOR AMPLIFIER CIRCUITS

Classes of Operation

Transistor amplifiers, like electron tube amplifiers, may be operated class A, B, AB, or C.

When operated class A, they are operated on the linear portion of the collector characteristic curve. The class A biased transistor has a continuous flow of collector current during the entire cycle, whether a signal is present or not; this flow corresponds to the action of an electron tube. Transistors may be operated class A in either single-ended or push-pull circuits.

Class B amplifiers can be biased either for collector current cutoff or for zero collector voltage. They are always operated push-pull to avoid serious audio distortion. The best power efficiency is obtained when they are biased for collector current cutoff, since collector current will flow only during that half-cycle of the input voltage that aids the forward bias. When biased for zero collector voltage, a heavy current flows when no signal is present, and practically all the collector voltage is dissipated across the load resistor. Although heavy current flows, the power dissipation in the transistor is very low because power is the product of both current and voltage, and the voltage is practically zero (due to the small voltage drop across the very low impedance of the transistor). The collector current varies only during that portion of the cycle when the input voltage opposes the forward bias. Under these conditions, low efficiency is obtained and the current gain is appreciably reduced.

The class AB transistor amplifier is biased so that the collector current or voltage is zero for less than a half-cycle of operation. In this case, the efficiency is somewhat greater than that for class A, but less than that for class B.

Class C amplifiers are biased so that the collector current or voltage is zero for more than a half-cycle; thus, they are not used for audio amplification because of the serious audio distortion produced. They are used, however, for RF applications.

Coupling Methods

Transistor amplifiers are connected in cascaded stages to amplify a low input signal to a high output. Coupling between stages is accomplished by using resistance-capacitance (RC) networks, impedance networks, transformers, or by directly connecting the output element of one stage to the input element of the succeeding stage.

As all coupling networks are frequency responsive to a certain extent, some coupling methods afford better results than others for a particular circuit configuration. Generally speaking, RC coupling affords a wide frequency response with economy of parts and full transistor gain capabilities; impedance and transformer coupling provide a more efficient power matching capability with moderate frequency response, while direct coupling provides the maximum economy of parts with excellent low-frequency response and DC amplification.

The RC coupling (Fig. 6A) utilizes two resistors and a capacitor to form an interstage coupling device which provides a broad frequency response, economy of parts, and small physical size. It is used extensively in audio amplifiers, particularly in the low-level stages. Because of its poor input-output power conversion efficiency, it is seldom used in power output stages. Resistor R_L (Fig. 6A) is the

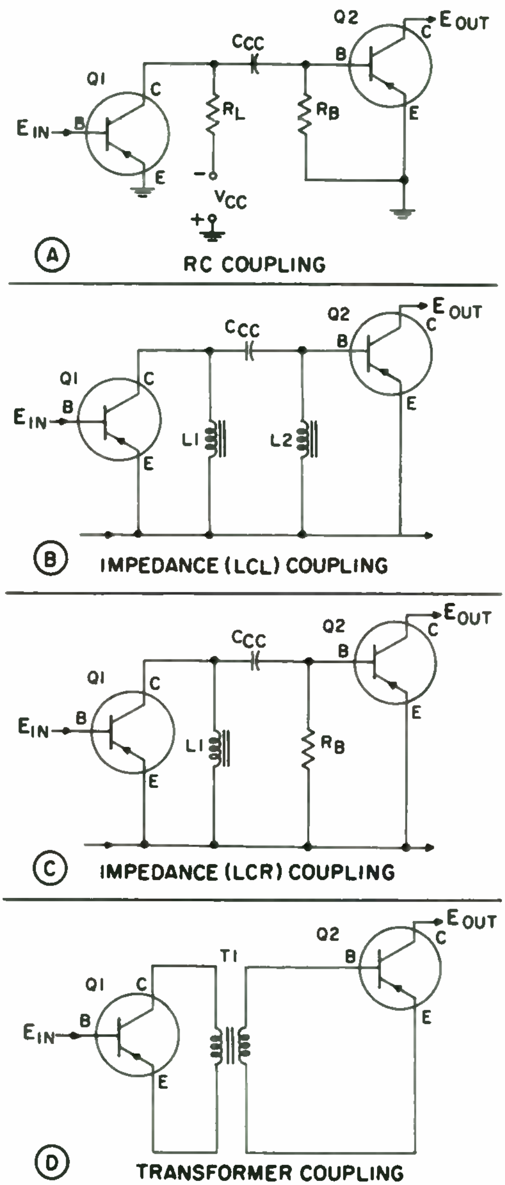

Figure 6 — Transistor amplifier coupling networks.

collector load resistor for the first stage, capacitor C_{CC} is the DC voltage-blocking and AC signal-coupling capacitor, and R_B is the input-load and DC return resistor for the base-emitter junction of the second stage.

As the input resistance of the second stage is low (on the order of 1000 ohms for a common-emitter circuit) and the reactance of the coupling capacitor is in series with the base-emitter internal input resistance, C_{CC} must have a low reactance to minimize low-frequency attenuation because of a large signal drop across the coupling capacitor. This is achieved by using a high value of capacitance; thus, for low audio frequencies, values of 10 to 100 microfarads or more are used.

To prevent shunting the input signal around the low base-emitter input resistance, the base DC return resistor, R_B, is made as large as practical with respect to the transistor input resistance. Since increasing the base series resistance deteriorates the temperature stability of the base junction, the value selected for the input resistor is a compromise between reducing the effective shunting of the input resistance and maintaining sufficient thermal stability over the desired temperature range of operation.

The high-frequency response is normally limited by the stray circuit capacitance plus the input and output capacitance; hence, the transistor itself is usually the limiting factor. The low-frequency response is normally limited by the time constant of the coupling capacitor, C_{CC}, and the base return (input) resistance, R_B. For good low-frequency response, the time constant must be long in comparison to the lowest frequency to be amplified.

The impedance coupling network is one in which one or both resistors of the RC network are replaced by an inductor as shown in Figure 6, parts B and C. The power-handling (and matching) capabilities of the inductor provide more output than the load resistor. While the overall frequency response of impedance coupling is not as good as that of resistance coupling, it is much better than that of transformer coupling, because there are no leakage reactance effects. The high-frequency response of the impedance coupler is limited mainly by the collector output capacitance, and the low-frequency response is limited by the shunt reactance of the inductor, L_1. The efficiency of the impedance coupler is approximately the same as that of the transformer-coupled circuit.

Transformer coupling (Fig. 6D) is used extensively in cascaded transistor stages and power output stages. It provides good frequency response and proper matching of input and output resistances with good power conversion efficiency. It costs more and occupies more space than the simple RC circuit components, but it compares favorably in these respects with the impedance coupler. Its frequency response is less than that of the resistance or impedance coupled circuit.

Coupling between stages is achieved through the mutual inductive coupling of the primary and secondary windings. As these windings are separated physically, the input and output circuits are isolated for DC biasing, yet coupled for AC signal transfer. The primary winding presents a low DC resistance, minimizing collector current losses and allowing a lower applied collector voltage for the same gain as other coupling methods. It presents an AC load impedance which includes the reflected input (base-emitter) impedance of the following stage. The secondary winding also completes the base DC return path and provides better thermal stability because of the low DC (winding) resistance. Since the transistor input and output impedance can be matched by using the proper turns ratio, maximum available gain can be obtained from the coupling.

As in the impedance coupler, the shunt reactance of the transformer windings causes the low-frequency response to drop off, while high-frequency response is limited by the leakage reactance between the primary and secondary windings, in addition to the effect of collector capacitance. Because of the low DC resistance in the primary winding, no excess power is dissipated, and the power efficiency approaches the maximum.

Direct coupling is used for amplification of DC and very low frequencies. As in electron tube circuits, this method of coupling is limited to a few stages since all signals are amplified, including noise. Its use in power output stages is limited because of the low conversion efficiency. It does offer an economy of parts, and it lends itself to the use of complementary-symmetry circuitry (discussed later).

Figure 7 shows a basic direct-coupled amplifier utilizing two PNP transistors and two power sources. When a signal is applied to the base of Q_1, the amplified output is directly applied to the base of Q_2

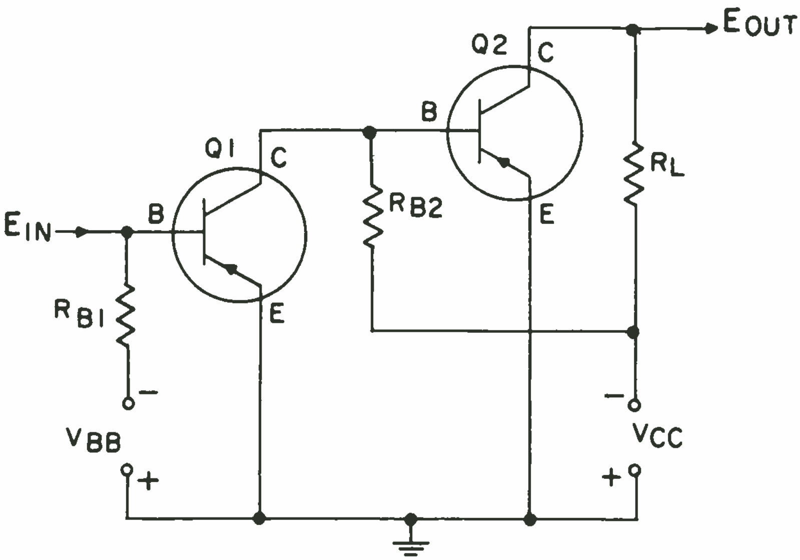

Figure 7 — Basic direct-coupled amplifier.

from the collector of Q_1. The output is taken from load resistor R_L of Q_2.

Figure 8 shows a basic direct-coupled amplifier connection not possible with electron tube amplifiers. The common-base circuit of Q_1 is direct-connected to the common-emitter circuit of Q_2. Thus the input circuit of Q_2 is the load for Q_1, and collector bias for Q_1 is obtained through the collector-to-base junction of Q_2. As Q_2 biases Q_1, only one power source is needed.

A complementary-symmetry direct-coupled amplifier circuit uses a NPN and PNP transistor as shown in Figure 9. As in Figure 8, the collector bias for Q_1 is obtained from the base-collector junction of Q_2.

If another stage were added, an additional and larger collector bias supply would be required to maintain the collector-to-base potential negative for each stage. This limitation is analogous to that of the DC supply for the electron tube amplifier. It is also evident that a shift of DC bias potential would be amplified and passed along to the second amplifier, whereas in the AC coupled (resistance-capacitance) amplifier such DC shift would be blocked by the coupling capacitor.

The use of complementary symmetry whereby one transistor is used to bias another with DC coupling affords the minimum of component parts possible, and represents an economic advantage that is possible only with transistors.

Bias Stabilization

The no-signal direct current and voltage values are determined by the applied bias, which sets the operating point of the transistor. Under ideal conditions, temperature would not affect the bias and the transistor circuit would be thermally stable. In actual operation, however, a temperature increase causes an increase in the flow of transistor reverse-bias collector current (I_{CBO}). (This current is also sometimes referred to as reverse

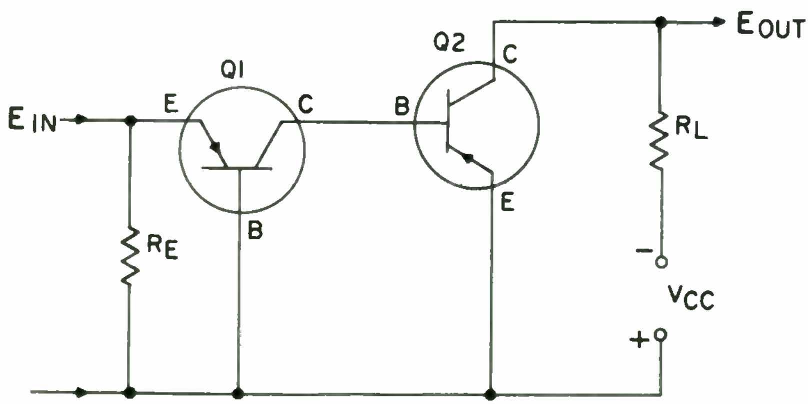

Figure 8 — Common-base to common-emitter direct-coupled amplifier.

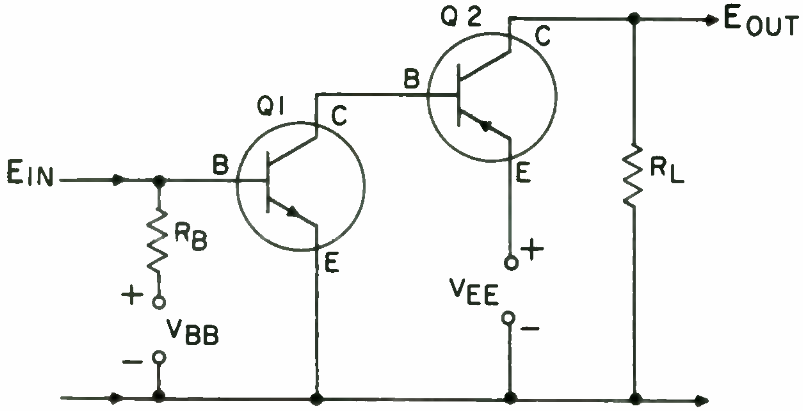

Figure 9 — Complementary-symmetry direct-coupled amplifier.

current, leakage current, back current, or saturation current.) The increase in I_{CBO} causes the temperature of the collector-base junction to increase, causing a further increase in I_{CBO}. This cycle can continue until severe distortion occurs or the transistor destroys itself. This condition, called thermal runaway, is minimized by using a low value, rather than a high value, resistance in the base circuit.

Variation of reverse current with the temperature of the base-collector junction is shown by the graph in Figure 10. Note that at temperatures below 10°C the reverse current causes no problem, and is negligible up to 50°C.

Another consideration is that the emitter-base junction resistance of a transistor has a negative temperature coefficient. Thus, as the temperature of the transistor increases, the emitter-base resistance decreasess, causing an increase in collector current. Figure 11 shows this variation of collector current with temperature. Each curve is plotted with a fixed collector-base voltage (V_{CB}) and a fixed emitter-base voltage (V_{EB}).

One method of reducing the effect of the negative temperature coefficient of resistance is to place a large value resistor (called a swamping resistor) in series with the emitter. This causes the variation of the emitter-base junction resistance to be a small percentage of the total resistance in the emitter circuit. The swamping resistor

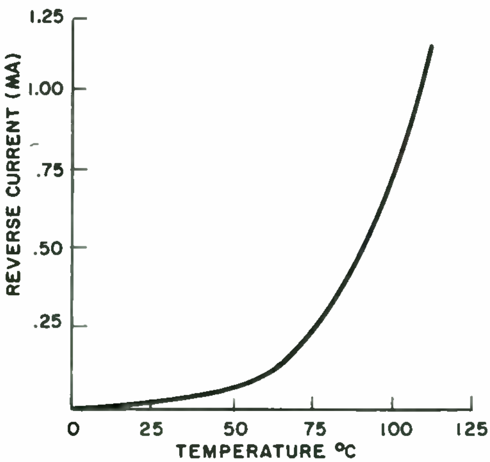

Figure 10 — Reverse current versus junction temperature.

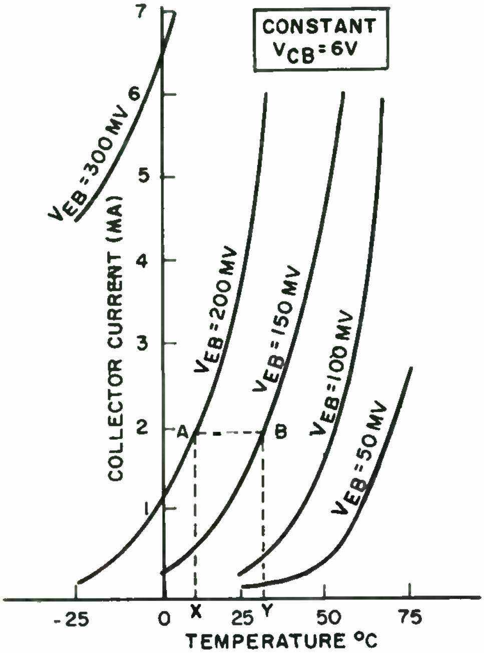

Figure 11 — Collector current versus transistor temperature.

swamps (overcomes) the junction resistance. Thus, the variation of emitter-base resistance with temperature is such a small portion of the total emitter series resistance that it has little effect on the collector current.

Another method of compensating for emitter-base resistance change with temperature, is to reduce the emitter-base forward bias as the temperature increases. For example, as shown in Figure 11, to maintain the collector current constant at 2 ma while the transistor temperature varies from 10°C (at X) to 30°C (at Y), the forward bias (V_{EB}) must be reduced from 200 MV (at A) to 150 MV (at B). This reduced forward bias with temperature increase effect, may be accomplished by various bias stabilization circuit arrangements as discussed below.

Feedback bias stabilization circuits compensate for emitter-base resistance change with temperature by feeding back an opposing voltage proportional to the temperature change.

In Figure 12, the circuit for part A represents both AC and DC feedback. When resistor R_f is divided into two parts and bypassed by capacitor C_1 as shown in part B, the feedback loop is shunted, and only DC bias variations affect operation.

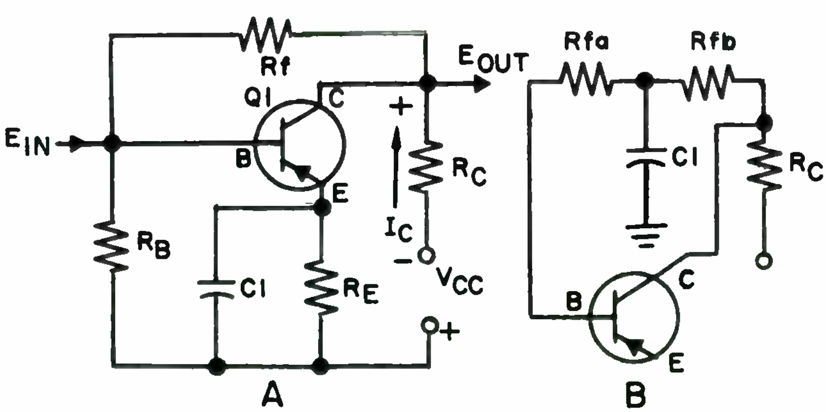

Figure 12 — Negative feedback bias circuit.

Compensation is achieved as follows: When the collector current (I_C) increases, the collector becomes less negative because of the larger positive voltage drop across resistor R_C. As the drop across R_C opposes the initial bias, less forward bias is applied to the base through feedback resistor R_f, and the collector current automatically decreases to the original value (provided that the proper feedback ratio is maintained). There are two other types of compensation for the circuit in part A of Figure 12: voltage-divider stabilization through R_B and emitter current feedback through R_E.

In Figure 13, three variations of the voltage feedback circuit are shown. The circuit of part A represents voltage feedback alone. Actually, for DC biasing conditions. R_f and R_C can be considered as one resistor having a value equal to that of an external self-bias resistor. Any change of current through R_C, therefore, will either increase or decrease the bias applied through R_F.

In part B of Figure 13, the addition of resistor R_B produces a voltage divider across the bias supply so that in addition to voltage feedback, the effect of voltage-divider stability is offered. In part C of Figure 13, current feedback through emitter resistor R_E is added, and when the resistor R_B (shown by dotted lines) is also added, a combination of voltage and current feedback, together with voltage-divider stabilization, is obtained.

Thermistor bias stabilization compensation circuits have been developed, but they all use the same principle of changing bias inversely with temperature to compensate for the change.

Figure 14 shows a voltage-divider base-bias arrangement using a thermistor to compensate for emitter current changes with temperature. When the emitter current tends to rise with temperature, the thermistor, having a negative temperature coefficient of

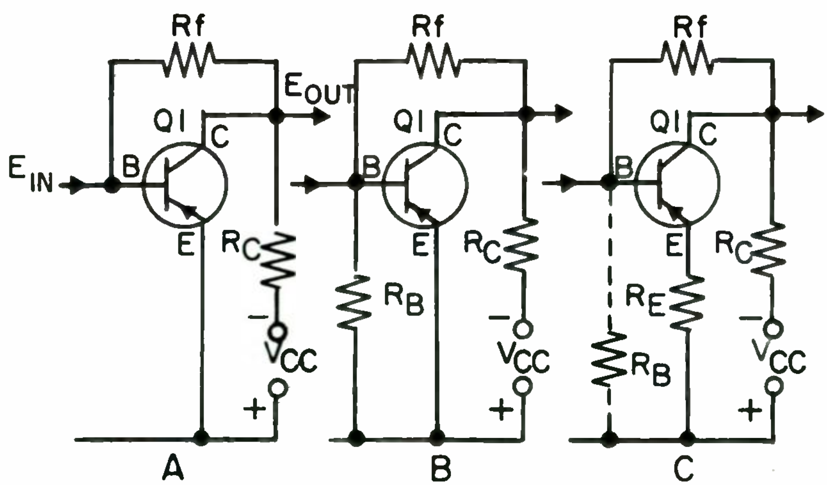

Figure 13 — Voltage feedback circuits.

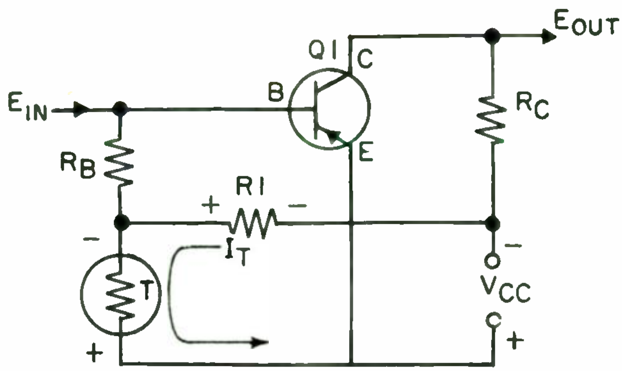

Figure 14 — Thermistor base-bias compensating circuit.

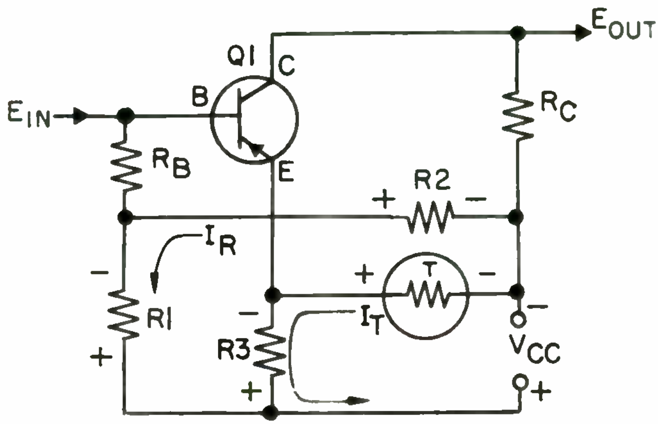

Figure 15 — Thermistor emitter-bias compensating circuit.

resistance, reduces in value as the temperature increases. This reduction in resistance increases the current flow from the V_{CC} supply and causes an increased voltage drop across R_1. The base bias is reduced correspondingly, lowering the emitter current and compensating for the temperature change.

Figure 15 shows an emitter bias compensator in which the base bias is provided by a voltage divider consisting of R_1 and R_2, and compensating emitter bias is provided by R_3 and the thermistor. The drop across R_3 applies a reverse bias to the emitter as the temperature increases, reducing the emitter current correspondingly.

As the thermistor is constructed of a material different from that of the transistor, it does not change resistance in exact proportion to the emitter current change; therefore, "tracking" is not very good and true compensation occurs at only a few points over the operable range. Semiconductor diodes provide more ideal compensation, as discussed below.

Forward biased diode stabilization. The bias stabilization circuit shown in Figure 16 uses semiconductor diode CR_1 as a forward biased diode to compensate for emitter-base resistance variations with temperature changes.

The path for the Q_1 base-emitter bias current (Fig. 16) is from the negative terminal of V_{CC} via R_1, the secondary of T_1, the Q_1 base-emitter and back to the positive V_{CC} terminal. The Q_1 base-emitter bias voltage (of the order of a few tenths of a volt) is equal to the V_{CC} voltage minus the voltage across R_1. (The DC resistance of the T_1 secondary is negligible.

Diode CR_1 has the same negative temperature coefficient as the Q_1 base-emitter junction. The CR_1 current path is from the negative V_{CC} terminal via R_1 up through CR_1 to the positive V_{CC} terminal.

An increase in the temperatures of Q_1 and CR_1 will cause each to decrease in resistance. As the resistance of CR_1 decreases, the current through CR_1 and R_1 increases, with a corresponding increase in voltage drop across R_1 resulting in a decrease in the Q_1 base-emitter bias voltage. As the Q_1 base-emitter bias current depends upon both the base-emitter bias voltage and the base-emitter junction resistance, if both decrease by the same amount, the Q_1 base-emitter bias current will remain constant, thus maintaining the collector current constant.

Reverse biased diode stabilization. The circuit of Figure 17 employs semi-conductor diode CR_1 as a reverse biased diode to compensate for transistor reverse current variations with temperature. This type of circuit is effective over a wide range of temperatures when the diode is selected to have the same reverse current as the transistor.

Two current paths are provided by the circuit shown in Figure 17. The base-emitter current (I_{BE}) flows internally from the base to the emitter, then externally through R_E and V_{CC}, and through resistor R_1 back to the base, and is not materially affected by diode CR_1 because

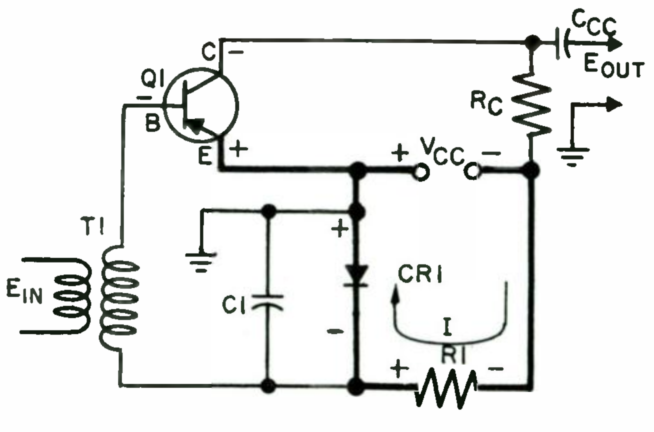

Figure 16 — Forward-biased diode stabilization circuit.

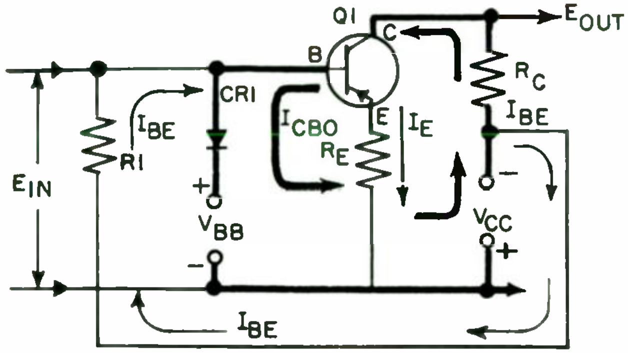

Figure 17 — Reverse-biased diode stabilization circuit.

of its high resistance in the reverse direction. The other path provides for the reverse current from collector to base, through CR_1, V_{BB}, and V_{CC}, and through collector load resistor R_C to the collector. The effects of temperature-dependent variations in the emitter-base junction resistance are minimized by the swamping action of resistor R_E in the first path. Variations of reverse current with temperature are compensated for by the second path, using diode CR_1.

When a temperature increase causes the I_{CBO} current in Q_1 to increase, the CR_1 diode resistance decreases, causing the shunt path around the Q_1 base-emitter junction to decrease in resistance, so that there is no chance for the I_{CBO} current carriers in the junction to pile up, increase the Q_1 base-emitter forward bias, and cause a consequent rise in collector current. As a result, although the I_{CBO} current does increase, the base-emitter current does not, and there is only a negligible change in Q_1 total collector current. In effect, diode CR_1 operates similarly to a variable grid-leak bias in an electron tube circuit. The reverse bias permits only a few microamperes to flow in the base-emitter circuit, while at the same time compensating for transistor collector to base reverse current changes with temperature.

Double diode stabilization. The circuit shown in Figure 18 utilizes two junction diodes in a back-to-back arrangement. Junction diode CR_1 is forward biased and compensates for emitter-base junction resistance changes with temperatures below 50°C. Diode CR_2 is reverse biased and compensates for higher temperatures, as discussed below.

Reverse biased diode CR_2 can be considered inoperative at room temperatures and below. When the junction temperature of Q_1 and CR_2 reach the point where reverse current flows, CR_2 conducts and current (I_1) flows through R_2, producing a voltage drop with the polarity, as shown. This voltage drop is in the proper direction to reduce the forward bias set up by diode CR_1 and R_1; its net effect is to reduce the total collector current in

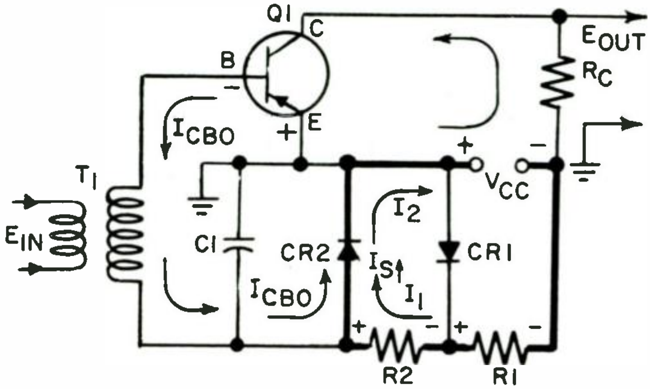

Figure 18 — Double diode stabilization circuit.

order to compensate for the increase in transistor I_{CBO} due to temperature increase.

The reverse biased diode CR_2 is selected to have a larger reverse current (I_S) than the transistor it stabilizes. Current I_2 consists of the Q_1 and CR_2 reverse currents, plus the current through R_2 ($I_2 = I_{CBO} + I_S + I_1$). Thus, the diode reverse current controls the transistor at all times, effectively reducing the forward bias as the temperature increases, and stabilizing the collector current. Capacitor C_1 bypasses both diodes for AC, so the bias circuit is not affected by signal variations.

Audio Amplifiers

The transistor audio amplifier is similar to the electron tube type. There are, however, some significant differences which must be considered. For example, the electron tube audio amplifier normally operates as a voltage amplifier except for the final output stage, while the transistor audio amplifier operates as a current amplifier in all stages. The electron tube represents a high-impedance, voltage-sensitive device, while the transistor represents a low-impedance, current-sensitive device.

As the transistor is basically a low-resistance device, it may draw current from the input source of the preceding stage.

While the types of transistor amplifiers are similar to the types of electron tube amplifiers (such as preamplifiers, driver-amplifiers and output stages), the power levels employed are much lower.

Cascade amplifiers. Transistor amplifier stages may be connected in cascade as illustrated in Figure 19. Transistors Q_1 and Q_2 are PNP junction transistor audio voltage amplifiers, and Q_3 is a PNP junction transistor power amplifier.

Each stage is *single-ended.* Transformer T_1 is a stepdown matching transformer that couples a high-impedance microphone to a low-impedance input circuit. Interstage coupling transformers T_2 and

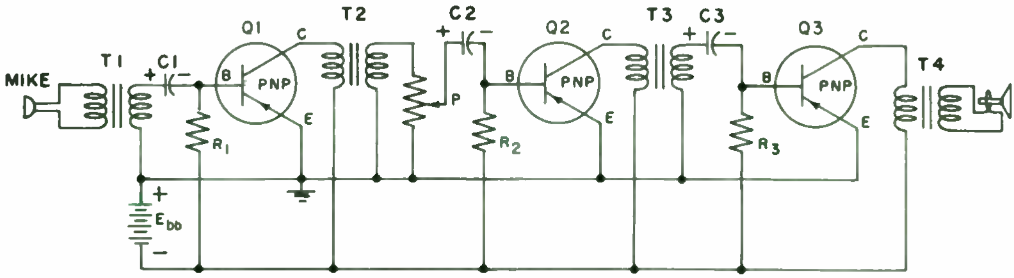

Figure 19 — Cascade connection of transistor amplifiers.

T_3 match the output impedance of one stage to the input impedance of the next. These impedances are not widely different. For example, the output impedance of Q_1 may be 2,000 ohms and the input impedance of Q_2 may be 1,000 ohms. Transformer T_4 is a stepdown transformer that couples the output signal in the collector circuit of the third stage to the low-impedance voice coil of the reproducer. Capacitors C_1, C_2, and C_3 block the DC bias from the secondaries of T_1, T_2, and T_3, and couple the signal to the input circuits. Potentiometer P serves as a volume control for the amplifier. Volume increases as the arm is moved toward the upper end of T_2. Resistors R_1, R_2, and R_3 limit the no-signal base-emitter bias current to the proper value for each stage. The grounded-emitter is common to all input and output circuits, and the polarities of the input and output DC voltages for each stage correspond to those required by PNP junction transistors.

Transistor power amplifiers are usually connected in *push-pull* because of the advantages over single-ended operation. The most important advantages are the reduction in distortion and the removal of DC core saturation from the output transformer. Second harmonic distortion and other distortion caused by even-order harmonics are cancelled in push-pull class A amplifiers. The load impedance and the output power are twice the values for single-ended operation. The incremental inductance of the output transformer is higher as a result of the elimination of the DC component of primary current.

A class A push-pull amplifier using PNP transistors is illustrated in Figure 20A. The characteristic curves for these transistors are illustrated in Figure 20B. When biased for class A operation, the no-signal collector current is 4 ma (point B on the load line). The corresponding base current is 100μ A. The voltage across the bias resistor, R_B, the difference between the battery voltage and the drop across the base-emitter circuit, or $7.5 - 0.1 = 7.4$ V. The no-signal base-emitter current through R_B is the sum of the base-emitter current supplied to each transistor, or 200μ A. The resistance of R_B is

$$\frac{7.4}{200 \times 10^{-6}} = 37{,}000 \text{ ohms}$$

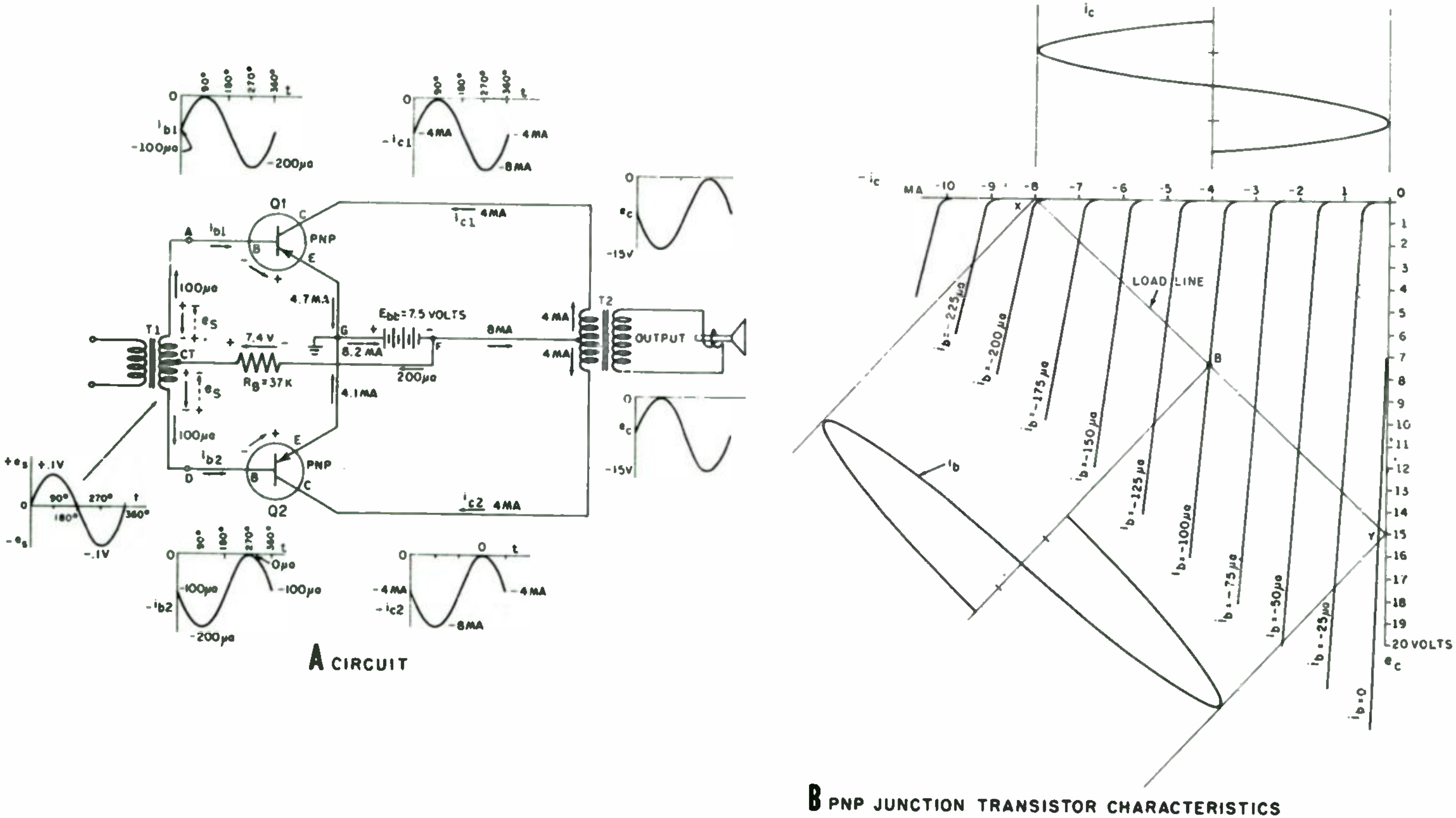

Figure 20 — Transistor push-pull amplifier.

Consider the action of the input signal on the base-emitter current of each transistor. When t = 0° the input signal is 0, and the base-emitter current through R_B divides at CT, flowing in opposite directions through the two halves of the secondary of T_1.

When t = 90°, the signal voltage has a peak value of 0.2 V, and the direction is represented by the solid arrows. The signal voltage is distributed equally between both halves of the secondary of T_1 with 0.1 V acting in each half. By tracing GFCABEG around the input circuit of Q_1, the voltage equation is developed.

By Kirchhoff's law of voltages,

$$\sum_{\text{GFCABEG}}^{\text{VOLTS}} = 0.$$

(See Figure 21 for explanation of formula.)

The symbol Σ is interpreted "summation of terms following."

The equation $\sum_{\text{GFC}_\text{T}\text{ABEG}}^{\text{VOLTS}}$ is read "summation of voltage drops."

G	to	F	=	7.5
F	to	C	=	−7.4
*C_T	to	A	=	−0.1
A	to	B	=	−0.0
B	to	E	=	0.0
E	to	G	=	0.0
Total			=	0.0 volts

*C in original formula

Figure 21 — Explanation of summation series.

The Corresponding equation is:

$$7.5 - 7.4 - 0.1 - 0 - 0 - 0 = 0.$$

The first term of this equation represents the battery voltage; the second term represents the drop across R_B; the third term represents the signal voltage across the upper half of the secondary of T_1; and the fifth term represents the drop across the base-emitter circuit of Q_1. (Terms not identified are paths that always have zero voltage drop.) At this instant (t = 90°), the signal voltage induced in the upper half of the secondary of T_1 opposes the flow of base-emitter current in Q_1, and the base current of Q_1 is 0.

At the same instant, the signal voltage induced in the lower half of the secondary of T_1 aids the flow of base-emitter current in Q_2. The voltage equation corresponding to the designation $\sum_{\text{GFCDBEG}}^{\text{VOLTS}} = 0$ is

$$7.5 - 7.4 + 0.1 - 0.2 = 0.$$

The first term represents the battery voltage; the second term represents the drop across R_B; the third term represents the voltage induced in the lower half of the secondary of T_1; and the fourth term represents the drop across the base-emitter circuit of Q_2 At this instant (t = 90°), the base-emitter current of Q_2 is 200μ A.

One half-cycle later, when t = 270°, the polarities of the signal voltage are reversed as indicated by the dotted arrows in the secondary of T_1. At this instant, the voltage in the upper half of the secondary of T_1 aids the base-emitter bias voltage of Q_1, and the base current of Q_1 increases to 200μ A. At the same instant, the voltage in the lower half of the secondary of T_1 opposes the base-emitter bias of Q_2, and the base current of Q_2 decreases to 0. For the upper circuit,

$$GFCABEG \sum_{GFCABEG} VOLTS = 0, \text{ and}$$

the voltage equation is

$$7.5 - 7.4 + 0.1 - 0.2 = 0$$

For the lower circuit,

$$GFCDBEG \sum_{GFCDBEG} VOLTS = 0, \text{ and}$$

the voltage equation is

$$7.5 - 7.4 - 0.1 - 0 = 0$$

From the fourth term in these equations, the voltage drop across the base-emitter terminals of the transistors is 0.2 V for Q_1 and 0.0 V for Q_2. Thus, the base-emitter current of Q_1 has increased to 200μ A, while that of Q_2 had decreased to 0.

The current through R_B remains constant over the input cycle; hence, the voltage drop across R_B is constant, and R_B does not require a bypass capacitor when the amplifier is operated class A.

The waveform of current in the collector circuits of Q_1 and Q_2 is like that of the input circuits. On no-signal, the collector currents flow in opposite directions through the primary of T_2 from the center tap. Because these currents are equal in magnitude, the ampere turns are equal. Because they are opposite in direction, they produce no effect on the magnetization of the iron, and there is no magnetization of the core when the input signal is 0. When the input signal current increases the collector current of Q_2 from 4 ma to 8 ma it decreases the collector current of Q_1 from 4 ma to 0. The increasing current in the lower half of the primary of T_2 and the decreasing current in the upper half combine additively in the secondary to produce the output voltage of T_2. Similarly, on the next half-cycle the increasing current in the upper half of the primary of T_2 and the decreasing current in the lower half combine additively in the secondary. The effect is the same as that of combining the output signal voltages of Q_1 and Q_2 in series addition across the two halves of the primary of T_2. Thus, the Q_1 output signal voltage of 15 V (peak-to-peak) combines effectively in series addition with the Q_2 output signal voltage of 15 V (peak-to-peak) to produce a peak-to-peak output voltage of 30 V. The peak-to-peak signal current through the primary of T_2 is 8 ma. Thus, the effective impedance looking into the primary of T_2 is

$$\frac{30}{0.008} = 3750$$

ohms. The power output is $e_{rms}\, i_{rms}$

$$\frac{30}{2} \times 0.707 \times \frac{.008}{2} \times 0.707 =$$

30 mW. This value of power output is twice that of a single-ended amplifier which employs a transistor of the same characteristics as those of the push-pull stage.

Single-stage and two-stage transistor phase inverter circuits are used in many transistor push-pull amplifier applications to replace the center-tapped transformer. The function of these circuits is similar to the electron tube single and two-tube paraphase amplifier circuits discussed earlier. In addition, a complementary-symmetry push-pull circuit is used for some applications.

Figure 22 shows a typical complementary-symmetry, push-pull circuit using an NPN transistor for one half of the circuit and a PNP transistor for the other half. As the polarities and currents in these transistors are opposite and equal (for matched units), one transistor works on one half of the input cycle and the other transistor works on the other half of the cycle. The out-of-phase outputs are added at the proper time to produce an output from the load resistor which is equal to the combined effect of the collector currents.

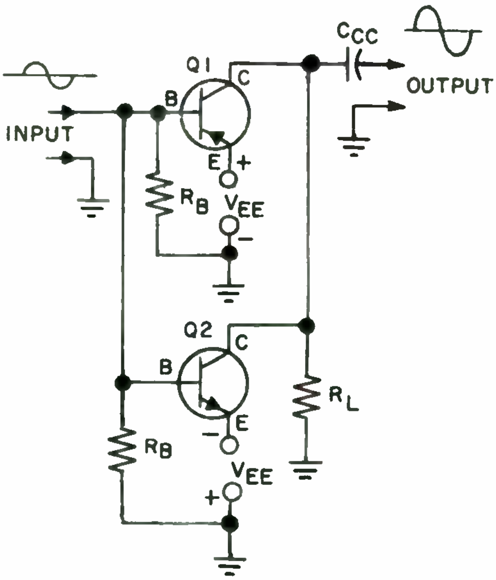

Figure 22 — Complementary-symmetry push-pull circuit.

Direct-Coupled Amplifiers

The direct-coupled transistor amplifier is used where high gain at low frequencies or amplification of direct current is desired. Applications for transistor DC amplifiers include voltage and current regulators, analog computers, oscilloscope circuits, and drivers for electromechanical and electromagnetic devices.

In the direct-coupled amplifier, the collector of the input stage is directly connected to the base of the second amplifier stage, as shown in Figure 23. Therefore, any collector supply variation also appears at the base of the second stage, just as if it were a change in the input signal. Since the transistor in the second stage has no way of discriminating between actual input signal variation and first stage collector supply variation, it is evident that either type of variation will be amplified in the second stage.

By the same type of reasoning, it can also be seen that, even in the absence of an input signal, a change in the gain of one stage (or the overall gain of cascaded stages) as a result of collector supply variations will produce an output signal. Similarly, a change in bias level in any stage or on any element will be amplified proportionally, and a change of output will occur. Such changes in bias levels normally occur as a result of temperature variations, aging, difference in transistor characteristics due to manufacturing processes, or changes in transistor leakage current, and are referred to as drift or DC drift.

In DC amplifiers, low drift is

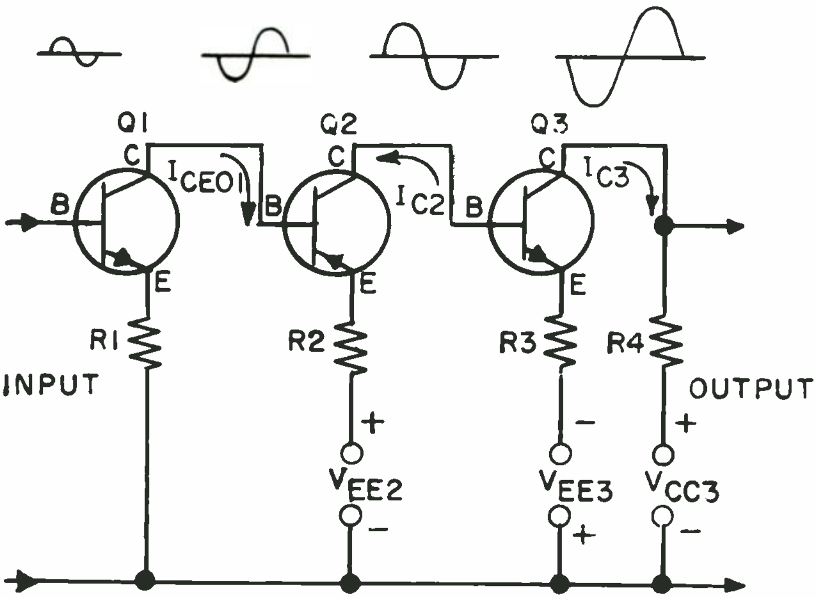

Figure 23 — Three-stage direct-coupled amplifier.

obtained by operating with low values of collector current; this reduces the reverse-leakage current by keeping the voltage between the collector and the base at a low value. Generally, any design precautions which reduce drift also reduce noise; conversely, with low noise, less drift is obtained. When the collector current is reduced, the gain decreases and the internal emitter resistance increases. Because of the reduction of gain, the amount to which the collector current of the first stage can be reduced is somewhat limited. Due to the inversion characteristic of single-ended common-emitter amplifier stages, both the current drift and the voltage drift in the second stage tend to help cancel the input stage drift.

Despite the apparent disadvantages of the DC amplifier, it does produce (for a two- or three-stage unit) high gain and good fidelity, particularly in the low-frequency portion of the spectrum. It also provides amplification with as few parts as possible; thus, it is economical to build.

Cascaded stages. Where more than one stage is required, transistor direct-coupled amplifiers offer circuit arrangements that are not possible with electron tubes. For example, through the use of complementary symmetry (as shown in Fig. 9), it is possible to connect the collector of the input stage directly to the input of the second stage without disturbing bias arrangements, and to use the same supply. By using alternate arrangements of NPN and PNP transistors, only one supply is needed. Recall that in the electron tube direct-coupled amplifier, as each stage is added, the plate voltage is increased, with the grid being tapped back onto the preceding stage plate voltage to obtain the bias.

The term "complementary-symmetry" is derived from the fact that the NPN transistor is the complement of the PNP transistor, with both circuits operating identically, but with opposite polarities.

THREE-STAGE DIRECT-COUPLED AMPLIFIER

A three-stage single-ended direct-coupled amplifier is shown in Figure 23. The input is applied to the base of transistor Q_1. The reverse bias collector current (I_{CEO1}) flows through the base of stage 2, which is biased by supply V_{EE2} in series with the emitter of stage 2. As stage 1 uses an NPN transistor, the positive emitter bias of stage 2 is of the proper polarity to act as collector voltage (reverse bias) for Q_1. Any change in the collector current of stage 1 appears at the collector of stage 2 in amplified form—that is, $I_{C2} = B_2 I_{CEO1}$, where B_2 is the current gain of stage 2. Stage 2 uses a PNP transistor; therefore, by complementary symmetry, stage 3 must also be an NPN stage similar to stage 1. The emitter bias for stage 3 is supplied through V_{EE3}, which is connected positive to ground. Thus, the collector supply of stage 3 (V_{CC3}) is of series-aiding polarity, and the total collector voltage is that of both the collector and emitter supplies of stage 3. In a similar manner, the collector voltage of stage 2 is supplied by V_{EE2} and V_{-EE3}

.

The collector current of stage 2 is the base current of stage 3. The output of the amplifier appears across collector resistor R_4, and the collector current is that of stage 2 multiplied by the amplification factor, or $I_{C3} = B_2 B_3 I_{CEO1}$. Emitter resistors R_1, R_2, and R_3, which are of a low value, provide degenerative feedback; they also act as emitter swamping resistors to help stabilize the amplifier with respect to temperature variations.

TONE CONTROLS

Listeners prefer a variety of tonal qualities from receivers; therefore, controls are sometimes included. With these, the listener can adjust for desired amount of high or low tones as suits his or her pleasure.

Tone controls increase or decrease high or low frequency response by means of networks which include knob controlled potentiometers. These networks are inserted between audio stages and either bypass certain frequencies to ground, or restrict the passage of certain frequencies to the following stage.

In Figure 24, we see a simple bypass form of tone control. The capacitor (C) offers a low impedance path, to ground, for the higher frequencies. The pot (R) can be varied by the listener to provide more or less resistance to these high frequencies before they get to the capacitor, thus giving the operator some measure of control over the output tonal response.

An improved tone control net-

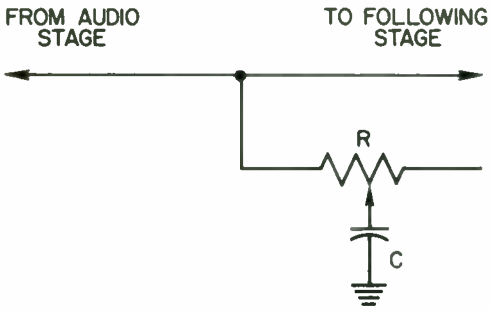

Figure 24 — Simple tone control.

work is shown in Figure 25. When R_1 is adjusted to the C_1 end, more of the high frequencies are coupled to the output. When R_1 is rotated toward C_2, the high frequencies appearing at the junction of C_3—C_4 are shunted to ground through C_2.

The base control function is similar to the treble, except that it boosts or attenuates low frequencies. At one end of its range (toward C_3), it passes lows to the following stage. As the control is rotated toward C_4, progressively more lows are bypassed to ground with less of them appearing in the output.

There are literally thousands of different tone control networks in use. They use single controls, ganged controls, and individual bass and treble controls. An analysis of any tone control network will reveal that it either offers variable impedance to certain groups of frequencies or bypasses them to ground.

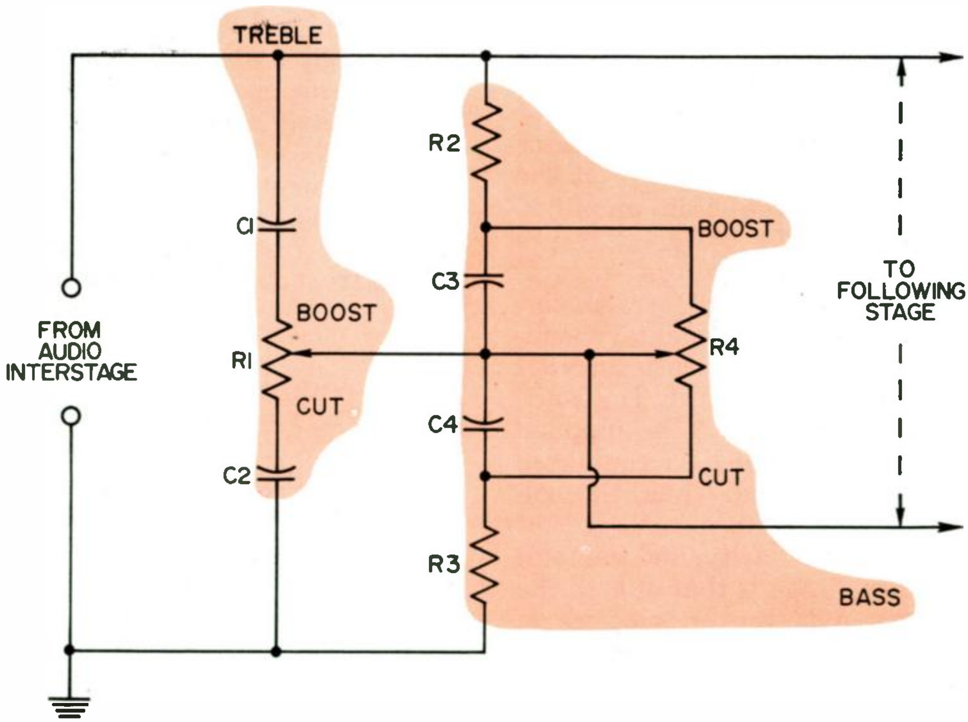

Figure 25 — Separate treble and bass boost controls.

VOLUME CONTROLS

Radios are provided with some means to control the audio output level. The networks incorporated for this purpose are identified by various terms, such as *audio-gain-controls, loudness-controls,* or, more frequently, *volume-controls.*

In its simplest form, a volume control is nothing more than a potentiometer with which a listener can increase or decrease the amount of audio signal into the voltage amplifier. By rotating a shaft knob on a potentiometer, either more or less signal is picked off by the variable contact. In Figure 26, we see a simple control typical of the ones used in most portable and table radios.

Audio signal voltage is developed across R in Figure 26, with progressively less voltage appearing as you approach point 2. Thus, a suitable level can be selected by rotating the shaft knob so that the variable contact picks off the required voltage (at some point between 1 and 2 of Figure 26) to appropriately drive the audio amplifier at the desired output level.

Simple resistive controls have the disadvantage that they effect the reactive components of associated circuitry differently at different settings. Thus, the frequency response is somewhat dependent upon the setting of the volume control. To overcome this disadvantage in better quality sets, special compensated control networks are used.

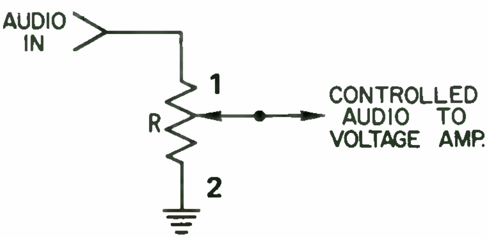

Figure 26 — Basic volume control network.

Compensated loudness (or volume) control networks use special tapped controls. These controls have one or more fixed taps (Fig. 27). The taps are located at percentage of rotation points as specified by the industry.

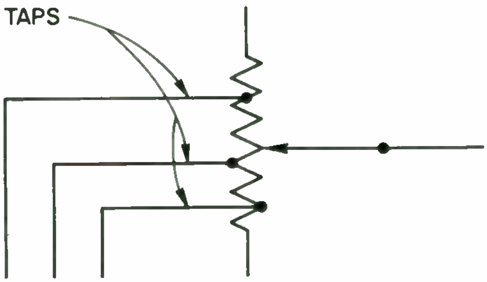

Figure 27 — Tapped volume control.

Figure 28 shows capacitors (C_1, C_2, and C_3) attached to the taps on a compensated control. They terminate at ground and bypass specific amounts of certain frequencies to ground whenever the variable contact is in the range of their point of fixed contact with the resistive material of the potentiometer. Thus, as more high frequencies appear along the range of the control, more of their signal is bypassed to ground. At positions where there are less highs, less of their energy is bypassed to ground. In this way, a relatively even frequency response is maintained in the output, regardless of the control setting.

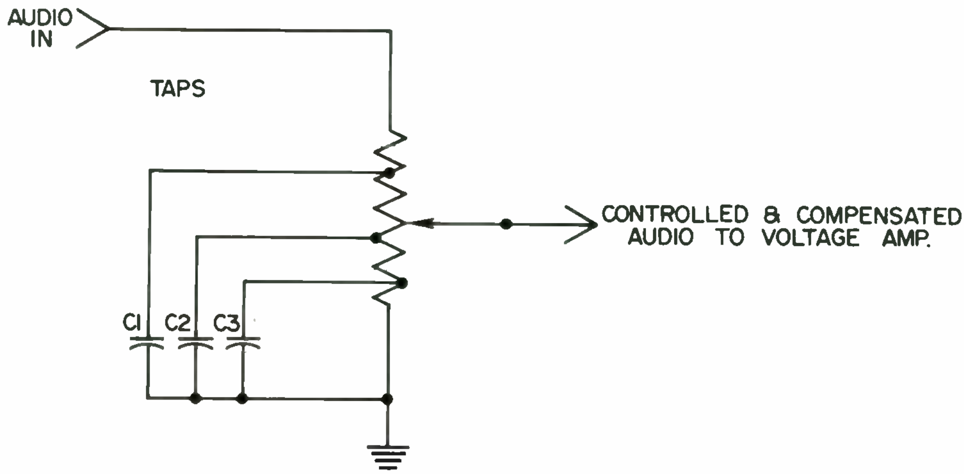

Figure 28 — Frequency compensated volume control employing capacitors.

SUMMARY

Many other circuits are associated with AM radios. They will not be discussed at this time, however, because they are associated only with commercial and special receivers. For servicing home variety radios, you will need only the knowledge presented in these two lessons (parts 1 and 2), your equipment, and appropriate service literature pertaining to the unit being serviced.

TEST

Lesson Number 62

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-062-1.

1. **An audio power amplifier that uses only one tube is called a ______ amplifier.**
   A. paraphase
   B. single ended
   C. voltage
   D. triode

2. **An audio power amplifier stage is nearly always preceded by**
   A. an audio voltage amplifier.
   B. a compensation network.
   C. a bass boost control.
   D. a treble boost control.

3. **The coupling capacitor between the output of one audio stage to the input of another passes the audio signal while rejecting**
   A. noise.
   B. interference.
   C. DC levels.
   D. AC signals.

4. **Two common methods are used to establish grid bias for the tube in voltage amplifiers. One method relies on the voltage drop across a cathode resistor; the other uses a ______ grid resistor.**
   A. small
   B. variable
   C. small value
   D. large value

5. **The tubes in two-tube audio power amplifiers are generally arranged in**
   A. series.
   B. cascade.
   C. push-pull.
   D. push-push.

6. The opposite polarity signals necessary to drive tube-type push-pull audio power amplifiers are often supplied by

3 A. split capacitors.
+ B. full-wave detectors.
4 C. transistors.
—D. paraphase amplifiers.

7. The signal for a push-pull tube power amplifier is often supplied by one tube and

A. an autoformer.
5 —B. a center tapped transformer.
C. one transistor.
D. an RF inductor.

8. A transistorized audio amplifier in which an element of one transistor connects directly to an element of the next is called a ______ amplifier.

10 A. paraphase.
& —B. direct coupled.
11 C. complementary.
D. symmetry.

9. A transistorized amplifier stage that uses a combination of PNP and NPN transistors is called a ______ amplifier.

—A. complementary-symmetry.
B. paraphased.
" C. cascaded.
D. class B.

10. Complementary-symmetry output stages

A. do not require transformers.
" B. do not need prior phase inversion.
—C. have few parts.
D. all of the above.

Portions of This Lesson from
Transistor Fundamentals
by Martin Gersten
Courtesy Howard W. Sams, Inc.

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YOU'RE ON THE RIGHT TRACK

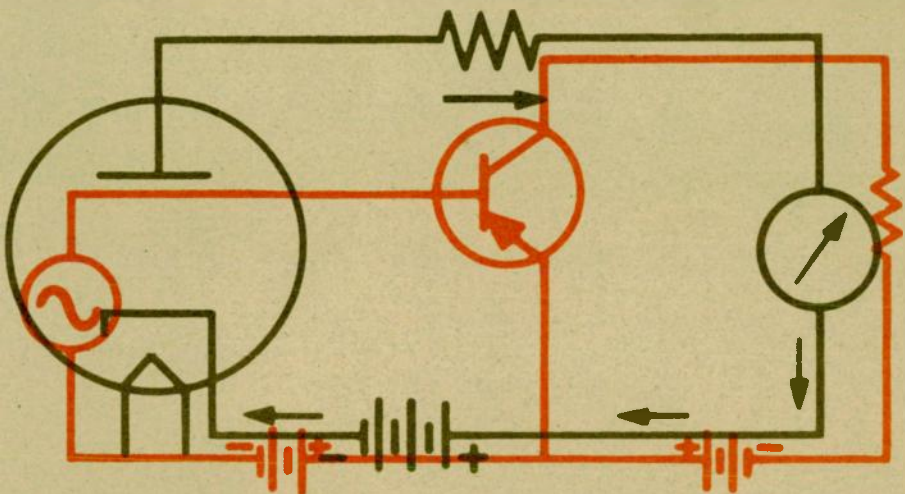
The United States Department of Labor says that in order to insure employment, workers

- must prepare themselves for a rapidly changing and more complex world of work . . . just as you are doing.
- will need further education and training with guidance and counseling . . . just as you are doing.
- will compete more keenly for the better jobs . . . just as you will be able to do after this course.

S. T. Christensen

LESSON NO. 63

REVIEW FILM OF LESSONS 59 THROUGH 62



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-063
407

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 4/73
Reprinted July 1974

REVIEW FILM TEST

Lesson Number 63

The ten questions enclosed are review questions of lessons 59, 60, 61, & 62 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and Film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER: YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

Lesson Number 63

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having the Test Code Number 52-063-1.

1. A sine wave has
A. an RMS value.
B. a peak value.
C. a peak-to-peak value.
D. all of the above.

2. Lissojous displays can determine
A. voltage values.
B. frequency ratio.
C. harmonic distortion.
D. peak-to-peak values.

3. A square waveform can be used for
A. analyzing an audio amplifier.
B. testing a VTVM.
C. checking an RF oscillator.
D. testing an audio generator.

4. If a square wave is applied to the input of an audio amplifier and an oscilloscope is connected to the output, the output waveform should
A. be a sawtooth.
B. have a rounded leading edge.
C. be the same as the input waveform.
D. have a rounded trailing edge.

5. **Side bands are created when a carrier is**
   A. AM modulated.
   B. FM modulated.
   C. pulse modulated.
   D. all of the above.

6. **An AM carrier is modulated by**
   A. adding power.
   B. subtracting power.
   C. shifting the frequency.
   D. none of the above.

7. **An FM carrier is modulated by**
   A. adding power
   B. changing its frequency
   C. adding pulse modulation
   D. all of the above.

8. **ICs are used for**
   A. digital applications.
   B. linear amplifiers.
   C. instrument applications.
   D. all of the above.

9. **Power supply half-wave rectifier circuits are**
   A. found mostly in Hi-Fi equipment.
   B. found only in lower priced products.
   C. never used in a battery charger.
   D. all of the above.

10. **Transformerless receivers have no**
   A. shock hazard.
   B. voltages above 24 volts.
   C. power line isolation.
   D. all of the above.

Kessler 44 Solder

Notes

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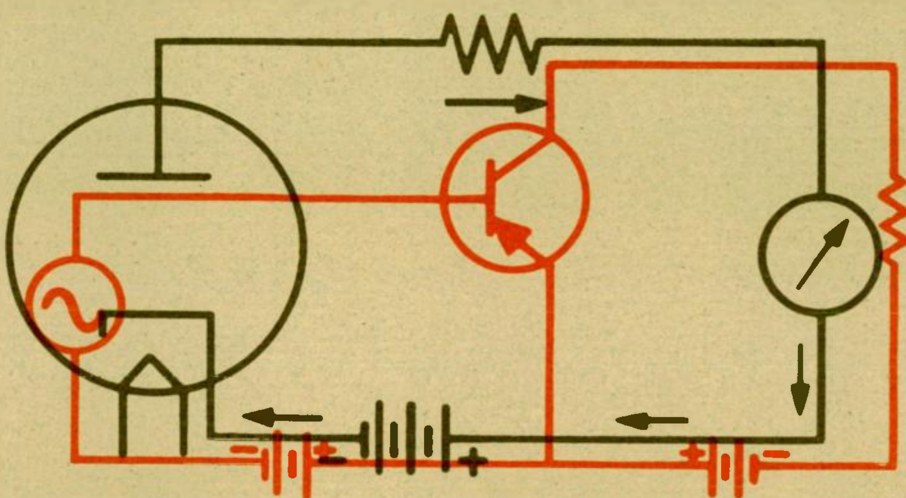
YOUR DEEDS

"Live for something. Do good and leave behind you a monument of virtue that the storm of time can never destroy. Write your name in kindness, love and mercy on the hearts of thousands you come in contact with, year by year; and you will never be forgotten. Your name, your deeds, will be as legible on the hearts you leave behind, as the stars on the brow of the evening. Good deeds will shine as the stars of heaven."

Chalmers

LESSON NO. 64

AM RADIO SERVICING



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-064

404

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Revised 4/73

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CONTENTS

AM RADIO SERVICING

INTRODUCTION

In this lesson you will learn how to apply the basic troubleshooting procedures shown in Figure 1 to faulty superheterodyne radio circuits. You will also learn proper alignment procedures for AM superheterodyne radios. The procedures explained in this lesson will prepare you for work on more complicated circuits, such as those found in television sets.

REVIEW OF TROUBLESHOOTING METHODS

In earlier lessons you learned that effective troubleshooting is based on a logical scientific method. Basically, this method involves narrowing down the possible causes of trouble to a specific faulty component or adjustment. The narrowing-down process is summarized in the following five steps:

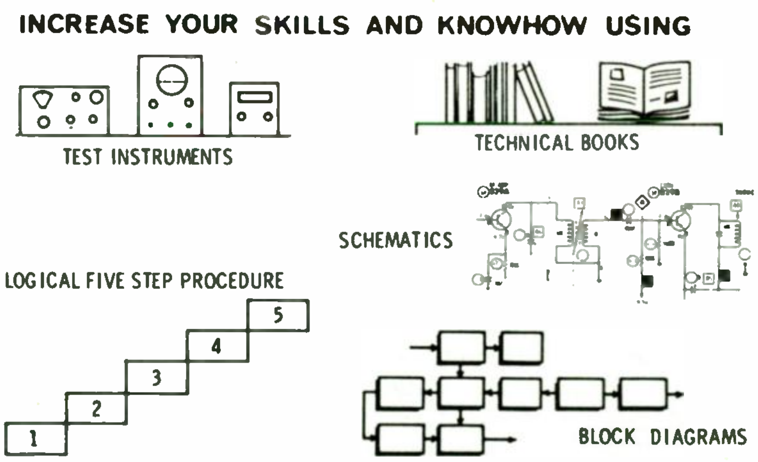


Figure 1 — Breakdown of troubleshooting technique

Step 1. Identify symptoms, carefully noting effect of front-panel controls.
Step 2. Make deductions about probable trouble spots using all symptom information and block-diagram analysis.
Step 3. Make check-list of probable trouble spots.
Step 4. Locate faulty circuit by use of schematics and test equipment.
Step 5. Pinpoint defective part or adjustment by further deduction and testing.

APPLICATION OF THE FIVE STEPS

In Step 1 you must identify symptoms and note the effect of front-panel controls. Simple portable superheterodynes usually have only two controls: the tuning dial and a volume control. More elaborate sets may have bass and treble controls as well. However, in all but specialized communication receivers, the controls will be part of the audio circuitry of the tuning circuits. Therefore, if the trouble is not located in one of these areas, the front-panel controls will have no affect on the symptoms.

In the case of a totally inoperative receiver, you may find it necessary to make somewhat generalized deductions about probable trouble spots and go directly to Step 4. Locating first the faulty area, then the defective part or adjustment by means of test instruments and schematics is easy once you have mastered the use of the instruments and have acquired the ability to interpret test results accurately.

Often, after replacing a transistor or other part in the RF, IF, or mixer circuits, it will be necessary to realign the circuit with the new part installed. This realignment is necessary because the stray capacitance and inductance of the new part will rarely be exactly the same as the old part. Any change in capacitance or inductance causes a shift in the resonant frequency of the circuit. When you align the circuit, you are tuning it back to the proper resonant frequency.

Complete alignment of a superheterodyne receiver is usually necessary only once and that is when the construction of the unit is completed. At that time, the RF and mixer circuits are adjusted for proper tuning-dial calibration and sensitivity, and the IF amplifier transformers are each adjusted to produce maximum signal strength.

In troubleshooting FM receivers, it is very important that the wiring and parts placement in the RF, mixer, and IF stages be disturbed as little as possible. Due to the very high frequencies at which these circuits operate, moving a capacitor or resistor even one-half inch may cause a change in stray capacity sufficient to detune a circuit. If a component must be replaced, the leads on the new component should be trimmed to the same length as those of the old component. The new component should then be mounted in the same position as the old one. Even taking these precautions, however, you may find that a slight realignment of the circuit may be necessary, as the exact value of the new part will probably not be the same as the one removed.

SYMPTOM IDENTIFICATION AND DEDUCTIONS

Figure 2 illustrates an AM superheterodyne radio in need of repair.

On energizing the unit, we find the following symptoms:

1. Weak but undistorted output from all stations is received;
2. Volume and tone controls appear to function normally;
3. At full volume, normal transistor noise is audible;
4. Tuning mechanism functions normally.

From the above list of symptoms and front-panel control information, you should be able to deduce that the trouble is *probably not* in the audio amplifier or converter circuits. Trouble in the audio section generally would show up as severe distortion, excessive noise, or malfunction of volume or tone controls —in addition to weak or absent audio. Trouble in the converter stage usually would show up as a total absence of received signals, due to the lack of local-oscillator injection.

Among the possible trouble spots left, after eliminating the converter stage and the audio amplifier, are the antenna and power supply. The connections from the antenna to the converter may be broken, or if a ferrite-loop antenna is used, it may be physically cracked, smashed, or shorted. Such damage can usually be found by inspection. When in doubt, the continuity of the antenna and its connecting leads can be checked on the *ohms* scale of a VOM or VTVM.

Low power-supply voltage due to

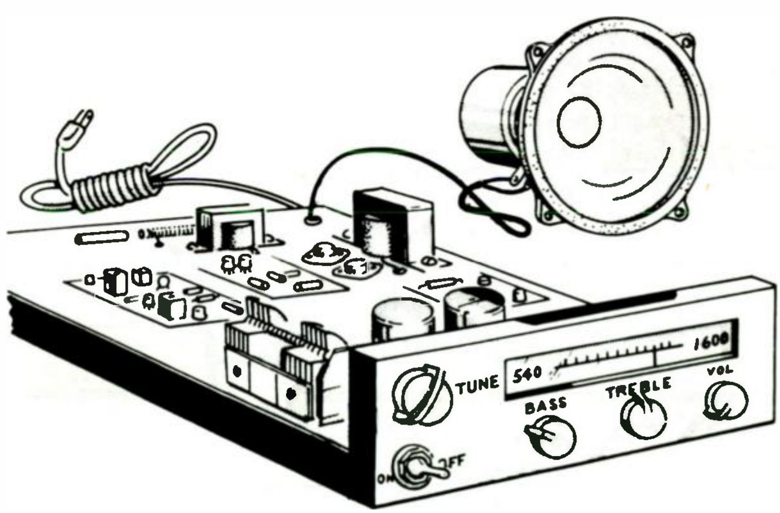


Figure 2 — Superheterodyne receiver.

a defective rectifier or filter capacitor can cause a multitude of problems. It takes only a few seconds to check the power-supply output voltage on the *DC volts* scale of a multimeter to eliminate this area as a possibility.

DEDUCTIONS AND BLOCK DIAGRAMS

The preceding deductions are summarized below:

1. There is no problem with the audio circuits;
2. There is no problem with the converter circuits;
3. There may be trouble in the power supply;
4. The antenna or its connections may be faulty.

The block diagram shown in Figure 3 will aid you in further narrowing down of the probable trouble spots.

The shaded areas of the diagram in Figure 3 indicate those blocks which have been eliminated as possible trouble spots. Tracing the signal flow from block to block, you can see that in addition to antenna and power-supply problems, a defect in either IF amplifier could cause a loss of signal strength. Such defects might be shorted transistors, open windings in the IF transformers, or improper transistor bias among many others. Gross mistuning of the IF stages is another possibility, although this problem usually occurs only when unqualified personnel have tampered with the tuning adjustments. The last possible trouble spots are the detector stage and AVC circuits. A partially shorted or open component in the detector stage could cause a serious loss of signal. However, improper AVC would tend to cause excess gain and severe distortion on strong stations. Therefore, you can deduce that the AVC cir-

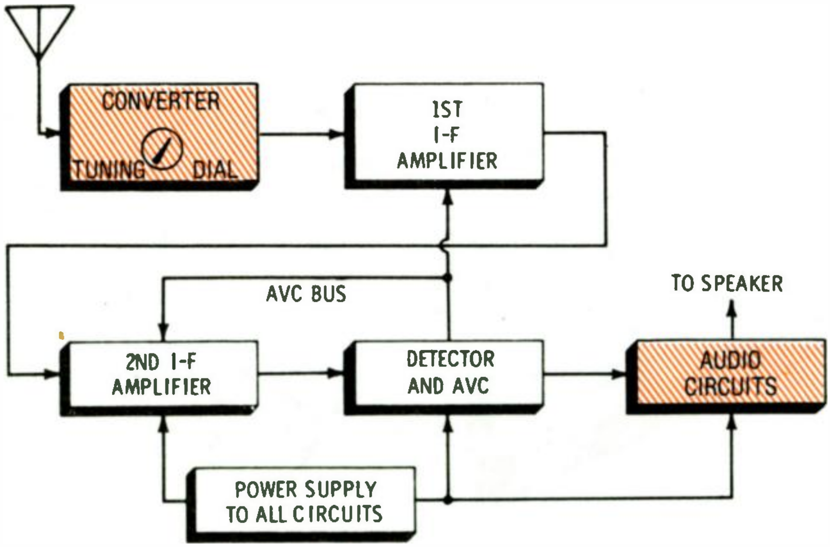


Figure 3 — Block diagram of superheterodyne.

cuits are probably functioning normally and they may be eliminated from your list of probable trouble spots.

At this point, you can complete Step 3 by making a check list of all probable trouble spots. Easily checked items, such as power-supply voltage are placed at the head of the list:

1. Power-supply voltage
2. Antenna
3. Detector stage
4. Second IF stage
5. First IF stage

You now proceed to Step 4, using schematics and test equipment to further bracket the faulty stage.

TEST INSTRUMENTS AND SCHEMATICS

RF Generator

A rapid way to check for signal flow in an audio amplifier is to inject a known test signal into the circuit and to listen for output from the speaker. This technique is very useful in troubleshooting superheterodyne receivers and is known as *signal substitution.* The instrument used to produce the test signal is called an RF *generator* and is illustrated in Figure 4.

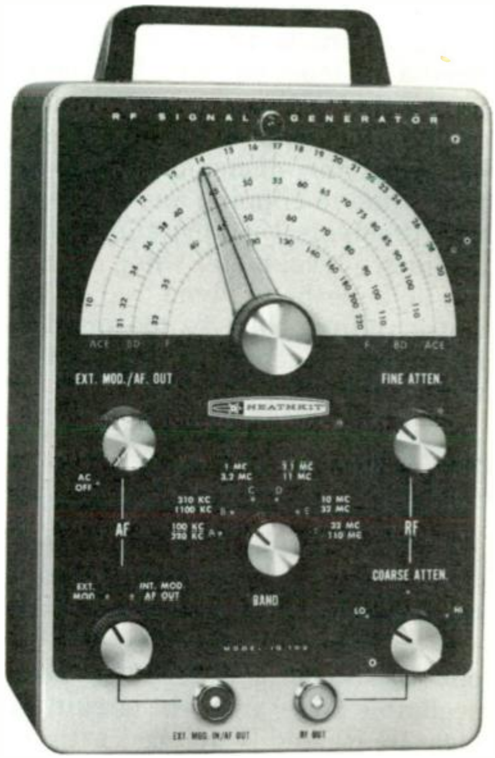


Figure 4 — RF Signal generator.

Note that the RF generator can be tuned to any frequency within its range by means of the tuning dial and the *bandswitch.* Therefore, it can be set to 455 kHz for checking IF amplifiers and detectors, and it can be set anywhere in the broadcast band (540 — 1600 kHz) for checking converters and RF amplifiers. The higher ranges are available for checking short-wave radios, television, and other high-frequency circuits. The RF generator also has an *output level control* and an *audio-output jack.* The level control allows you to adjust the RF output voltage from zero to a few volts. The internal audio-modulation signal is usually a 400-Hz tone, and is available directly from the *audio output jack* for making audio tests.

Oscilloscope

The oscilloscope is the best indicating and measuring instrument for use on superheterodyne radios.

It does not appreciably affect operating characteristics when connected to most circuits. The oscilloscope is used most often for measuring RF and IF voltage and checking for distortion of waveforms due to clipping and other severe problems. It is very effective as a relative-level meter when adjusting a superheterodyne radio, because voltage changes too small to be seen on a meter are displayed on the oscilloscope.

VTVM

5

The VTVM is very useful in checking audio and DC voltages in superheterodyne radios. In particular, AVC voltages are accurately measured because the very high input resistance of the VTVM takes negligible power from the circuit. To measure RF and IF voltages with the VTVM, a special RF *probe* is necessary for accurate readings.

Power Supply

Figure 5 is the schematic of the power-supply circuitry of the superheterodyne receiver.

Note that the correct output voltage is indicated at point A to be —9 volts. This voltage is measured between point A and ground (chassis) using the VTVM. Variations of ±10 percent from the rated voltage are not unusual and merely represent variations in component tolerances. We will find that
6 the power-supply voltage is correct and proceed to the next item on our list.

Antenna

The ferrite-loop antenna and its connecting leads should be checked carefully for broken wires and other signs of physical damage. A typical ferrite-loop antenna and schematic are shown in Figure 6.

Most loop antennas consist of two coils of wire wound on the same ferrite rod. One large coil is connected to the tuning capacitor and the other (small) coil is connected to the converter or RF input. This is actually a transformer arrangement, which provides better signal transfer than direct coupling. The ferrite-loop antenna is used in nearly all AM radio sets sold today.

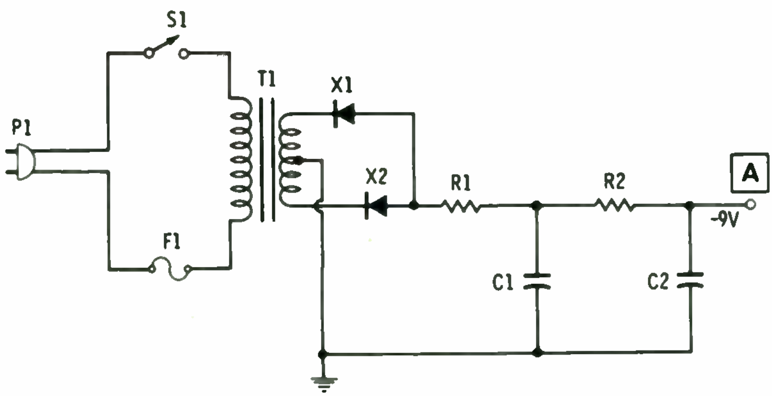
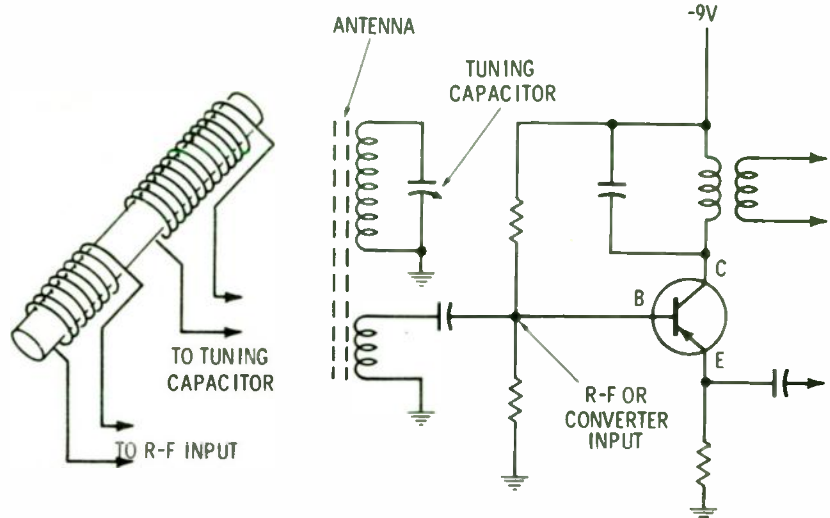


Figure 5 — Schematic of power supply.



(A) Coils. *(B) Schematic.*

Figure 6 — Antenna and converter.

It is not suitable for FM reception, however, and most FM receivers use some form of telescoping "rabbit ear" antenna or a separate external pickup.

Detector

Figure 7 is the schematic of the detector stage of the superheterodyne radio.

To check the detector operation, set the RF generator at 455 kHz and connect the output to the high side of the second IF transformer (can) secondary (point A in the schematic) through a small capacitor (100-1000 pf). Connect the ground clip of the generator to the chassis. Set the modulation control at 100 percent and slowly advance the RF *level control* until the 400-Hz tone is heard in the speaker. The speaker should produce full volume with no more than a few hundred millivolts of RF signal applied to the detector.

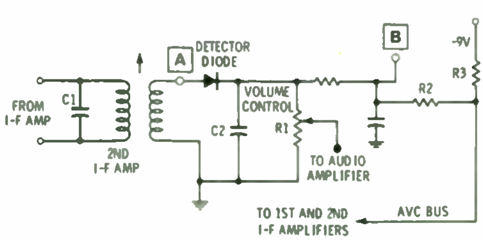


Figure 7 — Schematic of detector.

The AVC voltage can be checked at this time by connecting the VTVM between point B (shown in Figure 7) and ground. The meter should be set to the *-DC volts* scale and the 0 to 3-volt range. As the RF signal is varied, the AVC voltage will vary, showing that proper AVC voltage is being developed.

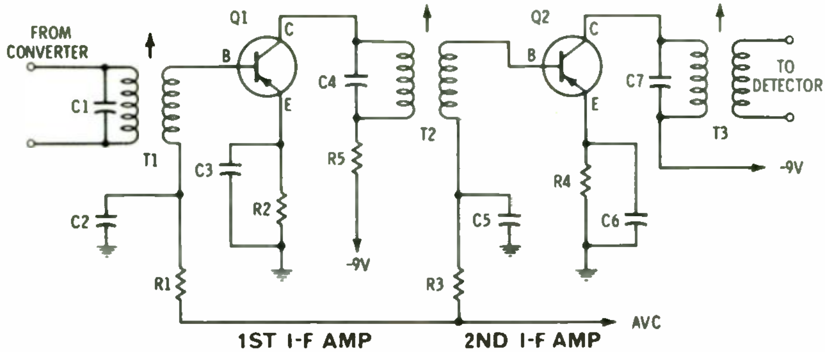


Figure 8 — Schematic of IF stages.

IF Amplifiers

The schematic of the two IF amplifier stages is shown in Figure 8.

Leaving the VTVM connected to the AVC bus, move the RF generator output clip to the base of Q2, (second IF amplifier transistor). The AVC voltage and the speaker output will rise sharply if the stage is operating properly. It may be necessary to turn down the RF *level control* on the generator to prevent overloading beyond linear AVC action.

Proper operation of the second IF amplifier stage leaves only the first IF amplifier stage as the trouble spot. Once again, leave the VTVM connected to the AVC bus and move the generator output to the base of Q1, the first IF amplifier transistor. We find that the AVC voltage does not go up as far as it did when the generator was connected to Q2. This lack of gain definitely pinpoints the trouble in the first IF amplifier stage. Further narrowing down must now take place to discover the specific faulty component in this stage.

Pinpointing the Trouble

Figure 9 is the schematic of the first IF amplifier stage, showing the correct operating voltages, with no input signal applied.

From the information given in the diagram you can make some deductions about which components could be responsible for the break in signal flow through the stage. The transistor (Q1) could be open or shorted. Another possibility is that the primary coil of T_2 or its resonating capacitor C_4 is open or shorted. A less likely possibility is that emitter bypass capacitor C_3 is open, causing the gain of the stage to be reduced substantially. It is unlikely that trouble would develop in any of the resistors, as the supply voltage is so low that even if the resistors were connected directly from the supply to ground, they would only be dissipating 1 percent or less of their rated power.

Using the VTVM, we find that the voltage at the emitter of Q1 is -8 volts, the voltage at the base is -8.2 volts, and the voltage at the collector is -8.3 volts. Looking at the

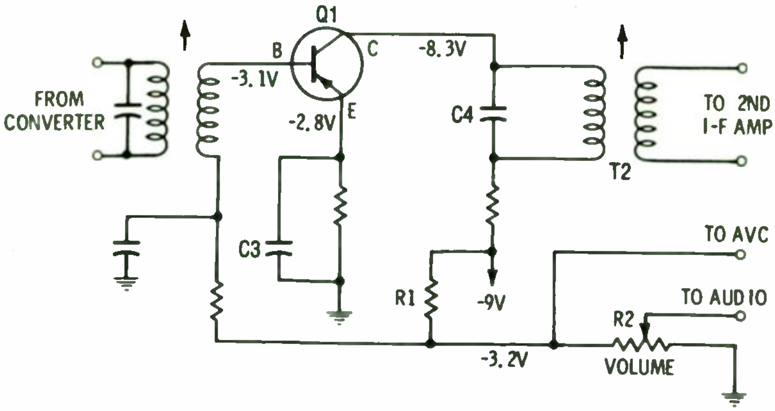


Figure 9 — Schematic of first IF stage.

schematic, you can see that the voltage at the base of Q1 is set by the voltage divider comprised of resistors R1 and volume control R2. Since it is most unlikely that the ratio of these two resistors would ever change more than a few percent under any circumstances, you can make the deduction that transistor Q1 is shorted from collector to base.

After replacing the transistor, it may be necessary to realign the IF transformers connected to it, because of the differences in internal and stray capacitances of the two units. Figure 10 illustrates the capacitances found within the transistor crystal structure and its protective can.

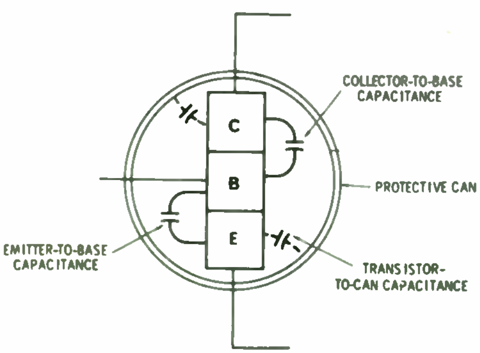


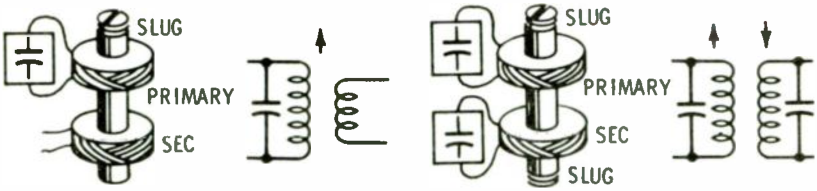
Figure 10 — Transistor capacitances.

Alignment Procedure for AM Superheterodyne Radios

Aligning a superheterodyne radio means adjusting the various tuned circuits and IF transformers for maximum sensitivity, optimum tracking of the tuning circuits, best dial calibration, and minimum distortion. The complete alignment is a two-part procedure:

a. IF amplifier alignment;
b. Front-end (RF, local oscillator, and mixer or converter) alignment.

The exact number of steps involved in aligning a receiver usually depends directly on the quality of the set. Inexpensive portable radios may have only one or two *single-tuned* IF transformers and one trimmer capacitor on each section of the tuning capacitor. More expensive sets usually have four or more *double-tuned* IF transformers (Fig. 11) and plug-tuned coils and padding capacitors in addition to the trimmers on the tuning capacitors. The front end of multiband receivers consists of a set of tuned circuits for each band, and each must be aligned separately.



(A) *Single-tuned.* (B) *Double-tuned.*

Figure 11 — IF transformers.

Exact alignment procedures for specific receivers may be obtained from the manufacturer. The service manual for the set will contain detailed information on performance and instrument set-up schematics, and may include easily accessible test points for connecting instruments. Whenever possible, the service manual should be at hand before attempting alignment of a complicated receiver.

The operating manual of the RF generator is another very useful aid in alignment procedures. It has information on proper calibration procedure for the instrument, which may be necessary from time to time, and, in addition, it tells you the most efficient ways to use your generator.

For best results you will need an RF generator, an oscilloscope and a VTVM for monitoring output signals and measuring voltages. (See Figure 12.)

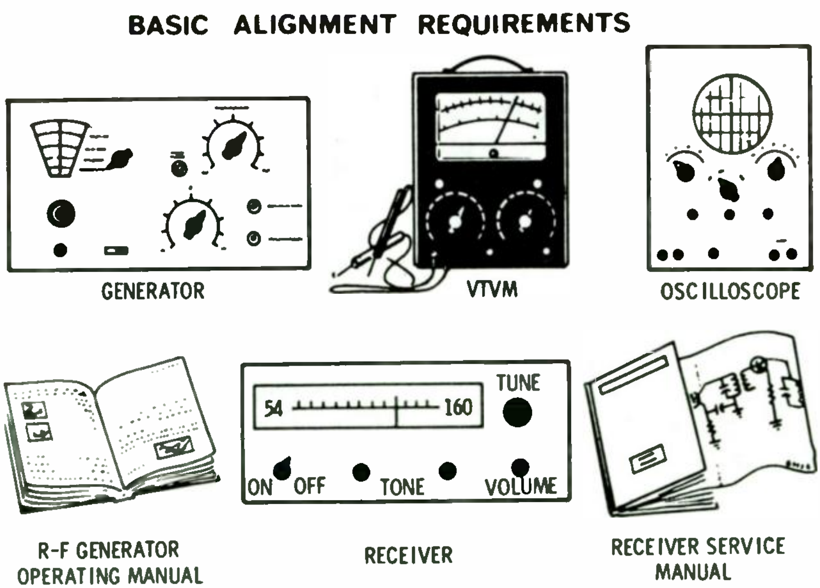


Figure 12 — Alignment tools.

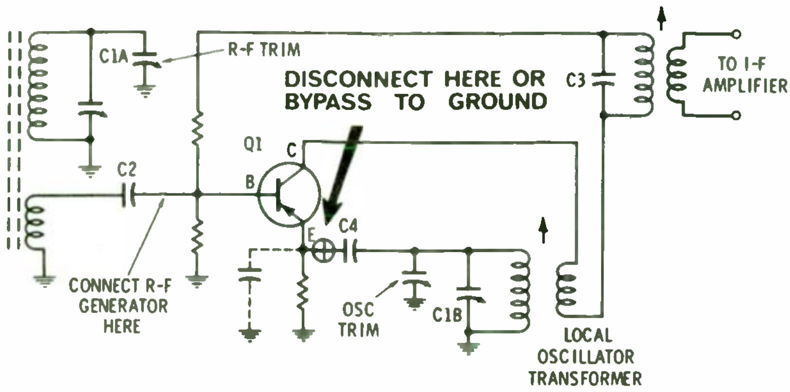


Figure 13 — Alignment connections.

IF Alignment

The first steps in IF alignment are the temporary disabling of the AVC and mixer functions. This is done to assure maximum circuit gain and to eliminate spurious signals that might interfere with the measurements. First, disconnect the AVC bus from the detector output. Next, either disconnect the local-oscillator coupling capacitor, C_4, (See Figure 13) from the emitter of Q1 or bypass the oscillator section of tuning capacitor C_{1B} to ground.

Next, connect the oscilloscope or VTVM across the speaker terminals. Set the RF generator to 455 kHz and connect it through a small capacitor to the base of Q1. Adjust the RF *level control* so that a clear output indication is visible on the oscilloscope or VTVM. Starting with the IF transformer nearest the detector, carefully rotate the tuning slugs for maximum output. Always work from the detector back toward the mixer or converter, adjusting each transformer for maximum output. As you "peak" each stage, it may be necessary to reduce the RF level to avoid overload. When each stage has been adjusted for maximum output, the IF alignment has been completed and the temporary shorts are removed. (See Figure 14.)

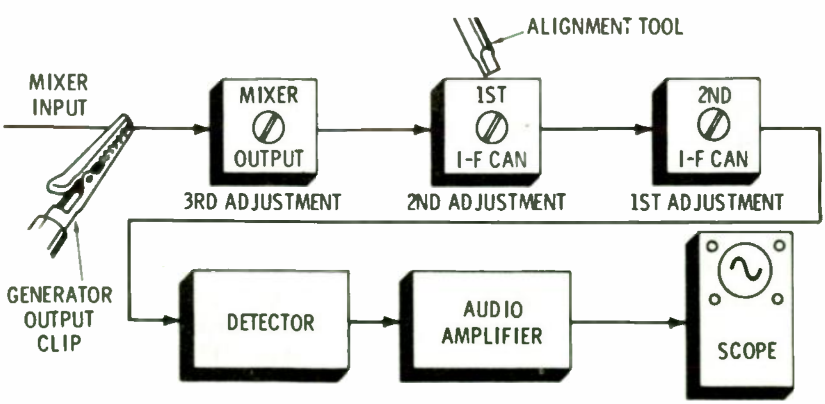
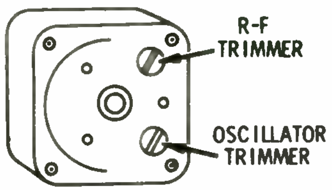


Figure 14 — Alignment of IF stages.

Virtually all receiver tuning capacitors have the RF and local-oscillator trimmers mounted directly on their frames. In small portables which have plastic-cased tuning capacitors, the trimmer adjustments are two small screws which extend through the plastic case. Location of the trimmers on the two types of trimming capacitors is shown in Figure 15.



(A) Plastic cased.

(B) Frame mounted.

Figure 15 — Variable capacitors and trimmers.

Front-End Alignment

Front-end alignment of the simple converter stage found in most portable radios involves adjusting the oscillator circuit for best dial calibration and setting the RF trimmer for best overall sensitivity. In some cases, the RF trimmer setting will be a compromise, if the oscillator and RF sections of the main tuning capacitor do not track well together.

With the oscilloscope connected across the speaker terminals, set

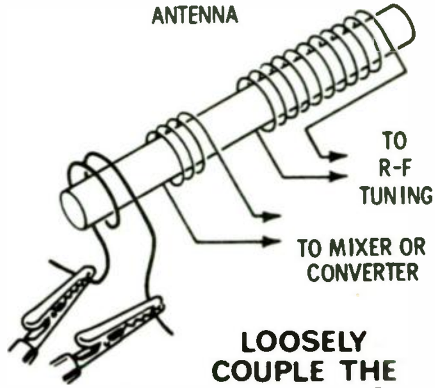


Figure 16 — RF generator coupling.

the RF generator to 1600 kHz and loosely couple it to the antenna by wrapping one or two turns of wire around the ferrite rod and connecting the ends of the wire to the generator output leads as shown in Figure 16. Set the tuning dial of this receiver to exactly 1600 kHz. You should get an indication of the test signal on the oscilloscope. Adjust the oscillator trimmer capacitor for maximum output. If the oscillator is very far out of alignment, no signal may be found at 1600 kHz on the dial. In that case, carefully tune the receiver until you locate the test signal and then carefully adjust first the oscillator trimmer, then the main tuning dial, alternately, slowly working back to 1600 kHz.

Next, tune the receiver and the generator down to 600 kHz. Adjust the oscillator coil or transformer slug for maximum output. It may now be necessary to readjust the oscillator-trimmer capacitor at 1600 kHz. If necessary, repeat these adjustments until maximum performance is obtained.

The RF trimmer should first be peaked at 1600 kHz and then the sensitivity checked at several other points across the dial. You may find that some inexpensive sets will give better *overall* performance if the RF trimmer is peaked at 1300 kHz or some lower frequency.

For elaborate receivers having an RF amplifier stage, follow the same basic procedure outlined above. The trimmer capacitor is peaked at the high end of the band and the RF coil is peaked at the low end of the band. Some local-oscillator circuits contain a *padding capacitor* in series with a fixed-inductance-oscillator coil. This padding capacitor is used to adjust the low frequency end of the band.

TOOLS AND TECHNIQUES FOR TRANSISTORIZED CIRCUITS

There are many differences between transistorized and electron tube circuits from the standpoint of servicing. For instance, the reliance placed on the senses of sight, touch, and smell in the visual inspection of electron tube circuits is not feasible in transistor circuits. Many transistors develop so little heat that nothing can be learned by feeling them. High-frequency transistors hardly get warm. Usually if a transistor (except a high-power transistor) is hot enough to be noticeable, it has been damaged beyond use.

In electron tube circuits, a quick test is often made by the tube substitution method; that is by replacing the tube suspected of being bad with one known to be good. In transistorized circuits, the transistors are frequently soldered in and the substitution method is impractical. Furthermore, indiscriminate substitution of transistors and other semiconductors should be avoided. It is preferable to test transistors using a transistor test set.

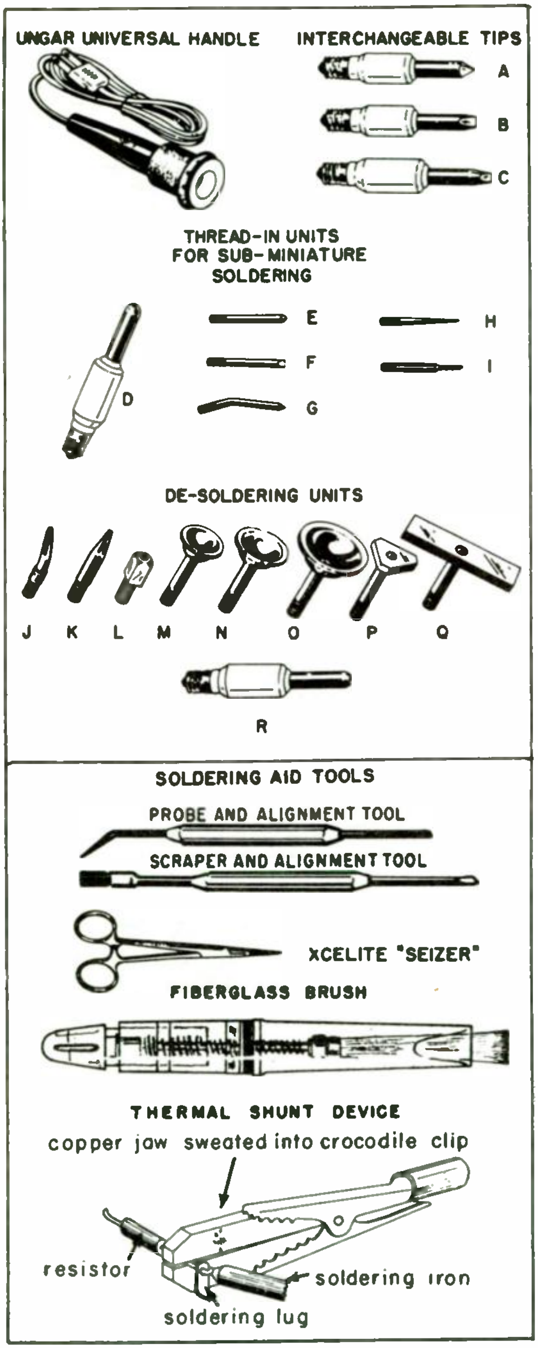
TESTING

Most good quality test equipment used for electron tube circuit testing may also be used for transistor circuit testing. Signal generators, both RF and AF, may be used if the power supply in these equipments is isolated from the power line by a transformer. Before any tests are made with a signal generator, a common ground wire should be connected from the chassis of the equipment to be tested to the chassis of the signal generator before any other connections are made.

Signal tracers may be used on transistor circuits if the precautions concerning the power supplies are observed. Many signal tracers use transformerless power supplies; therefore to prevent damage to the transistor, an isolation transformer must be used.

Multimeters used for voltage measurements in transistor circuits should have a high ohms-per-volt sensitivity (at least 20,000 ohms per volt) to ensure an accurate reading.

Ohmmeter circuits which pass a current of more than one milliampere through the circuit under



Item	Description
Soldering Iron	
A	Pyramid tip, 5/16" diameter
B	Chisel tip, 3/8" diameter
C	Chisel tip, 1/4" diameter
D	Thread-in element for thread-in tips
E	Thread-in straight cone tip, 3/8" diameter for element D
F	Thread-in straight chisel tip, 3/8" diameter for element D
G	Thread-in bent cone tip, 3/8" diameter for element D
H	Thread-in straight needle tip, 3/8" diameter for element D
I	Thread-in micro tip for element D
De-soldering Units	
J	Thread-in offset slotted tiplet for element R
K	Thread-in straight slotted tiplet for element R
L	Thread-in hollow cube tiplet for element R
M	Thread-in 5/8" diameter cup tiplet for element R
N	Thread-in 3/4" diameter cup tiplet for element R
O	Thread-in 1" diameter cup tiplet for element R
P	Thread-in 5/8" diameter triangle tiplet for element R
Q	Thread-in 1-1/2" x 3/8" bar tiplet for element R
R	Thread-in element for de-soldering tiplets

Figure 17 — Recommended special tools and aids.

test cannot be used safely in testing transistor circuits. Before using an ohmmeter on a transistor circuit, check the current it passes on all ranges. Do not use any range for testing that passes more than one milliampere.

Conventional test prods, when used in the closely confined areas of transistor circuits, often are the cause of accidental shorts between adjacent terminals. In electron tube circuits the momentary short caused by test prods rarely results in damage, but in transistor circuits this short can destroy a transistor. Also, as transistors are very sensitive to improper bias voltages, the practice of troubleshooting by shorting various points to ground and listening for a click must be avoided. Remember the sensitivity of a transistor to surge currents when testing transistor circuits.

SPECIAL TOOLS AND TECHNIQUES

Special soldering tools and aids are required for servicing transistorized circuits. To avoid overheating and damaging the transistors and other semiconductor devices, a small, low wattage (50 watts or below) soldering iron with a narrow point or wedge must be used. An iron with interchangeable tips as shown in Figure 17 is recommended but a high wattage iron can be converted for emergency use.

To make the conversion, closely wrap any number of turns of clean No. 10 copper wire around a thoroughly clean soldering iron tip,

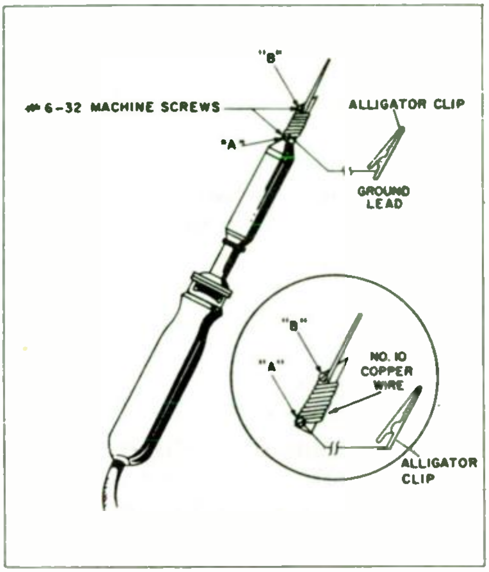


Figure 18 — Improvised low wattage soldering iron.

extending the other end of this wire 1 inch beyond the original soldering iron tip as shown in Figure 18. Thoroughly tin the formed end of the new tip before using. To provide a tight connection and prevent possible twisting of the tip, the No. 10 wire coil end should be secured at points "A" and "B" with No. 6-32 machine screws. A flexible ground wire should be attached to point "A," Figure 18. The other end of this wire should be provided with an alligator clip to permit convenient grounding of the soldering iron.

Soldering Techniques

When it is necessary to solder or unsolder a transistor or other semiconductor device, use a clean, well-tinned pencil soldering iron and a good-quality, low-temperature solder. Complete the soldering process as quickly as possible.

In the application of solder, remember that the iron must heat the metal to solder-melting temperature before actual soldering can take place. The flat side of the soldering-iron tip should be held directly against the parts to be soldered. The solder-melting temperature is reached in a matter of seconds (5 to 10 seconds), therefore, the soldering iron and the solder strand must be applied simultaneously. Apply the solder to the point of soldering-iron contact—not to the soldering iron. Figure 19 illustrates both the correct and incorrect manner of solder application.

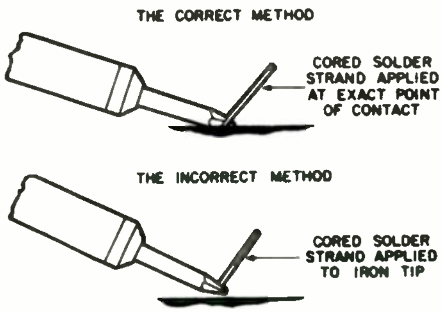


Figure 19 — The correct and incorrect methods of solder application.

Be sure the terminal, lead, or any portion of a part to be soldered has been properly cleaned and tinned before positioning it for soldering. Do not tin printed circuit terminals; clean moisture, grease, or wax from the printed ribbon with a stiff-bristle brush and an approved solvent.

De-Soldering

The Ungar off-set or straight slotted tiplets (J and K, Figure 17) will simultaneously melt the solder and straighten the leads, tabs, and small wires bent against the board or terminal (as illustrated in Figure 20A). If this tool is not available, the improvised soldering tip shown in Figure 18 may be used with a split-end probe and alignment soldering-aid tool (Figure 17), or with a pocket penknife as illustrated in Figure 20B.

The bar-type tiplet (Q, Figure 17), will remove straight-line multi-terminal parts quickly and efficiently, as illustrated in Figure 20C. The removal of this type of part may be accomplished by individually heating each solder connection and brushing away the melted solder with a wire brush, as shown in Figure 20D. In using this method, particular care must be taken to prevent loose solder from making contact with other parts or with the circuit board where it may cause a possible short circuit.

Another method involves the use of a piece of No. 10 copper wire. One end is wrapped around the soldering iron tip and the other end of the wire is fashioned to cover all of the lug connections simultaneously, as illustrated in Figure 20E. Care must be exercised to ensure physical contact with the terminals to be unsoldered and nothing else. Do not allow the tool to remain in contact with the connection for prolonged periods of time. Remove the tool after a short time, wipe off the excess solder, and then reapply. This permits the area to cool, thus protecting the circuit board and associated parts.

The cup-shaped tiplets (M, N, and O, Figure 17), the triangle tiplet (P), and the hollow-cube tiplet (L), are specially designed to withdraw solder from the circular or triangular mounted parts in one operation, as illustrated in Figure 20F. If these tools are not available,

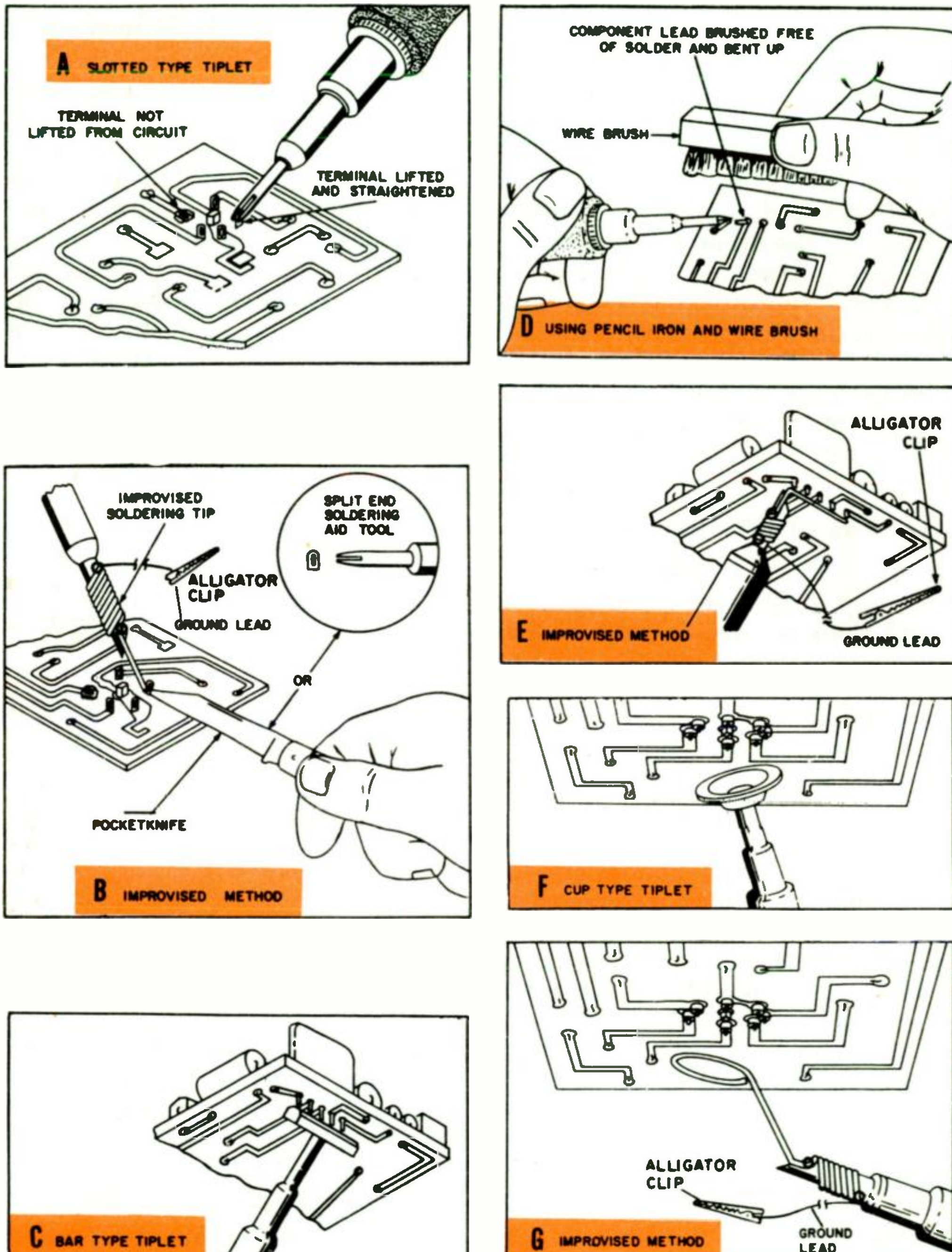


Figure 20 — Special soldering iron adaptations.

an improvised soldering tip can be used for circular or triangular mounted parts in the same manner as described previously for the improvised tip for straight-line multi-terminals. This method of removing circular or triangular mounted components requires the use of No. 10 copper wire with one end wrapped around a soldering iron tip, the other end of the wire shaped to cover all of the lug connections simultaneously, as illustrated in Figure 20G. This tool must be applied with care to the terminals of the part to be removed, so as not to touch the circuit board or its associated parts.

Transistor Replacement

To replace a proven defective transistor, first cut all of its leads, and then remove it from the assembly. Transistors are mounted on circuit boards in many different ways; thus it is necessary to study how a particular transistor is secured before attempting to remove it. A transistor with clamp-type mounting requires only a pointed tool between the clamp and the transistor to remove it. A transistor mounted in a socket may have a wire or spring clamp around it. Remove this clamp before pulling the transistor out of the socket. In some instances the transistor is bolted through the board. Remove the nut and washer, and then remove the transistor. Where vibration is a prime factor, the manufacturer mounts the transistor through the circuit board and bonds it (with epoxy resin or similar compound). For this type, a flat-ended round-rod-type tool (drift punch) of a diameter less than that of the transistor case is required. Place the printed circuit board on which the transistor is mounted in a chassis holding jig, in such a way that pressure exerted against the board will be relieved by proper support on the other side, as shown in Figure 21. Apply a hot-pencil soldering iron to the bonding compound and simultaneously apply the drift punch against the top of the transistor, exerting enough pressure to force the transistor from the softened compound, and on through the board, as indicated in Figure 21.

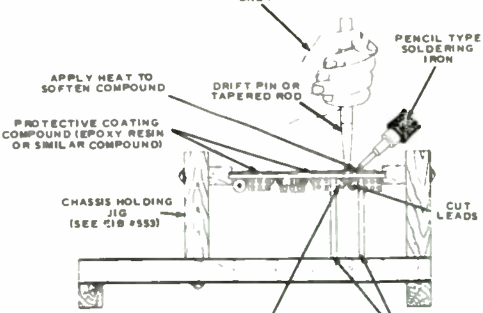


Figure 21 — Removing a transistor that has been through-board mounted.

Before installing the new transistor, great care must be taken to prepare the part for installation. Test the transistor in a transistor tester before installing. This precaution will assure that the transistor is good before it is installed. Preshape and cut the new transistor leads to the shape and length required for easy replacement. Use sharp cutters, and do not place undue stress on any lead entering the transistor. The leads are fragile, and are therefore susceptible to breaking by excessive bending or too sharp a bend. Shape any bend required in a gradual curve, and at least $1/4$ inch to $3/8$ inch from the base of the transistor. A safety measure which can be taken to ensure that the lead will not break off at the base is to use two pairs of needle-nose pliers. With one pair grasp the lead close to the transistor base, while shaping the rest of the lead with the other pair.

After the remaining pieces of the defective transistor-terminal leads have been removed and the terminals on the board cleaned and prepared, connect the new transistor to its proper terminals.

PRECAUTIONS

The following precautions should be observed when servicing transistorized circuits.

Ensure that all power has been removed from the equipment under test before connecting any test equipment.

Connect a common ground lead from the chassis of the set under test to the test equipment before making any other connections.

Use an isolation transformer with all test equipment unless the test equipment has a transformer in its power supply.

Before using an ohmmeter to check resistance in a transistor circuit, ensure that the meter will not apply an excessive voltage or voltage of the wrong polarity to the circuit. Do not use a range that passes more than 1 ma.

When unidentified transistors are encountered in equipment, their type must be identified before any testing is started. PNP and NPN transistors are not interchangeable.

When testing transistor circuits, do not remove a transistor while the power is on as the transistor or circuit under test may be damaged. Do not ground transistor elements while the power is on.

When soldering or unsoldering, use a light duty soldering iron rated at 50 watts or less. If there is any doubt concerning leakage current in a soldering iron, use an isolation transformer. If an isolation transformer is not available, the iron should be brought to soldering temperature, removed from the AC outlet, and then applied to the part to be soldered.

When soldering or unsoldering transistors or other semiconductor devices, exercise caution to avoid overheating the devices. If necessary, use heat sinks, or a thermal shunt device as shown in Figure 17.

SERVICE LITERATURE

The first servicing tool you will need is adequate service literature. For some reason, many beginners try to get along without technical literature. Yet the professional regards his file of service data as perhaps his most important servicing tool. In fact, he is reluctant to tackle any tough service job without it, because he has found that it can save him hours, and time is really all any professional has to sell. Further, it can keep him out of unexpected technical traps—special circuits and tricky mechanical arrangements which can be puzzling until seen on a diagram and labeled on photographs.

The professional's answer to "What kind of service literature should I get?" is usually "As much as you can lay your hands on." This may include manufacturer's literature, when available, or PHOTOFACT Folders published by Howard W. Sams & Company, Inc.

The literature supplied by manufacturers varies greatly. Some are well prepared and complete, and others offer only a schematic. Also, the location of the various parts on the schematic varies with each manufacturer, so look the literature over and become familiar with it before attempting servicing. Each PHOTOFACT Folder follows the same pattern. All contain the schematic, parts list, photos of the chassis, alignment information, and any other applicable data. The same method is always used to lay out a schematic and the same symbols are always used. Once you become acquainted with the system, you will know exactly where to look for data on any amplifier, radio, or TV set.

The servicing information in the remainder of this lesson is based upon the use of PHOTOFACT Folders. Of course, it also applies when using manufacturers' literature except for a few differences in the methods by which the manufacturer presents the data.

Obtaining the Correct Data

10

To obtain the service data for your set, first track down the *model* and *chassis* numbers. These usually appear on a sticker (or stamped into the metal) on the back of either the chassis or case. Give these numbers (if in doubt, write down *all* the numbers there) and the brand name of the set to your radio parts jobber, most of whom stock a complete supply of service literature.

The data is in the form of folders in a package, called a set. Of course, you will receive data for other equipment in addition to what you need, but the folder for your set alone is worth many times the price of the set, in the time saved in troubleshooting. Furthermore, the beginner can learn many interesting and useful facts by studying the data in the other folders.

Now let's assume you have the service literature for an AC-DC radio. With it on hand, you're ready to tackle the actual servicing. As mentioned previously, the starting point for any servicing is an overall look at the symptoms. Suppose we start with an easy one first.

TUBE-TYPE RADIO SERVICING

Completely Dead Set

Yes, a dead set is easy to fix. The tough ones are those which are only half-dead! (By "completely dead," we mean none of the tubes are lit.)

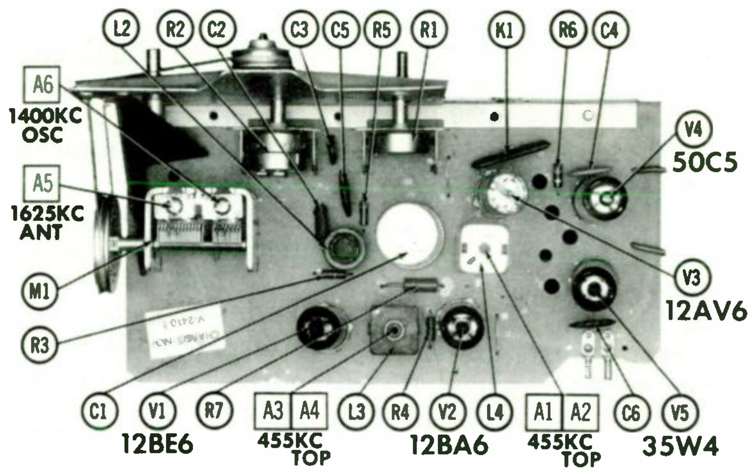


Figure 22 — Top view of radio chassis.

Your first move is to look for a short, which might melt a part or blow a fuse. Figure 22 is a photo of the top of the chassis. Notice that this set has a printed-board chassis — commonly used in modern receivers to reduce costs and eliminate wiring errors.

1. With this set, the power cord is automatically disconnected when the back is removed. This so-called interlock protects inquisitive owners from shock. The fact that power is cut off is no problem, since the first test is static (requires no power to the set). Now measure the resistance *across* the two power-plug pins on the chassis board. With the switch (on the volume-control) off, the meter should read a very high resistance.

2. Now snap the switch on and again measure the resistance across the power-plug pins.

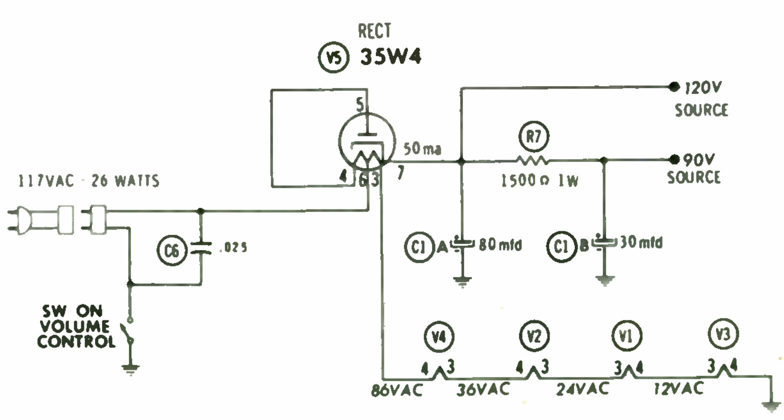


Figure 23 — Schematic of radio power supply.

This time you will need the low-ohms scale, since the resistance should be about 150 ohms (the total of all the tube heaters in series—see Figure 23).

3. A *low-resistance* measurement (less than 100 ohms) probably means a short. First, use the test procedure for a paper or ceramic capacitor to determine whether power-line filter capacitor C_6 is shorted or leaky. Then check filter capacitor C_{1A}, using the test for electrolytics. Of course, should *either* capacitor be shorted or leaky, the next move is to replace it.

4. Assuming no short is present, next apply power to the set with a "cheater cord" (Figure 24). Aptly named, this cord lets you override the interlock in the back of the set. The tubes should now light. In Figure 23, the tubes are all in series. So if one is open, none of the others will be lit. When this happens, the trick is to determine which tube is open.

If your service requirement has not progressed as yet to the point where you have felt the need to purchase a professional quality tube checker you have an alternative.

Figure 24 — A "cheater cord" for applying power to set with back removed.

One easy way is to take all five tubes to a radio-TV service shop and have them checked. *Definitely* go to a service shop—while any drugstore tube tester will usually indicate an open filament, this is about all some of them will reliably tell you. While you are at it, you might as well find out if the other tubes are all right, and a service shop will be more likely to have a tester which will tell you the actual condition of each tube.

6. However, if you are the self-sufficient type, you can find the dead tube yourself, with your ohmmeter. There are two methods of checking the filaments. The first, and usually the easiest, is to remove the tubes one at a time and check the resistance between the filament pins on the tube. Referring to Figure 23, we see that the filament connections for all tubes are to pins 3 and 4 except for V5, which has an additional connection to pin 6. Be sure to check between pins 3 and 6, then between 6 and 4. (Looking toward the base, start at the blank space and count in a clockwise direction for pin numbers.) The resistance of the filaments will vary from 15 to 65 ohms, but if you obtain a low-resistance reading, you can assume this tube is not the faulty one.

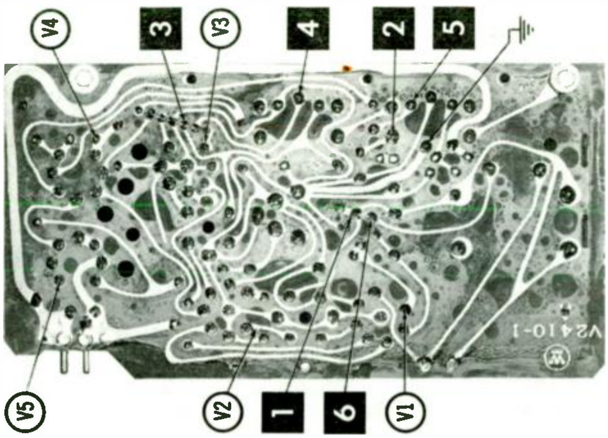


Figure 25 — View of bottom of printed board.

7. For the second method of checking the filaments, remove the "cheater" cord, and *carefully* remove the chassis from the cabinet. Put knobs, clips, screws, etc., in a box or dish so that you can find them later. It is always embarrassing to explain that you fixed the bedside radio but lost the original knobs, and the substitutes don't match the cabinet! The printed board looks distressingly complex, but fortunately help is at hand in the form of the printed-board illustration in Figure 25. Notice that the tubes are identified by the arrow which points to pin 1. You can determine the other pins simply by counting clockwise around the circle. Then by referring to the circuit diagram in Figure 23 and the resistance chart in Figure 26, you can measure resistance down the tube heater (filament) string in the following manner. Hook one of the test leads to the switch to obtain a ground. (Switch *on*, with power plug, or cheater, out of wall socket.) Then measure the resistance to ground of pin 3, tube V3; pin 3, tube V1; pin 4, tube V2; pin 4, tube V4; and pin 4, tube V5. Compare each resistance with the chart in Figure 26. What you have been doing is progressively moving up the chain of in-series tube heaters. The tube at which you don't measure the proper resistance in the open tube.

RESISTANCE READINGS

ITEM	TUBE	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7
V1	12BE6	22K	1Ω	30Ω	15Ω	†1500Ω	†1500Ω	3.8meg
V2	12BA6	3.8meg	0Ω	30Ω	45Ω	†1500Ω	†1500Ω	150Ω
V3	12AV6	6.8meg	0Ω	15Ω	0Ω	500K	0Ω	†470K
V4	50C5	180Ω	470K	45Ω	110Ω	470K	†1500Ω	†210Ω
V5	35W4	NC	NC	110Ω	155Ω	155Ω	150Ω	‡ INF

† THIS READING WILL VARY DEPENDING UPON THE CONDITION OF THE ELECTROLYTIC IN THE CIRCUIT.
MEASURED FROM PIN 7 OF V5

NC NO CONNECTION

Figure 26 — Resistance chart.

Dead Set (Tubes Lit)

The foregoing test procedure will probably repair over half of all AC-DC sets, since open tube heaters are the most frequent problem. But what if the set is *still* dead?

1. Then suspect the power supply next. First, measure the resistance from pin 7 on the 35W4 tube (set off). In effect, you measured across the electrolytic capacitors; the needle should swing to one side of the scale and then climb back to a very high resistance as the electrolytics charge up. If the resistance is *low,* the capacitor is probably defective.

   Replacing a capacitor will take some care. Both sections (are in the same can), so you will have to replace the whole unit. Refer to the parts list in the folder; it shows the manufacturer's part number, plus the part numbers of several other brands of replacement capacitors. Your parts jobber is almost certain to stock at least one of them. Of course, if using one manufacturer's service literature, only that manufacturer's part numbers will be given.

2. Soldering and other work on a printed board requires caution. However, if you have had experience with a *light* pencil-type iron (preferably fitted with a "tiplet" instead of the regular tip) and use 60/40 low-melting-point solder, replacing the parts should not be too tough. But don't heat up anything unless you have to, and don't get too heavy-handed or you may crack the printed board.

   If pin 7 has the proper resistance, you can be reasonably certain the power supply is not shorted. Now you can apply voltage to the set (i.e., make dynamic tests) to find out why the set is dead.

   Caution: Instead of a transformer being used, the power line connects directly to one side of the circuit. So the full 115 volts is right out where it can "nail" you. Furthermore, depending on how the plug is inserted into the wall socket, you can get the full force of the voltage when touching a ground or B− point in the set if you are grounded to the basement floor or if you touch a water pipe or other object connected to earth ground.

Professional service technicians enhance their chances of reaching old age by using an isolation transformer to make the chassis far less lethal. Furthermore, an isolation transformer *greatly* helps in eliminating stray hum and other spurious responses which might interfere with servicing.

These transformers seemingly are expensive—but caskets cost much more. So a transformer is *strongly* recommended between the power line and *any* AC-DC equipment you work on. A 50-watt transformer, which is adequate for the average small radio, sells for about eight dollars and may be the best investment you ever made.

Let's assume you are powering the set from an isolation transformer. Next you will want to find out whether there is any DC voltage.

1. A quick check can be made at pin 7 of the 35W4 tube (V5). The circuit diagram in Figure 23 shows 120 volts between pin 7 and the switch or "ground" point on the printed board. If there is no voltage, the cathode of the rectifier tube has probably burned out. Before replacing the tube, however, again turn the set off and make a resistance check from pin 7 to ground. If little or no resistance is present there, chances are a faulty capacitor has placed a short across the power supply, and the short has burned out the tube. The capacitor must be replaced, of course, otherwise, the new rectifier tube will also burn out the moment power is applied.

2. If the DC voltage at pin 7 of V5 is all right, the next step is to find out whether the "low" voltage is available. Check it from pin 6 of either the 12BE6 or 12BA6 tube in Figure 27. As the diagram shows, it should be approximately 90 volts.

3. If this voltage is absent, or less than specified, check C_{1B} and R_7. Note that in this particular set the AC is applied to pin 6 on the rectifier tube, and that DC should be present on pin 7 (the output of the rectifier). Resistor R_7 is used instead of a filter choke.

DC Voltage Present, Set Still Dead

Since the problem described above could be coming from any stage, the next move is to isolate the dead stage, again by using dynamic tests.

Quick Check: First make a quick check, using the signal injection technique described in previous lessons. Apply an audio signal to test point 4, identified by the number 4 in the black square on the schematic of Figure 27. As you can see from the circuit diagram, the signal will be fed into the AF amplifier (driver stage) and then to the output amplifier. Thus, you should hear sound from the speaker. If you don't, you know the audio portion of the set is not working and you will have to apply the audio to points progressively closer to the output until you locate the points from which a signal is heard in the output. The problem will immediately preceed this point.

Component Combinations: In much equipment manufactured today, a number of parts are commonly combined into a single molded unit. In a circuit diagram a molded unit is indicated by a dotted line around all parts included in it.

Unfortunately, whenever any part *within* the unit is defective, usually the whole unit must be replaced. In Figure 27, for example, if you fed a test signal onto the plate of the 12AV6 (pin 7) and heard nothing from the speaker, but did hear a signal when you inserted the test signal at pin 2 on the 50C5, it is reasonable to assume that the 5,000 pf capacitor inside K_1 is open—in which case all of K_1 would have to be replaced.

This means breaking connections 1 through 7 on K_1. There are different ways of doing this, but the

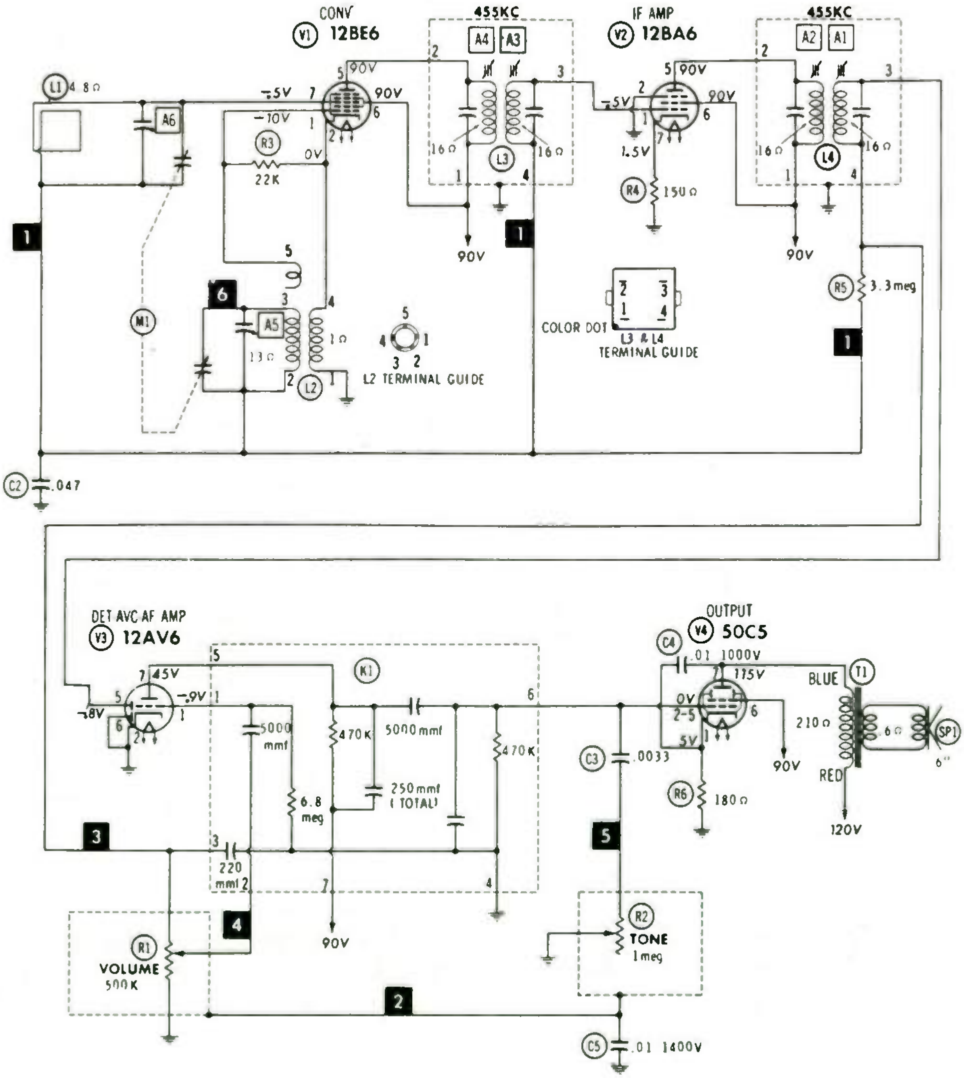


Figure 27 — Schematic of radio, less power supply.

most common is to carefully clip the leads *above* the board, and solder them to the replacement leads. This is much easier than making seven connections to a printed board. But before clipping any wires, pencil in a diagram of the connections. Otherwise, you may have quite a time remembering what wire goes where.

The technique of soldering to clipped-off leads (a resistor is often deliberately split open with side-cutting pliers to get the longest possible leads) is highly useful in working on printed boards. Again, it cannot be overemphasized that you should use a light pencil-type iron and 60/40 resin-core solder. Do not use a substitute.

Checking Converter and IF Stages

If the audio amplifier (AF amplifier and output) seems to be working satisfactorily, the next reasonable assumption is that the signal isn't getting through the converter or IF amplifier stage. Apply the signal generator to the grid (pin 1) of IF amplifier V2. If the signal gets through at that point, move on to the grid (pin 7) of the converter. If both are all right, there is nothing left but the oscillator. Here are some suggestions for checking the oscillator:

One test is to see whether the oscillator signal can be picked up by another set. If not, replace the

Figure 28 — A test capacitor for bridging across suspected filter capacitors.

tube. If the oscillator still does not operate, check the following parts with an ohmmeter, in this order:

1. Grid resistor R_3 for resistance as specified.

2. Coil L_2; if its resistance varies as the test leads are pressed against the lugs, resolder the leads onto the lugs. If that does not stop the resistance change, replace the coil.

3. Trimmer capacitor A_5 for shorts. To check, unscrew A_5 out as far as possible, noting the number of turns (so you can readjust it later). Now see whether the oscillator starts.

4. The variable capacitor for bent or shorted plates.

5. As a last resort, replace oscillator coil L_2. Coil troubles sometimes are very difficult to locate.

Hum In Speaker

Finding the source of speaker hum calls for a sort of "brute-force" servicing method.

1. Bridge *both* sections of the filter capacitor with a suitable good capacitor. Fig. 28 shows an easily constructed test capacitor unit for this purpose. Alligator clips are attached to the capacitor leads for easy connection into the circuit, and are wrapped with tape to prevent shock. (Note: The value of the test capacitor is not critical. The unit in Fig. 28 will work for any circuit as long as the voltage does not exceed the 150 volts of the test unit.) Fig. 29 shows how the test capacitor is bridged across the circuit. *Don't* forget to observe *polarity.*

2. If the hum continues, chances are there is filament-to-cathode leakage in a tube. With your signal tracer, check at the plate and grid of each tube, starting with V_1 and working through the circuit. When you find the stage where hum first appears, you have just located the bad stage.

3. Other possibilities are an open in the grid circuit (for example, the 6.8-meg resistor in K_1) or open line filter C_6.

Radio Whistles And "Plop-Plop-Plops"

1. Check the filter capacitor by bridging filter C_{1A} and C_{1B} as described earlier.
2. Substitute a new 12BA6 tube.
3. Substitute a new 12BE6 tube.
4. Check capacitor C_2.

Music And Voice Distorted

1. Check the filter capacitors by bridging filters C_{1A} and C_{1B} as described earlier.

2. Starting at the grid (pin 7) of the 12BE6 and working through

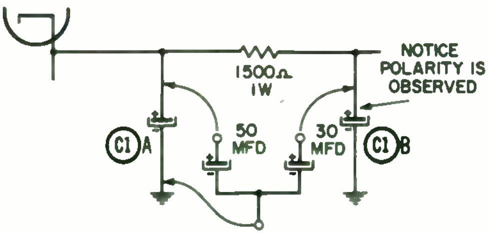


Figure 29 — Connecting test capacitor into the circuit.

the set, signal-trace until you locate the stage where distortion starts. Then replace that tube.

3. If replacing the tube does not solve the problem, make voltage checks at tube terminals and resistance checks of parts connected in the tube circuit.

SUMMARY

The foregoing methods—plus logical thinking and common sense—should enable you to easily uncover 90% of the troubles in an AM radio. If you still cannot uncover the trouble, a review of lessons related to components and basic circuitry is recommended . . . . .to refresh your memory.

TEST

Lesson Number 64

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-064-1.

1. Logical troubleshooting procedure is usually divided into ________ steps.
A. three
B. five
C. two
D. six

2. Before any attempt can be made to isolate a problem, you must
A. check the tubes.
B. have the spare parts.
C. know the symptoms.
D. localize the trouble area.

3. A necessary aid to troubleshooting is
A. adequate service literature.
B. a large stock of tubes.
C. a large stock of transistors.
D. a large stock of small parts.

4. The instrument used for the signal substitution method of trouble-shooting is a/an
A. VTVM.
5 B. VOM.
C. RF signal generator.
D. oscilloscope.

5. **Accurate voltage measurement can be made with a/an**
   A. RF signal generator.
   B. VTVM.
   6 C. signal tracer.
   D. tube tester.

6. **Voltage measurements should be first made in the __________ section.**
   A. mixer
   B. IF
   6 C. RF
   D. power supply

7. **After replacing certain defective components in a mixer or IF stage,**
   A. realignment may be necessary.
   9 B. other components will have to be changed.
   C. power supply voltages will have to be altered.
   D. the associated transistor must always be changed.

8. **Before aligning the RF, mixer, and oscillator stages, the ________ should be aligned.**
   A. detector
   9 B. audio
   C. IF stages
   D. none of the above

9. **Care must be exercised when repairing printed circuitry to prevent**
   A. breakage.
   B. foil damage.
   C. damage to components.
   D. all of the above.

10. **To obtain the correct service literature you must know**
   A. the transistor types used.
   20 B. the tube line-up.
   C. the model and chassis number.
   D. how many tubes the receiver contains.

Notes

Notes

Notes

Portions of this lesson from
Electronic Equipment Circuits by Martin Gersten
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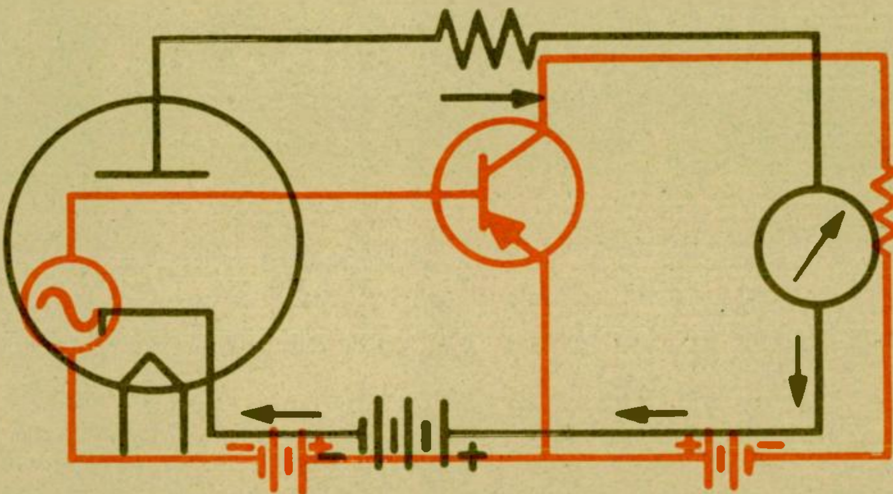
THE HOME STUDY STUDENT

Studies completed through home study are tougher than if you were studying in a classroom. As William Rainey, the late president of the University of Chicago said, "The work done by correspondence is even better than that done in a classroom. The correspondence student does all the work himself. He does twenty times as much reciting as he would in a class where there were twenty people. He works out the difficulties himself and the results stay with him."

S. T. Christensen

LESSON NO. 65

FM RECEIVERS
PART 1



RADIO and TELEVISION SERVICE and REPAIR

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CONTENTS

FM RECEIVERS—PART 1

INTRODUCTION

On January 24, 1933, the late Major Edwin H. Armstrong applied to the United States Patent Office for a patent to cover a system of broadcasting which he titled simply, "Radiosignaling." The resulting patent—#1,941,069—was issued December 26 of that same year. (At that time, technology in the electronic field had not reached the level of complexity that required the patent office to spend approximately five years before issuing a patent.)

The patent called "Radiosignaling" was, in fact, the beginning of "wideband" FM broadcasting as we know it today. Actually, FM broadcasting principles were known long before 1933, but it took Armstrong to separate the techniques from those so long employed in AM broadcasting, so that FM might realize its inherent advantages of low-interference, high-fidelity performance. Today nearly thirty million FM receivers are in use in the United States alone. Of these, some ten million are capable of reproducing "stereo FM" via the multiplexing techniques also conceived by Major Armstrong and refined primarily by another important inventor in the FM field, Murray G. Crosby.

Another encouraging factor in the belated popularity of FM was the decision of the Federal Communications Commission regarding separate programming for FM and AM. This ruling decrees that owners of both AM and FM stations must provide different program material for their AM and FM outlets at least fifty percent of the time they are "on the air." In this way, the FCC elevated the status of FM from that of a tag-along "stepbrother" to that of a full member of the broadcasting family.

In these lessons we will cover the important details of FM receivers, and some basic alignment procedures to be followed. We will start at the antenna input terminals and examine each of the important sections of an FM receiver.

FM TUNERS

First, let's define the word "tuner," because it means different things to different people. In high-fidelity terminology, the *tuner* is all the circuitry needed to convert the

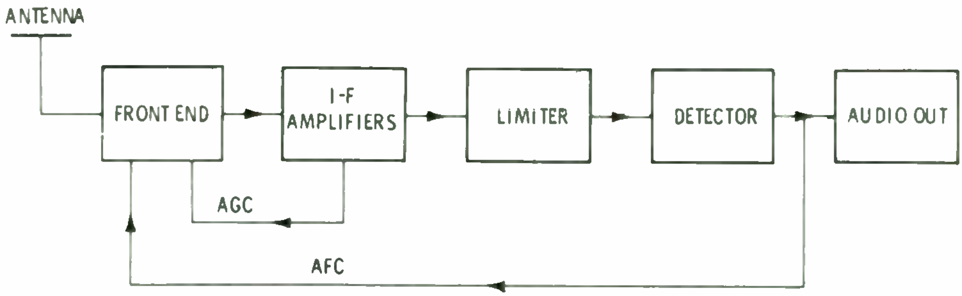


Figure 1 — Block diagram of an FM tuner.

received signal at the FM antenna into audio information suitable for application to an audio amplifier. *Package* or console manufacturers often refer to a *tuner* too, but they mean just the early portion of the receiver devoted to amplifying the radio frequencies and converting them to an intermediate frequency of 10.7 MHz. It is this section of a *tuner* that we call a "front-end."

Figure 1 is a block diagram of a typical *tuner*. Today's tuners almost invariably employ solid-state amplifying devices in the front end, as well as in the IF section. More recently, many manufacturers are using field-effect transistors in at least the RF stage of the front end. These solid-state devices more nearly approximate the performance of the highly perfected RF tube designs that were popular a few years ago. If this seems a bit paradoxical, one must realize that the pressures of marketing forced designers into complete transistorization a bit too soon. Only now are the solid-state devices used for front-end design catching up with some basic performance capabilities long associated with vacuum-tube performance. For this reason, we shall first examine a cascode RF amplifier, as used in a radio receiver several years ago.

Circuit Noise

The ability of a receiver to amplify a signal is not limited by the amplification attainable from the vacuum tubes or transistors, but rather by the noise which arises from these devices and their associated circuitry. Further, the noise developed in this first RF stage is actually the most significant: whatever noise voltage appears at the grid of this stage will be amplified along with the signal. The best choice for low noise (confining the discussion to tubes, for the moment) is a triode amplifier tube. Unfortunately, the gain of most triodes is less than that obtainable from pentode tubes.

The circuit shown in Figure 2, known as a cascode amplifier, combines the gain features of a pentode with the low-noise features associated with triode operation. L1 and L2 constitutes a matching transformer arrangement known as a "balun." While most antenna transmission lines used for home FM receivers are the familiar 300-ohm twin-lead type, coaxial transmission line has been shown to be more advantageous when fighting local man-made noise, such as ignition from vehicles, etc. Coaxial transmission line sold for this purpose has an impedance of 72 ohms, and if no provision were made for impedance matching, the signal lost by virtue of the mismatch to a 300-ohm receiver input might well offset the gains resulting from the use of coaxial lines in the first place. Some high-quality sets provide inputs matched for *either* 72 or 300 ohms for this reason.

The signal from secondary L2 is applied to the first tuned circuit, which in turn connects to the control grid of the first triode section. The signal at the plate of the first triode is coupled to the *cathode* of the second triode section, while the grid of the second triode is grounded (as far as RF is concerned). Thus, the first stage is operated as a conventional amplifier, while the second stage is employed as a grounded-grid amplifier.

The other blocks in Figure 1 (local oscillator and mixer stage) constitute the rest of this "front end"; operation of these blocks will be discussed in more detail later. At this point, however, before we present analogous transistorized

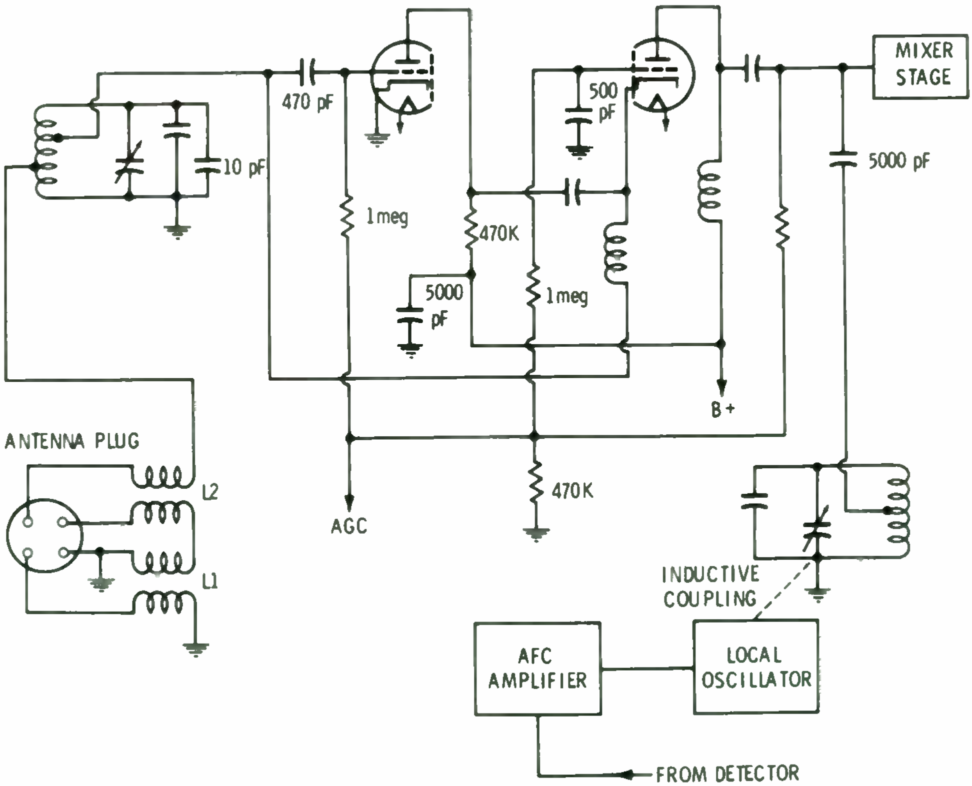


Figure 2 — Good-quality front end from the vacuum-tube era, featuring a popular "cascode" dual-triode RF stage of the period.

stages, it would be well to examine some of the other features of this first section of an FM tuner. For one thing, we glossed over the means of tuning.

Tuning the Receiver

Tuning is generally accomplished by means of a variable air capacitor, much like those used in AM receivers. Over the years many other schemes of tuning or changing frequency have been devised. For example, coaxial variable capacitors were tried by one manufacturer some years ago. Instead of the plates meshing, as in a conventional capacitor, a coaxial capacitor consists of a stationary cylinder into which is plunged a movable cylinder. The two are separated by a dielectric (usually a glass cylinder, onto which the outer conductive plate is heat shrunk or vacuum plated).

Permeability tuning (where the inductance rather than the capacitance of the resonant circuits is varied) in various forms has also been used in a great many designs over the past two decades. Somehow, however, the good old air-dielectric variable capacitor seems to have won out, at least insofar as high-fidelity front ends are concerned (diode tuning has of late been adopted by some manufacturers, however). Permeability tuning is still used in automotive receivers, perhaps due to space requirements and because some physical arrangements of inductance tuning are a bit more stable and less susceptible to dust and road shock.

Confining the discussion to variable capacitors, then, the next question is: "How many sections, or tuned circuits, are needed for quality performance?" As you peer underneath FM tuners, examining construction, you are likely to find some having only two-gang capacitors, others using three gangs (these are by far in the majority), and even a few employing four sections. The minimal-quality sets employing only one tuning section for radio frequency selection (the second gang tunes the local oscillator frequency) will, of course, have minimum selectivity. More selective sets have a three-gang capacitor for tuning the input antenna circuit, the interstage coupling circuit (as in the example of Figure 2), and the local oscillator. Four-gang capacitors will be found in sets which employ more than one RF stage or in designs where the interstage coupling is accomplished by means of a double-tuned circuit.

Automatic Gain Control

AGC, or "automatic gain control," is often applied to the RF stage to prevent overloading of the stage when particularly strong signals are applied. This means that the first stage must have the capability of exhibiting varying gain with different bias settings. This was easily accomplished with "variable mu" vacuum tubes and is equally easy to accomplish with today's transistors, which depend on bias for varying figures of gain. Note that this feature is called automatic gain control, rather than AVC (automatic volume control), the term used in AM receivers. This is because changing the *amplitude* of the RF signal in an FM receiver does alter the volume or "loudness" of the resultant output unless we are speaking of signals so weak that they do not cause full limiting in subsequent IF stages.

Design Techniques

Other features of an FM stage which are not apparent from examining the schematic alone should be noted. Coils represented in the usual manner in the schematic become just four or five turns of heavy wire, with rather large spacing between turns, often using air as a dielectric. The variable capacitor sections themselves usually have just two or three plates in the rotor or stator, since we are dealing with total capacitances of just a few picofarads. Dress and layout of parts are much more critical than in AM RF stages, because even an inch or so of excess wire length implies a significant amount of additional inductance. Proper grounding is very important, too.

The techniques used to design and lay out RF sections of an FM receiver have evolved over a great many years. It is not the sort of thing a novice kit-builder should attempt to do from simple referral to a schematic. It is for this reason, incidentally, that most tuner kit manufacturers supply the front end in preassembled form, often even prealigned. To really appreciate the differences between a broadcast-band RF design and one intended for FM reception, you should examine the front-end construction of an FM tuner. Note the overall shielding. Good FM tuners usually enclose the entire front end in a metal shield—to preclude excessive radiation from the local oscillator and to prevent accidental or intentional tampering with precisely-aligned coils, trimmers, etc.

SOLID STATE RF FRONT ENDS

The early attempts at RF front-end transistorization resulted in performance that was inferior to the tube designs displaced. A brief discussion of why these first designs fell short of the mark will help in understanding some vital FM RF design considerations.

There are several things that an RF stage is expected to do, in terms of overall FM performance. For one, it is expected to establish a suitably low noise figure. Since the
3 RF incoming signal is at its lowest level at the input to this critical first stage, it is this first RF stage which ultimately determines overall noise figure. Another characteristic expected of an RF stage is satisfactory selectivity. In general, the RF stage will be tuned (either double-tuned at input and output, or single-tuned at output) to provide as much selectivity as possible without restricting necessary channel bandwidth. An RF stage may be expected to encounter signal input levels ranging from a few microvolts to a volt or more—in other words, a dynamic range approaching one million! If the stage is to handle this range without overload, some means must be provided to vary the gain of the active device,

be it tube, Nuvistor, transistor, or FET (field effect transistor). Such variation, as mentioned earlier, is accomplished by means of an automatic gain control (AGC) voltage. Finally, a good RF stage should 3 produce a minimum of spurious responses of its own and be subject to a minimum of interference brought about by certain combinations of multiple frequencies related to, but not identified with, the desired signal frequency.

Transistorized RF Stage

With all of the preceding requirements in mind, let us examine a typical early RF stage attempting to use high-frequency germanium transistors for an RF amplifying circuit. The circuit is shown schematically in Figure 3. The first big problem here is that, in the common-base configuration, input impedance of a bipolar germanium transistor is quite low. If the input is pretuned with a parallel tank circuit, one of two detrimental things will happen: (1) If we just place the tank circuit across the input, it will load it down, reducing circuit Q and selectivity; (2) If we compensate for the basic impedance mismatch, and "tap down" on the tank circuit, we will be tapping down on the signal voltage, or reducing gain capability.

To make matters worse, AGC, while present in the circuit of Fig. 3, is limited in its action by the gain-changing characteristics of the typical bipolar transistor. These devices are limited in dynamic range and, therefore, could be subjected to overload even in the presence of carefully worked out schemes.

With operating points established along the nonlinear characteristics of the transistor (to enable gain control), several forms of spurious response were often present. The two most important spurious responses that plagued early transistorized front-end designs were cross-modulation and intermodulation distortions. Cross-modulation distortion can occur

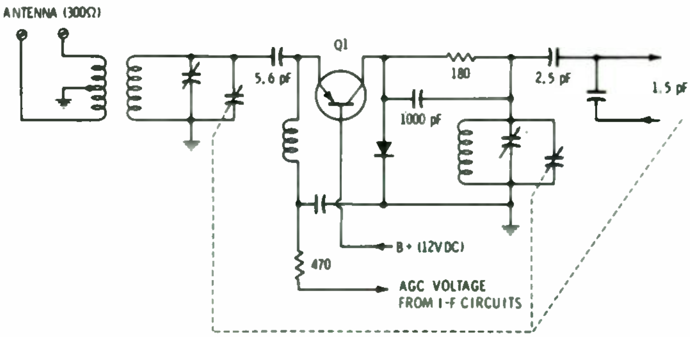


Figure 3 — Typical FM RF stage employing an ordinary bipolar PNP transistor.

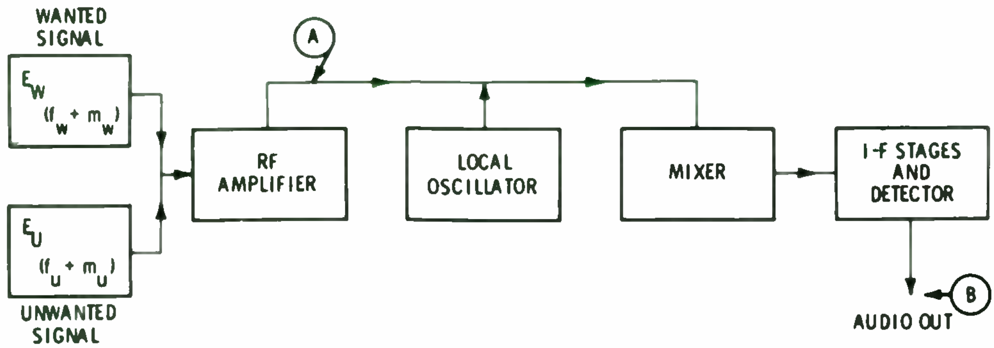


Figure 4 — Unwanted signal Eu may appear at B if receiver has poor AM rejection and/or poor IF limiting.

when a receiver is tuned to a small, wanted signal (E_w), while a large, unwanted signal (E_u) causes interference. With poor selectivity, the large signal is usually within the range of selectivity of the RF stage.

Figure 4 shows the wanted and unwanted signals as inputs to the RF amplifier. E_w consists of carrier frequency f_w and modulation frequency m_w. E_u consists of carrier frequency f_u and modulating frequency m_u. When E_u is very large with respect to E_w, an actual transfer of modulation, m_u from f_u to f_w, is accomplished because of the nonlinear input of the RF amplifier stage. The output waveform contains $f_w + m_w + m_u$ instead of the desired $f_w + m_w$ only. The amplified signal at A may contain the desired carrier, plus modulation of both desired and undesired carriers if a strong unwanted signal is close in frequency to a weak, wanted signal.

Intermodulation Distortion

When two or more frequencies are applied to a circuit with nonlinear characteristics, additional undesired frequencies are produced. These undesired frequencies are the sums and differences of two or more input frequencies. The harmonics of these undesired frequencies will beat together to create additional intermodulation products.

When we speak of nonlinearity of the input characteristic of early RF transistors, we must quickly add that this nonlinearity enabled the control of gain so vital in preventing severe overload and allowing for the dynamic range necessary in an FM RF stage. Nonlinearity, by itself, is not a bad thing, provided the nonlinearity follows the curve of a square-law device. Such a device, in effect, will produce second-harmonic distortion in its output, but practically no third-or higher-order harmonics. In the case of intermodulation distortion, second-harmonic distortion corresponds to first order (or sum and difference) intermodulation products. Thus, if one signal is 103 MHz and the other is 104 MHz, the sum will be 207 MHz and the difference will be 1 MHz. Neither of these products is anywhere near the selective range of the mixer or IF stages that follow. Consequently, there is no problem. Still, gain control is made possible because of the nonlinear characteristic still present.

FET Amplifier

The up-to-date circuit of Figure 5 illustrates the use of a field-effect transistor (FET) in the critical RF stage. This device fills the square law requirement, and does a lot more, too. Unlike the bipolar transistor, the input impedance at the gate element is very high, higher in fact than was the grid input impedance of the old triode vacuum tube. (Incidentally, the elements of the FET are called *gate, drain* and *source.*) The gate is the controlling element, similar in function to the grid of a vacuum tube. Sometimes the drain and source, equivalent to a tube's plate and cathode, may be physically interchanged with no difference in performance of the device. Many forms of FETs are appearing on the market, and the numerous differences between the various types cannot be detailed here.

This high input impedance enables the designer to resort to classical high-impedance resonant-circuit coupling at the input, improving selectivity, while at the same time permitting the full, useful gain of the device to be realized. The improved selectivity, coupled with the square-law action of the FETs has resulted in cross-modulation rejection of nearly 100 db! Such superior rejection exceeds rejection figures typical of tube circuits, which generally run about 80 or 85 db. Certainly, it surpasses anything that was possible with conventional bipolar transistors, where typical cross-modulation figures ran 60 to 70 db!

Thermal Noise

Thermal agitation arises from the random motion of electrons in any conductor having a finite resis-

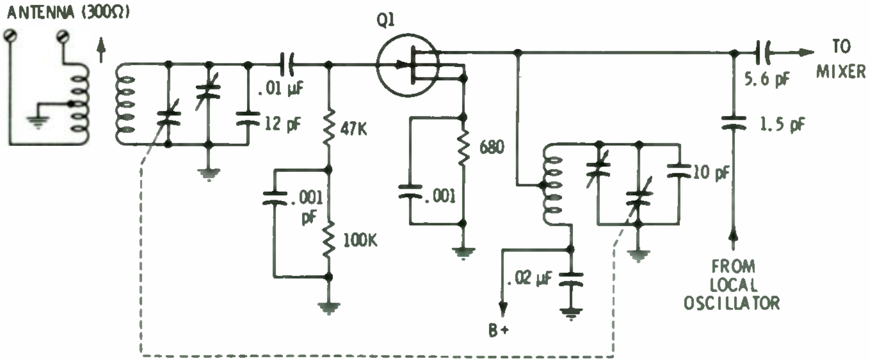


Figure 5 — Modern amplifier design using a FET device. Note the similarity to a triode amplifier circuit.

tance or impedance. This produced an equivalent thermal noise in early tube or transistor stages of an FM receiver. The equivalent noise resistance is, in effect, a fictitious resistor connected in series with the input of the RF amplifier. This equivalent resistance determines the ultimate noise figure of the front end. In the case of a typical triode, the equivalent noise resistance (simplified from a more complex formula) reduces to $2.5/G_m$, where G_m is the transconductance of the tube. Thus, a triode having a G_m of 8,000 micromhos would have an equivalent noise resistance of approximately 310 ohms. The 2.5 figure is used because a triode operates at a temperature which is about 2.5 *times* as high as room temperature, when both are expressed in the absolute (Kelvin) scale. Room temperature is about 300K, whereas tube operation is at about 750K. The ratio of the two is, therefore, 2.5.

Since a transistor (and that includes a FET) operates at just about room temperature, the equivalent noise resistance becomes $1/G_m$, rather than $2.5/G_m$, so that a FET having a transconductance of 8000 micromhos would represent an equivalent noise resistance of only about 125 ohms, and the lower the equivalent noise resistance, the better the noise figure!

LOCAL OSCILLATORS AND MIXERS

Frequency Conversion

FM superheterodyne receivers, like their AM counterparts, require conversion of the incoming signal to a lower intermediate frequency (IF). The IF almost universally used is 10.7 MHz. The signal received at the antenna terminals of the receiver is either amplified by means of a radio-frequency stage, or is fed directly to a mixer or converter stage (a practice employed only in very inexpensive sets).

The terms "mixer" and "converter" are not synonymous, even though they are often used interchangeably. A converter will involve the use of a tube or transistor which produces an oscillator voltage *and* mixes this voltage with the incoming RF signal. A mixer, on the other hand, fulfills only one of the above functions—the beating together of the incoming signal with a separately produced oscillator voltage. At the relatively low AM band of frequencies, it has become almost standard practice to use a converter stage. At signal frequencies of the FM band, however, operation of the local-oscillator stage becomes more critical. Stability of output voltage is more difficult to achieve, and interaction between oscillator and incoming signal voltage is more likely to occur with converters. While this does not rule out the use of converters in FM receivers (see Figure 6), all but the most inexpensive units will separate the mixer and oscillator functions by using individual devices (tubes or transistors) for each.

Tubes Versus Transistors

In examining the various circuits which compose an FM tuner or

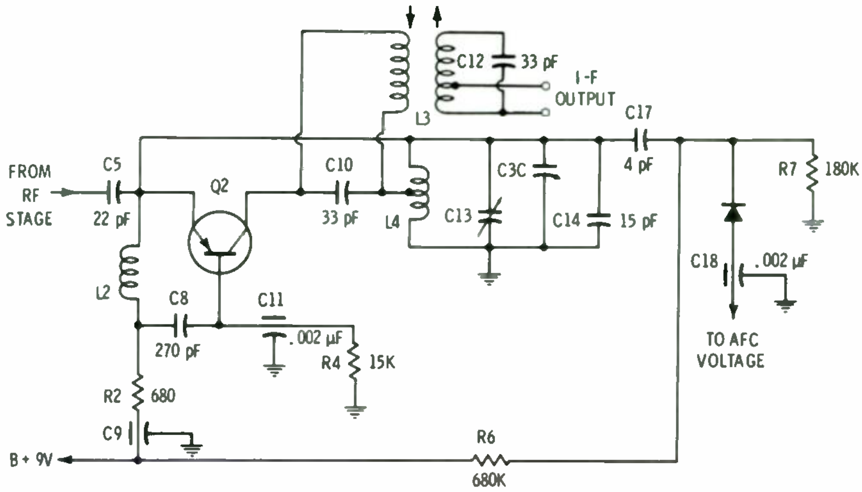


Figure 6 — Example of low-cost FM RF front-end "converter".

receiver, it is our practice to examine performance of these circuits in terms of relative advantages and disadvantages as the state of the art has advanced from tubes to solid-state circuitry. Accordingly, we shall first examine a high-quality tube-type oscillator circuit, followed by a modern transistorized local oscillator.

The first of these circuits is shown in Figure 7. It is the local-oscillator circuit of a Fisher Radio Model 500-C. Oscillation is obtained by the feedback circuit involving C22 (plate to grid circuit); resonant frequency is determined by the tank circuit consisting of L4, C8C, C19, C24 and C25. The variable capacitor section (C8C), along with its RF sections, is used to vary the oscillator frequency so that it is always 10.7 MHz removed from the received incoming signal. Trimmer capacitor C19 permits optimization of frequency tracking across the FM band.

Frequency Stability

Frequency conversion and the whole superheterodyne concept depends on beating an incoming frequency against an accurately maintained local oscillator frequency to produce an accurate intermediate frequency. Transmitter channel accuracy is maintained and safeguarded by many electronic techniques (not to mention the surveillance of the FCC). At the receiving end, therefore, the accuracy of the intermediate frequency will depend primarily upon the frequency stability of the local oscillator. A drift of only 1 percent at 100 MHz represents a shift of 100 kHz, enough to shift the converted signal partially or completely outside the range of the tuned IF stages which follow.

Heat that is generated in a tube-type receiver (from tubes, transformers and even resistors) is largely responsible for oscillator drift, and 1 percent or even 2 percent is the magnitude of drift you might typically expect if certain design precautions were not taken. Increased temperature causes an increase in *both* coil inductance and capacitor capacitance. It is for this reason that drift in an FM tuner will always be *downward* in frequency, since resonant frequency varies inversely with the square root of both inductance and capacitance.

Proper precautions (such as careful layout of components), which permit air to circulate and position heat-producing elements far away from critical inductances and capacitances, will partly reduce drift in the local oscillator. Additional, final compensation is usually achieved by the use of small, fixed capacitors having a *negative* temperature coefficient. This means that these capacitors actually exhibit a *decrease* in capacitance with increase in surrounding temperature.

As an example (referring again to Figure 7), C22 and C23 are shown as having an N1500 temperature coefficient, while C24 is listed as N330, and C25 is an "NPO" type. N1500 means that the particular capacitance will decrease by 1500 parts per *million* for every degree centigrade *increase* in ambient temperature. Similarly, N330 means a decrease in 330 parts per million (of capacitance) for each degree centigrade increase in temperature. "NPO" means negative-positive-zero—or, a temperature-stable capacitor that neither increases nor decreases in capacitance with temperature changes. Less expensive design would have attempted to stabilize frequency with only *one* temperature-compensating capacitor in the resonant circuit. By using both an N330 and an NPO type for C24 and C25, the circuit achieves precisely the compensation desired during the short-term and long-term drift time period.

Compensation to Prevent Drift

Figure 8 illustrates typical drift conditions for compensated and uncompensated oscillator designs. Other measures taken to provide frequency stability include regulation of power supply voltage (oscillator frequency will vary with change of supply voltage), and de-

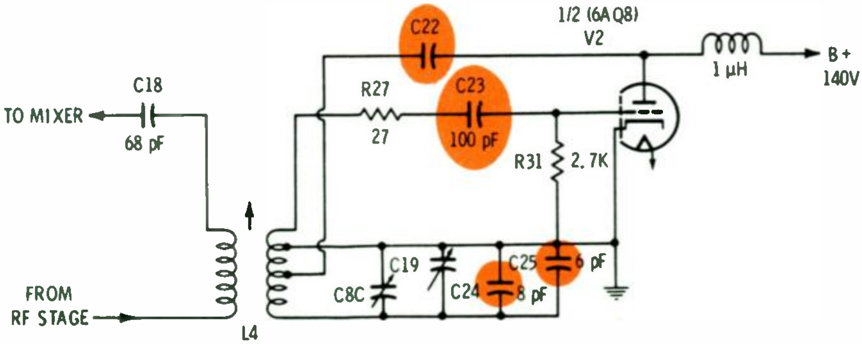


Figure 7 — Local oscillator circuit (Fisher 500-C receiver).

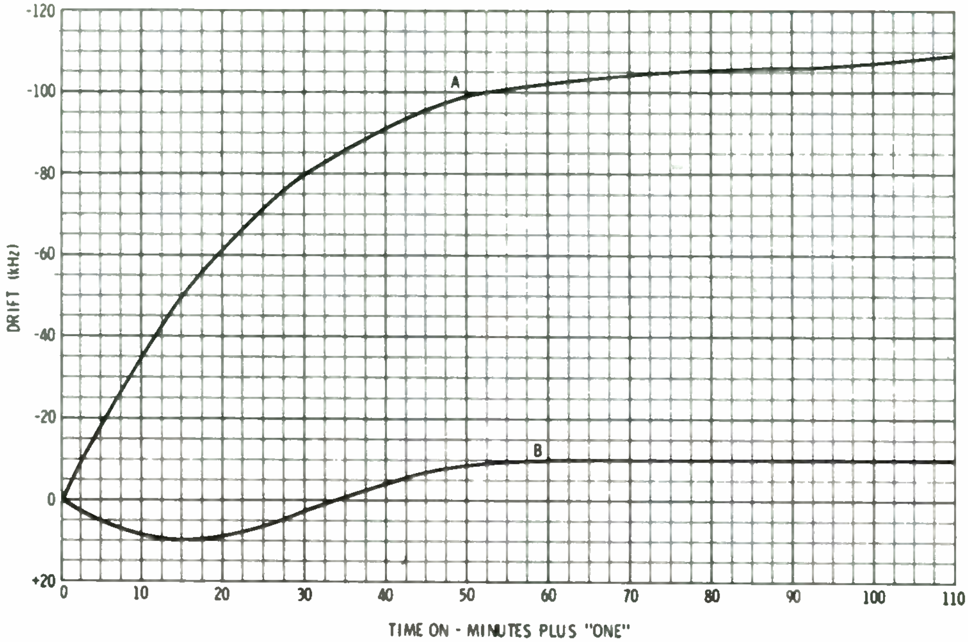


Figure 8 — Uncompensated and heat-compensated drift of FM local oscillators.

sign of resonant circuits in such a way that internal tube capacitances are a negligible percentage of the total capacitance present across the tuning circuit. This last requirement is necessary because the internal capacitance of a tube changes during tube warmup. Oscillator voltage coupling to the mixer tube (the other half of the 6AQ8 tube) is accomplished inductively, by means of a secondary winding on coil L_4. In many other designs (both transistor and tube), coupling is achieved by means of a very small capacitor (often just a few pf in value).

SOLID STATE OSCILLATORS

Not very long ago, the designers of FM receivers were not as concerned with *which* transistor to use as a local oscillator in FM sets as they were with the problem of getting *any* transistors which would oscillate at frequencies in the vicinity of 100 MHz. Today, of course, many types are available for the purpose, each with minimal input and output capacitances and with sufficiently high cut-off frequency to permit oscillation at the required frequencies. Furthermore, the battle against drift is much simplified because the amount of heat produced by all-transistor FM tuners is very much less than that associated with tube sets.

Lest you get the notion that *all* precautions can be abandoned, however, consider the design shown in Figure 9, the oscillator used in the Harman-Kardon SR900 solid-state receiver. In this "grounded base" circuit, the feedback which sustains oscillation is accomplished from collector to emitter by means of C_4, while coupling to the mixer stage is through a 2-pf capacitor, C_{11}. Note, however, that at least one temperature-compensating capacitor, C_{13}, is still used since there is still some increase in chassis temperature with warm-up of output transistor heat-sinks and other components in the chassis.

Examination of the power supply section of this receiver (not shown) discloses that the 10-volt (positive) supply required by the oscillator stage is zener-diode regulated to prevent variations in line voltage from affecting oscillator frequency.

In AM receivers intended for the broadcast band and utilizing an IF of 455 kHz, positioning of the oscillator frequency *above* the incoming

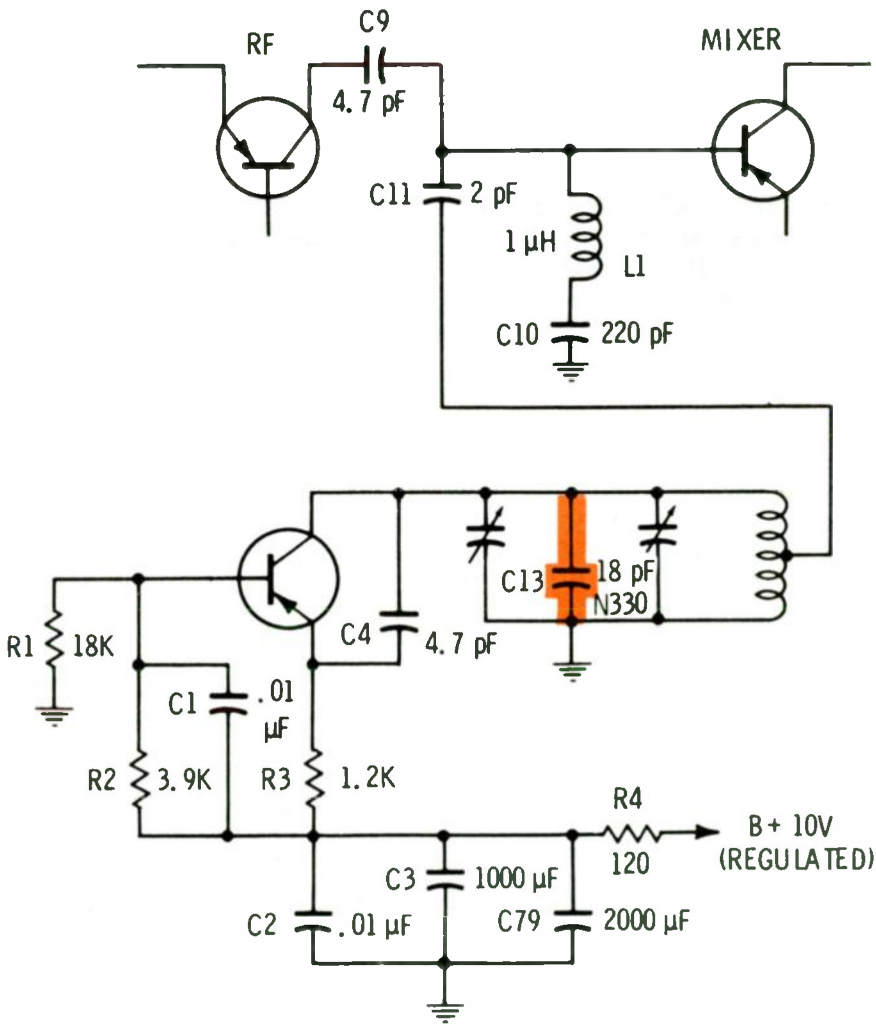


Figure 9 — Local oscillator in the Harman-Kardon SR-900, FM section.

signal is dictated from practical design considerations. Since the broadcast band extends from 535 to 1605 kHz, placing the local oscillator frequency *below* the incoming signal would mean having an oscillator frequency range from 80 kHz to 1150 kHz. This represents a tuning ratio of nearly 15 to 1 and, therefore, a variable capacitance ratio of nearly 225 to 1. This is hardly practical, physically.

With FM, however, the case is not as one sided. With the FM band extending from 88 to 108 MHz and the IF desired set to 10.7 MHz, the oscillator frequency range could be set either from 77.3 to 97.3 MHz or from 98.7 to 118.7 MHz. Either range is practical from a design point of view. If the lower frequencies had been selected, as a matter of fact, design would be somewhat simpler in terms of attaining frequency stability, ease of construction and the use of somewhat less critical components. Unfortunately, TV channels 5 (76-82 MHz) and 6 (82-88 MHz) fall right in the range of the lower frequency alternative and, although shielding of local oscillators to prevent excessive radiation is a requirement of the FCC, it would not take much radiation of this type to interfere with one's own TV set (particularly if a common antenna is used). For this reason, nearly all FM sets produced today utilize a local oscillator tuned to the *higher* set of frequencies. An indirect advantage of this choice is the somewhat reduced tuning ratio this requires.

AFC AND OSCILLATOR STABILITY

To those unfamiliar with AFC and how it works, a brief explanation of Figure 10 will suffice. In this schematic, the oscillator section of the Eico Model 3200 tuner is shown. The diode component identified as FECR2, in series with a 15-pf capacitor, is effectively in shunt with part of the frequency-determining tuned circuit of the local-oscillator stage. This diode acts like a small variable capacitor when varying DC voltages are applied to it.

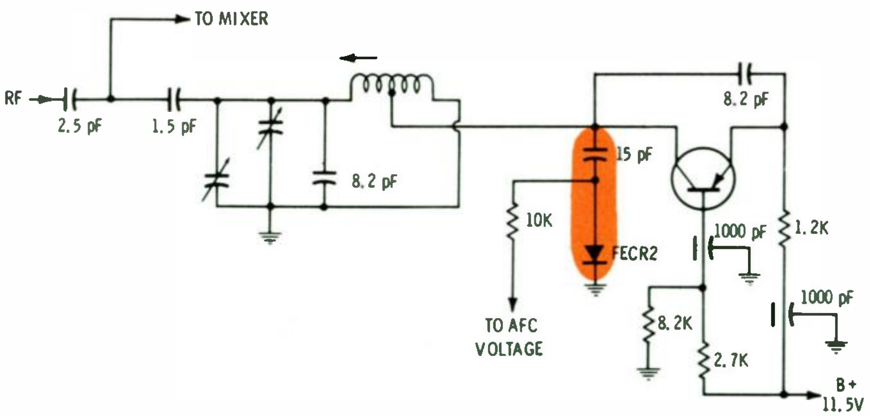


Figure 10 — Local-oscillator section of EICO 3200 tuner. AFC is accomplished by voltage-tuned diode.

Both popular forms of detector circuit used for FM demodulation
7 (the ratio detector and the Foster-Seeley discriminator) produce negative and positive DC voltages as stations are detuned above or below center frequency. These voltages are used as error-correcting voltages by causing a corrective shift in local-oscillator frequency. This corrective scheme may be thought of as a first-order servo loop and, as such, cannot be expected to offer total correction since some finite amount of error must be present for the corrective frequency shift to occur.

The real purpose of the AFC is to make it somewhat easier for the user to tune in stations. With AFC, stations "pop in" and stay fairly well tuned (though not perfectly so). Notwithstanding the advertising slogans, AFC, does not, of itself,
8 provide drift-free tuning. It is *not* a substitute for a frequency-stable oscillator design. On the contrary, AFC often shows up a drifting oscillator even more. The user often thinks he is tuned to center of channel (in the absence of a good tuning meter) and actually may be on the edge of "drop-out" of the desired channel. Most instruction manuals prescribe that desired stations be tuned in with the AFC turned off (if it is defeatable). Only after center-of-channel has been tuned in properly should AFC be introduced.

Many manufacturers have eliminated AFC altogether, claiming that equally smooth tuning action can be obtained through the use of wideband IF designs. They further maintain that all but the most carefully designed AFC schemes contribute a measure of distortion to the output and that, since AFC is really no true substitute for oscillator stability, it serves little or no purpose in modern, stable, solid-state FM designs. Ten years ago, absence of AFC circuitry was a mark of "skimping" in design. Today, it is fast becoming a mark of distinction when accompanied by good wideband design.

IF AMPLIFIERS

The need for an IF section arises from the use of the superheterodyne principle common to both AM and FM equipment. By reducing all incoming signal frequencies to a single, lower frequency, subsequent amplification is relatively simpler and more stable, and reliable designs can be produced. Actually, the lower the intermediate frequency, the easier it is to come up with an effective design. Why, then, did the industry choose 10.7 MHz as the universally accepted IF for FM, as opposed to, say, 455 kHz (used for AM IF stages) or some other low frequency? For one thing, such a small spread between local oscillator frequency and incoming signal frequency might well cause a strong incoming signal to "pull" the frequency of the local oscillator, until both were "locked" at the same frequency. Result: no IF output from the converter for the IF stages to amplify! Still, an intermediate frequency of a couple of megahertz would eliminate this problem. So why 10.7 MHz?

Well, suppose, for the moment, that we were to choose an IF of 4.5

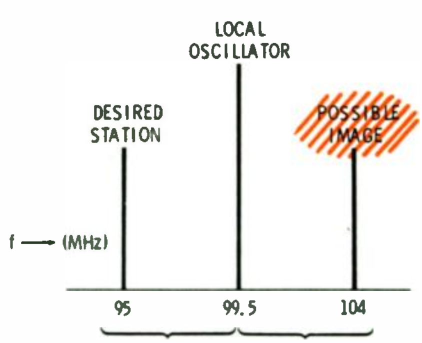
MHz (as is, in fact, done for the sound portion of some TV receivers), and suppose we were tuned to a signal frequency of 95.0 MHz. If the oscillator were designed to operate *above* the incoming frequency, it would be oscillating at 99.5 MHz. Next, assume there were another station (and a strong one at that) in the vicinity, transmitting at a frequency of 104MHz. Despite the selectivity of the tuned RF stage (assuming there *is* one), this higher frequency would beat with the 99.5 MHz of the local oscillator to produce a second signal, also at 4.5 MHz. Before you decide that the local oscillator should have been designed to operate *below* the incoming signal frequency, take a look at Figure 11B, which shows that the same thing can happen, only this time with the desired stations at the high end of the dial and the undesired station 9 MHz lower.

10.7 MHz IF

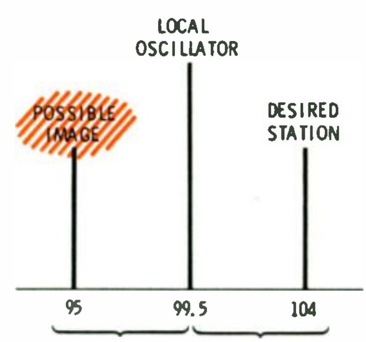
It's pretty obvious, therefore, that given an FM band of 20 MHz (from 88 MHz to 108 MHz), the lowest IF necessary to avoid image responses would be some frequency greater than 10MHz. The last major consideration which led, specifically, to the choice of 10.7 MHz has to do with "direct IF response." If some station is transmitting at the chosen intermediate frequency itself, such a received signal could easily reach the IF circuits either through the usual input channels (which might lack sufficient selectivity to exclude them) or by the appearance of IF signal voltage directly at the input of the first IF stage when adequate shielding is not provided. To avoid this possibility, the chosen frequency (10.7 MHz) is one that is never or seldom used for commercial transmission. This choice does not eliminate every type of spurious response possible, but it seems to be the best compromise choice available.

Bandwidth

Having established the frequency of the FM IF strip, we can now consider the additional char-



A - Local oscillator 4.5 MHz above desired station frequency.



B - Local oscillator 4.5 MHz below desired station frequency.

Figure 11 — Image frequencies in a receiver.

acteristics which must be considered. They are surprisingly few in number (though often a design can be quite difficult to achieve). Gain, of course, is one. Bandwidth is another, phase response a third, and that's really about all there are. Remember, we are excluding limiter stages from the discussion, even though many consider them to be part of the IF strip (structurally, they usually are). We shall deal with limiters and their special additional requirements later.

While you might suppose that a bandwidth of 150 kHz is all that would ever be required of an IF stage (based upon the maximum allowable modulation of ± 75 kHz), recall that sidebands may actually exist well beyond these superficial limits. This is especially true now, since the advent of stereo FM (multiplex), which involves higher modulating frequencies. A bandwidth of 6 db (attenuation) for around 250 to 300 kHz is now accepted as being adequate for high quality, stereo FM reception. Ideally, the shape of the response curve of the IF system should be that shown in Figure 12. Generally, however, the expense involved in attempting to come close to such perfect response is prohibitive. There is at least one manufacturer who comes mighty close to this ideal by means of complex, multiple-section filter networks. Most manufacturers achieve their response by means of double-tuned, interstage IF transformers, as represented in Figure 13.

Depending upon the number of stages used and the excellence of the particular design, the resultant response curve might be something like that shown in Figure 14. It should be noted that when we speak of a 6-db loss for a bandwidth of 250 kHz we mean the total attenuation of the entire IF system, not simply of a single stage. Thus, in the example cited, if there were three tuned circuits in the IF system, each circuit would contribute 2 db of attenuation at the "end points," but the total response of the entire system would then be down 6 db at 250 kHz.

Still another method of achieving a desired bandwidth characteristic involves the use of newly devised crystal and ceramic filters between amplifying stages. Still relatively new in FM use, these mechanical filters are actually already in use in the IF systems produced by several well-known receiver manufacturers. Rapid progress in this field is sure to occur in the very near future.

All tuned amplifiers exhibit phase shift between secondary current at resonance and secondary currents at frequencies off-resonance. At resonance, this current is in phase with the IF transformer's secondary voltage. Above resonance, secondary current leads the secondary voltage, while below resonance the converse is true. If this phase shift does not vary linearly with changes in frequency within the IF pass-band, time-delay errors in the received FM signal can occur. Though not terribly serious in monophonic FM reception, such delays can be disastrous in the case of stereo FM, where so much depends upon phase relationships between

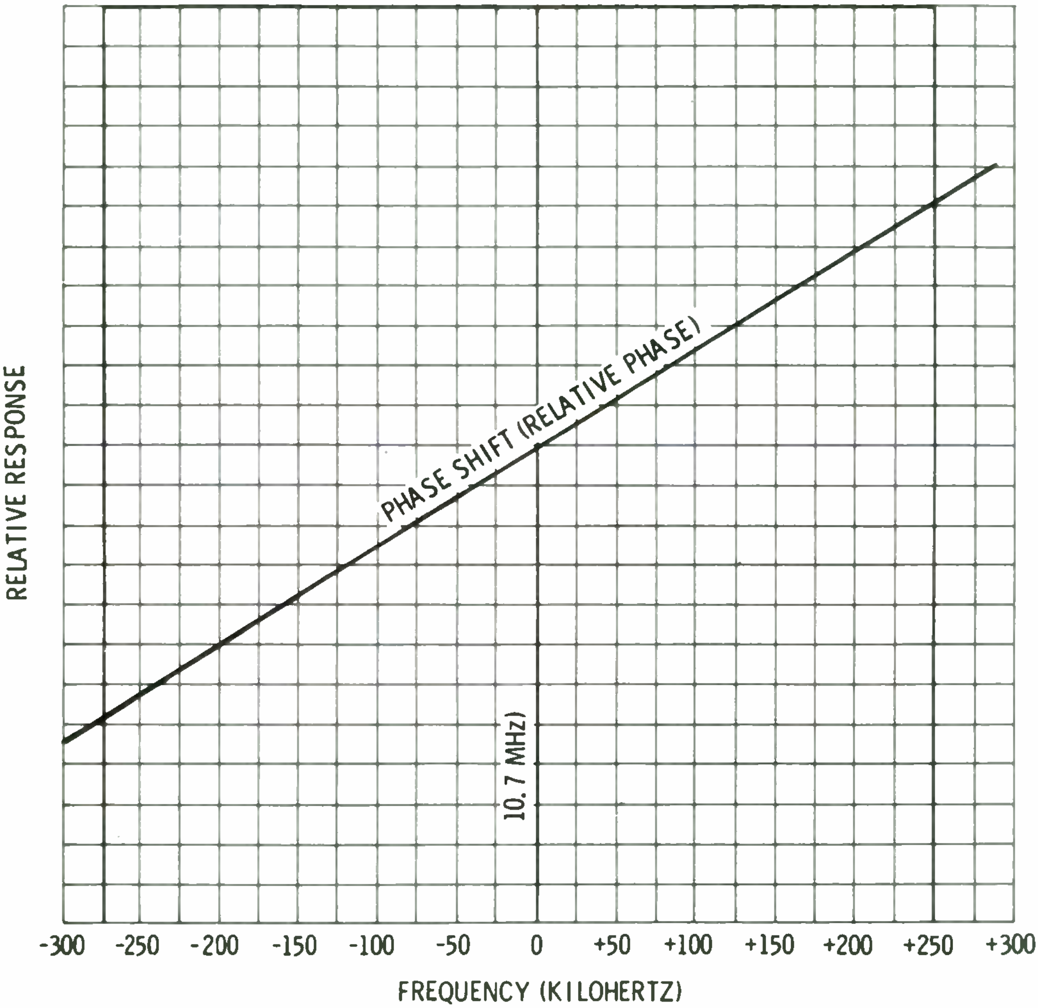


Figure 12 — Idealized IF response showing output and phase shift for the "perfect" IF system.

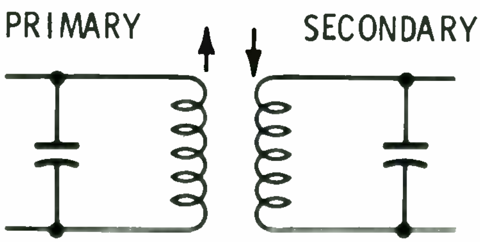


Figure 13 — Schematic representation of IF interstage transformer. Arrows indicate "slug" or permeability tuning of both primary and secondary.

main-channel audio, 19 kHz pilot sub-carrier, and the stereo sub-carrier information. Proper selection of coefficients of coupling Q's of the various stages, and required bandwidths helps to achieve a proper frequency-phase relationship.

Signal Gain

Gain in an IF system (as with any amplifying system) is achieved by means of active amplifying de-

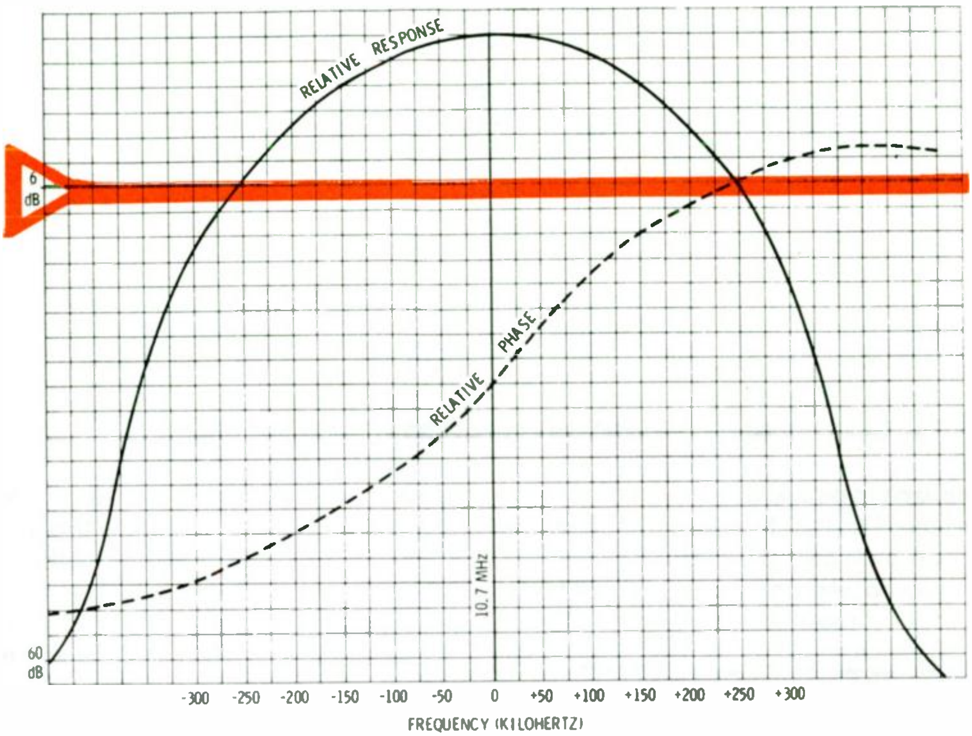


Figure 14 — Typical IF response and phase shift achieved by using transformer coupled circuits.

vices, whether tubes, transistors, or integrated-circuit linear amplifiers. A typical IF stage utilizing a pentode as the active amplifying element is shown in Figure 15. Pentodes were often used because they could be constructed to provide a high transconductance while exhibiting relatively low interelectrode capacitances. In a tuned circuit, a high Q means a high L/C ratio. Thus, if high Q circuits are desired (and they are, for gain and for fashioning desired response curves), we should seek to make L as high as possible. If the C in the

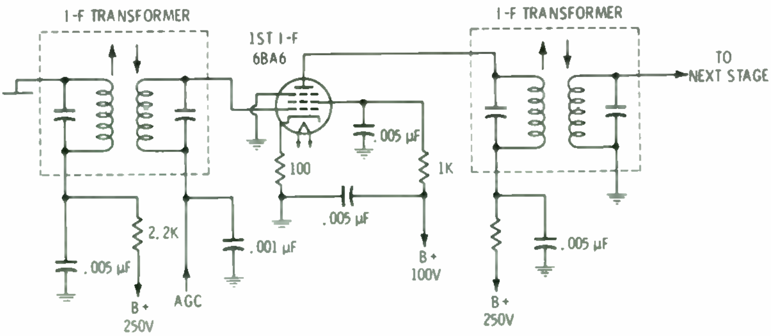


Figure 15 — Typical IF stage using a pentode tube amplifier with AGC.

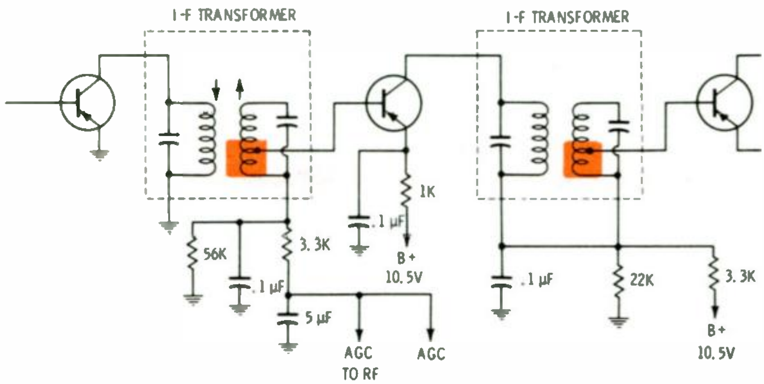


Figure 16 — Typical stage using discrete, bipolar transistors.

picture consists not only of a fixed, selected value, but also of the stray interelectrode capacitances, we are immediately limited as to how high we can choose L to be. The need for a high value of L also led, indirectly, to the use of inductive tuning rather than capacitive tuning for interstage IF transformers, for with permeability tuning a wider frequency range can be covered without resorting to relatively large variable capacitor values which would again restrict the value of L in the resonant circuit.

The IF stage illustrated schematically in Figure 16 shows the use of a transistor as the active device. Notice, that because of the low input impedance characteristic of common emitter stages, it becomes necessary to alter the construction of the secondary of the interstage transformer. A tap is brought out near the bottom of the winding to provide a proper impedance match to the transistor base input and to prevent loading of the entire secondary, with subsequent reduction in Q. In some circuits the primary winding is connected to the previous collector by tapping down on the coil.

Integrated Circuit

Finally, in Figure 17, we see the use of an integrated circuit in an IF stage. The contents of this tiny chip (as shown in Figure 18) stagger the

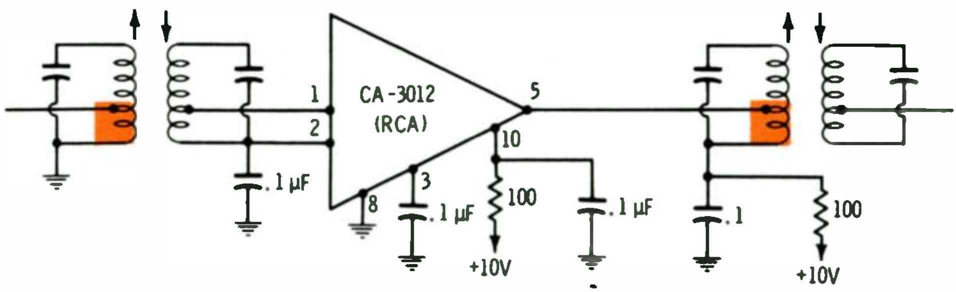


Figure 17 — Integrated circuit used in the IF systems of some present-day FM receivers.

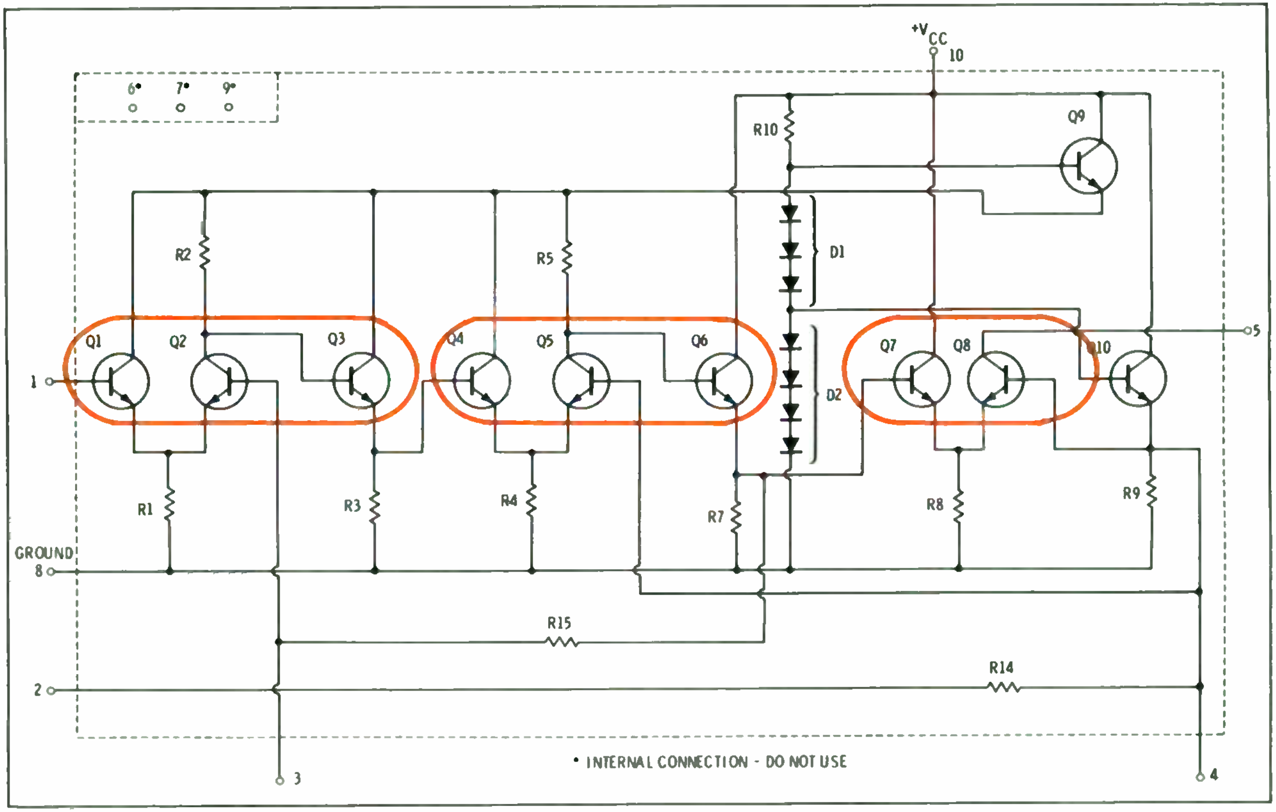


Figure 18 — Schematic diagram of the CA3011 or CA3012 integrated-circuit wideband amplifier shown in Figure 17.

imagination, for what we see are *ten* transistors, *eleven* resistors and *seven* diodes. What you *don't* immediately see is that not *all* these microscopic devices are contributing directly towards amplification. For example, the triplets Q1-Q2-Q3, Q4-Q5-Q6 and the doublet Q7-Q8 each constitute but a single stage of moderate, though highly stable amplification. Q9 establishes correct bias for the Q7-Q8 doublet, while Q10 and all those diodes act as a voltage regulator for the rest of the circuit.

These wonderful new devices enable construction with fewer external components and, properly employed, they can and are being used in truly great IF designs, but let us not succumb to the over-enthusiastic claims which state ". . . equals ten transistors, nine resistors and umpteen diodes if discrete components were used." At least let's understand what is really meant by such claims. What is *not* needed is a return to the days when tubes were used (often in profusion) as series dropping resistors, so that advertisers could claim radios having "more tubes than anybody."

SUMMARY

Radios used for the reception of FM signals employ a tuner to receive and amplify the RF signal. Good selectivity in the *front end* of the tuner, plus its ability to amplify the incoming signal without creating undue electrical noise, are features of a good design. FETs are now being used in the input stage due to their superior noise rejection.

Variable capacitors are used to tune the radio frequency selector circuit, the local oscillator frequency, and any additional circuits such as the antenna input circuit and the IF coupling stage. The local oscillator in FM tuners must have good frequency stability and low frequency drift.

An IF of 10.7 MHz is generally used in present-day FM receivers. The IFs should give adequate gain, have sufficient bandwidth, and acceptable phase response. As a high value of Q is related to a high value of the inductance L, permeability tuned IFs are used. In conjunction with integrated circuits, fewer external components are required.

TEST

Lesson Number 65

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-065-1.

1. The ability of a receiver to amplify a signal is limited by the
A. number of IF stages in the receiver.
2 B. noise in a particular circuit.
C. use of a grounded grid stage.
D. type of speaker used.

2. Selectivity of an FM tuner can be increased by using
A. a two-gang capacitor.
4 B. a low Q tuning coil.
C. a three-gang capacitor.
D. more resistance in the antenna's input circuit.

3. The first RF stage of amplification in an FM receiver should
A. have an extremely narrow bandwidth.
5 B. be double tuned.
\+ C. have a low noise figure, good selectivity, and a minimum of spurious responses.
6
D. produce a maximum of spurious responses.

4. The use of FETs in FM receivers
A. offers no improvement over a tube input.
B. is limited by the small number of designs available.
8 C. has not improved performance but has decreased the manufacturing cost.
D. provides superior cross-modulation rejection.

5. An increase in the temperature of an oscillator causes
A. an increase in inductance and capacitance, resulting in an increase in frequency.
11 B. an increase in inductance and capacitance, resulting in a decrease in frequency.
C. a decrease in inductance, capacitance, and frequency.
D. an increase in inductance, with a decrease in capacitance and frequency.

6. Most FM receivers use a local oscillator tuned to a frequency higher than the station frequency, and an AM receiver has its oscillator tuned

A. below the incoming signal.
13 B. above the incoming signal.
C. either above or below the incoming signal.
D. none of the above.

7. The popular forms of FM detector circuits are

A. Foster-Seeley discriminator and ratio detector.
15 B. slope detectors.
C. envelope detectors.
D. all of the above.

8. AFC in FM sets does

A. produce a louder signal.
B. eliminate completely the need to tune in a station.
15 C. not provide drift-free tuning.
D. eliminate the need for a local oscillator.

9. IF transformers employ inductive tuning

? A. as it provides a cheaper means of construction.
B. as it is simpler to adjust.
19 C. because this design provides a high-Q circuit.
D. because this design provides a low-Q circuit.

10. An "NPO" capacitor will

A. be a temperature stable capacitor.
B. decrease by 1500 parts-per-million capacitance for every degree centigrade increase.
11 C. decrease by 330 parts-per-million of capacitance for every centigrade of temperature increase.
D. be found only in mixer circuits.

Notes

Notes

Portions of this lesson from
FM From Antenna to Audio by
Leonard Feldman
Courtesy of Howard W. Sams, Inc.

"School Without Walls"

"Serving America's Needs for Modern Vocational Training"

YOUR SUCCESS

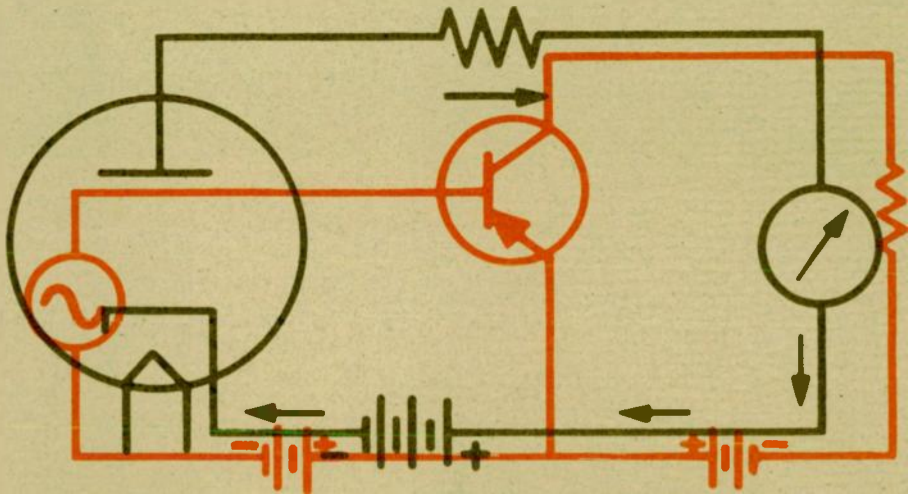
You can be a success at anything—if you give your best and really want to succeed.

Set a goal and then go after it. And don't stop until you reach it. Just remember, if you're happy in what you're doing and have reached your goal consider it a success, a personal success.

S. T. Christensen

LESSON NO. 66

FM RECEIVERS
PART 2



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FM RECEIVERS—PART 2

INTRODUCTION

The preceeding lesson described the features of FM tuners, and dealt principally with what is known as the front end of the tuner. The front end of a tuner selects the signal, amplifies it, and after amplifying it in one or more stages of RF amplifiers, mixes this signal with the local oscillator frequency. The resulting signal is the intermediate frequency, which in most modern IF systems is 10.7 MHz.

This lesson deals with the signal from this point on. It describes *limiters* that eliminate any amplitude modulation that has affected the FM signal. After the RF signal at the intermediate frequency has been limited in amplitude, it is delivered to the detector portion of the tuner. The detectors used in FM receivers must respond to the variation in frequency and convert these variations into amplitude variations at an audio frequency.

LIMITERS IN FM RECEIVERS

Strictly speaking, a limiter stage in an FM receiver is really another stage in the IF amplifier section of the receiver. Its distinction is that—unlike the stages which precede it—its function is not necessarily one of amplification but rather that of removing amplitude modulation by providing a constant amplitude signal for a rather large range of input signal voltages. The signal frequency is, of course, 10.7 MHz, just as in the rest of the FM IF system.

If it were possible to design a "perfect" FM detector or demodulator, there would be no need for limiters. As it is, however, all forms of FM detectors (including the popular discriminator and even the ratio-detector types) are, to some degree, sensitive to amplitude as well as to frequency variations in an FM signal. Without the presence of a limiter, the recovered audio output would contain voltages corresponding to both the amplitude and the frequency modulations. A limiter stage (or multiple stages) removes the amplitude-modulation component and passes on a pure frequency-modulated signal for final detection. In general, a discriminator (often called a Foster-Seeley detector, after its inventors) will require a full stage of limiting or more, whereas, a ratio detector, because of its own partial limiting characteristic, is sometimes designed into a set with no limiters ahead of it, often with a partial limiter stage and at other times (in better sets) with a full stage of additional limiting.

Limiter Action

A simple illustration of the action of a limiter is shown in Figure 1. A clearer understanding of the functioning of a limiter will be gained by looking at Figure 2, the transfer characteristic of a typical limiter. When applied to this stage, all signals having more than a certain minimum will produce an output voltage which is substantially constant. In the region beginning at point "2" and to the right, the stage is a limiter in its action.

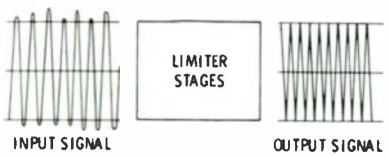

Figure 1 — Use of limiter to remove amplitude variations from the FM IF signal.

A signal which is too weak to drive the limiter beyond point "2" will cause, in the output of this stage, amplitude variations which are not part of the original desired

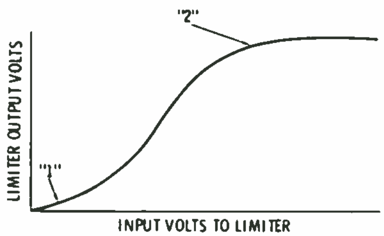

Figure 2 — Limiter output curve. Effective limiting occurs at all input signal levels to the right of point 2.

audio information. Thus, for a limiter to operate properly, it is necessary that the incoming signal be strong enough to drive the limiter into full limiting.

Amplitude Variation in FM

You may be wondering how amplitude variations are imparted to an incoming frequency-modulated waveform in the first place. There are two basic causes for this form of distortion. First, there are atmospheric disturbances covering all frequencies used in radio communication. These disturbances may be from natural sources, such as lightning storms, or they may arise from man-made interference such as automobile ignition systems, sparking of electrical motor brushes and the like. These types of noise sources are all external to the receiver itself and, in that respect, are beyond the control of the design engineer. In the receiver proper, unequal response of the various tuned circuits above and below resonance contributes toward amplitude variations. You will recall from the discussion in the preceding chapter that the ideal response curve through an IF system would be rectangular in shape. Such response is seldom achieved, however; the response is usually more like that shown in Figure 3. A frequency-modulated 10.7 MHz signal fed to an IF system having such a response will be amplified *more* at the instant the carrier is passing through the center frequency, and somewhat less when deviation caused by audio information shifts the carrier above or below the center frequency (in this

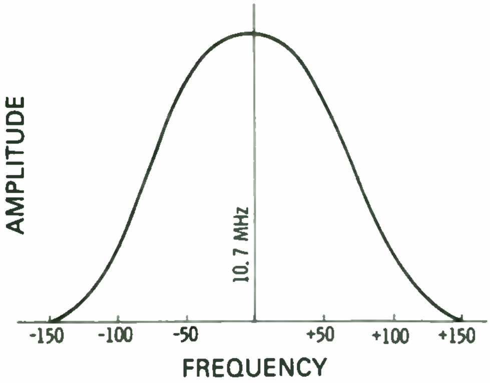

Figure 3 — Practical intermediate-frequency response results in varying amplitude as signal is modulated above and below the center frequency.

case, 10.7 MHz). For effective limiting, the circuit must function beyond the "knee" of its response curve for *all* frequencies that are likely to be encountered under conditions of normal program modulation. For this reason, the limiter has a great influence over the design and selectivity of the preceding IF stages, as well as upon their degree of amplification.

LIMITER CIRCUITS

The two most widely used circuit schemes for limiting (in the days of vacuum tube equipment) are combined in the typical limiter shown schematically in Figure 4. The RC circuit consisting of a 100-pf capacitor and a 50k-ohm resistor form a grid-bias network which, in the presence of an incoming signal, sets the bias point of the grid at some negative value, determined by the amplitude of the signal. Thus, a given amplitude of output is determined by the bias point. If the incoming signal were to undergo a sudden increase in amplitude, the developed grid-leak bias would increase, lowering the effective gain of the stage or, to put it another way, attempting to keep the amplitude of the output *constant.* Unfortunately, the time constant of this arrangement is such that high-frequency amplitude variations are too fast for the grid-leak bias to adjust. As a result, this form of limiting is not very effective in reducing the effects of sharp

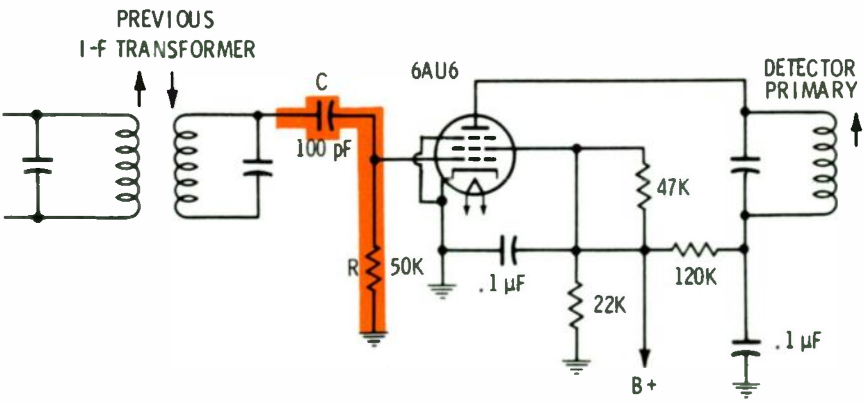

Figure 4 — Typical tube limiter using grid-leak bias and reduced plate and screen voltages.

impulses of noise, such as those arising from automobile ignition systems. The time constant of the bias circuit is determined by the numerical product of the R and C elements in the grid circuit. In this instance, $t = 100 \times 10^{-12}$ (farad) $\times$ 50,000 (ohms) $= 5 \times 10^{-6}$ seconds. For most amplitude variations encountered, such a time constant will be adequate. In the case of sharp pulses such as ignition noise, even 1- or 2-microsecond time constants may be too slow for the bias to follow, and noise results in the output of the detector which follows.

In addition to grid-circuit limiting, the circuit of Figure 4 utilizes limiting action brought about by reduced plate and screen voltages. Such reduced voltages alter the normal transfer characteristic in such a way that much less input signal is required to drive the plate current into saturation. With a tube (or with a transistor, as we shall soon see) operating in a saturated mode, sharp positive pulses applied to the grid do not alter the amplitude of the output waveform. This is, after all, a form of limiting.

Dynamic Limiter

A dynamic limiter overcomes the inability of the grid-bias type limiter to follow high-frequency amplitude variations. Utilizing semiconductor diodes (one or more) that respond instantly to amplitude variations, the dynamic limiter has an RC circuit which holds its characteristic constant with regard to audio variations, but permits relatively slower changes to adjust the signal level. A simplified circuit of dynamic limiting is shown in Figure 5. Many experts maintain that the combination of a dynamic limiter followed by a well designed ratio detector affords the best results obtainable in an FM tuner or receiver. Of course, solid-state limiters, including IC (integrated-circuit) stages, have changed some of the design philosophy of limiters, but the end goals remain the same.

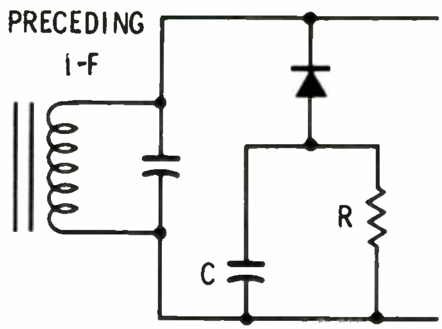

Figure 5 — Simplified diagram of a dynamic limiter.

Partial Limiter

An example of a transistorized partial limiting stage is shown in Figure 6. Unless you had the rest of the IF circuitry before you, it would be difficult for you to know, for sure, that the stage is operating as a limiter. The key lies in the operating voltages. While the preceding stage (not shown) had an emitter-to-collector potential of 9.8V, here the voltage is only 4.2. Essentially, we have saturation limiting translated to solid-state circuitry. Since this stage is followed by a conventional ratio detector (which affords some limiting, too), the limiting is only partial, the rest of the required action being provided by the action of the ratio detector itself.

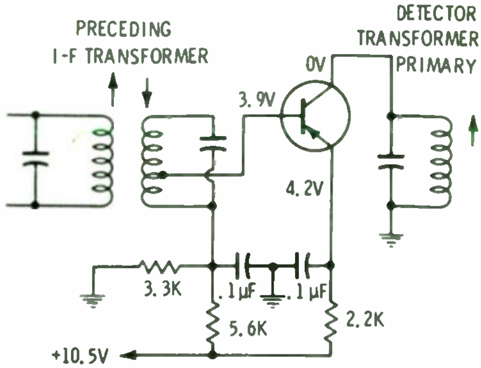

Figure 6 — Partial limiter using a PNP transistor rebiased for this function.

ICs as Limiters

The principal advantage of the new ICs designed for FM IF use is that they can be used as amplifiers as well as for limiting purposes. In the previous lesson, an RCA CA-3012 was shown used in an IF circuit. A second such IC, cascaded after the first one and operating with virtually the same voltages, operates as a very stiff and effective limiter above certain required input voltages. This limiting action is illustrated graphically in Figure 7. Note that with an input voltage of only about 1 millivolt, full audio recovery (which is the same as saying full limiting) takes place. Since the IC can be designed in the circuit to provide a voltage gain of about 60db, an input of only 1 *microvolt* applied to the first of two cascaded IC stages could, in theory, result in full limiting! In practice some other losses occur, but it is easy to see that no more than two such high-gain limiting circuits would generally be enough for a complete FM IF design right up to the discriminator. Some of the newest ICs even include the few parts necessary for FM detection. We are beginning to see complete IF systems consisting of nothing more than a couple of ICs, a couple of crystal filters or other frequency-sensitive devices,

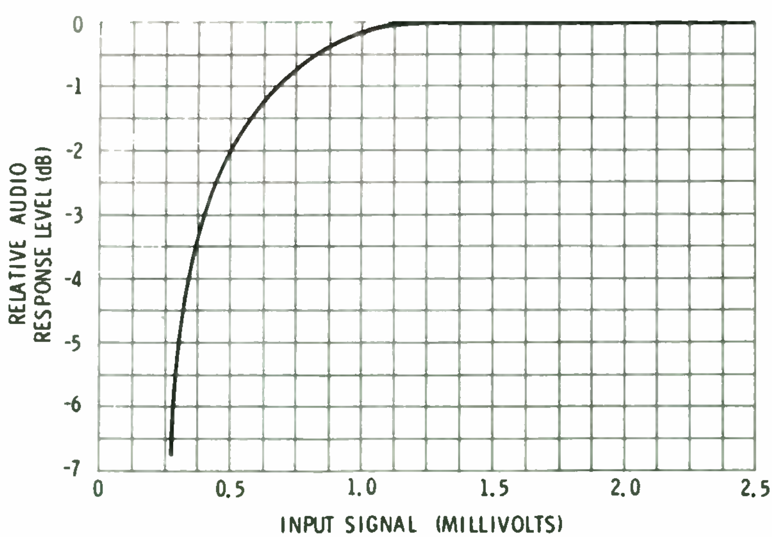

Figure 7 — Limiting characteristic of RCA integrated circuit used at 10.7 MHz for IF and limiting purposes.

and a few necessary surrounding capacitors which cannot be included because of their large size.

FM DETECTORS

The Discriminator as a Detector

Having followed the FM signal through its conversion to an IF of 10.7 MHz and its subsequent amplification and limiting, we now have to remove the audio information from its IF carrier. This process is known as FM detection or demodulation. The two most popular circuits used for this vital function remain basically unchanged. They are the so-called Foster-Seeley discriminator and the ratio detector. We shall first examine the discriminator.

Figure 8 is a schematic of an early form of discriminator and, although it is not in use today, it is simpler to understand than the later-developed Foster-Seeley type. L_1 and C_1 form the output load of the preceding final limiter stage. This tuned circuit is broad enough to pass the 200 kHz (or more) bandwidth deemed necessary in FM reception. L_1-C_1 energy is inductively coupled to two secondary tuned circuits, L_2-C_2 and L_3-C_3. To obtain FM detection, L_2-C_2 is tuned to a frequency about 100 kHz below the IF (10.7 MHz), while L_3-C_3 is tuned above the IF center point by an equal number of kHz. Figure 9 is a combined plot of the response curves of the two adjacent resonant circuits. Note that the L_3-C_3 response curve is inverted with re-

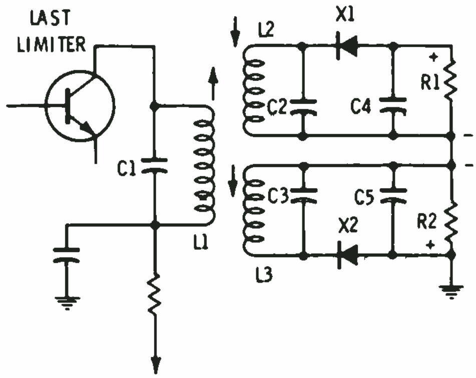

Figure 8 — An early version of a discriminator or FM detector.

spect to the L_2-C_2 curve, indicating an inverted polarity conforming with the actual hook-up and polarities established in Figure 8. Thus, if the voltage appearing across R_1 is larger than the voltage across R_2, the net output voltage (with reference to ground) will be positive. A negative resultant output voltage will result if the voltage across R_2 is greater than the voltage across R_1. It should be noted that each of these resonant circuits may be looked upon as a complete AM detector, including its own diode rectifier, load resistor, and even RF bypass capacitors C_4 and C_5.

Since each of the resonant circuits is tuned to a different frequency, the amplitude developed across their respective loads will differ, depending upon the instantaneous frequency present. With no modulation present (frequency dormant at 10.7 MHz), equal, small positive and negative voltages will be developed across R_1 and R_2, respectively. Being opposite in polarity, these voltages will cancel out each other and the resultant will be zero, as it should be for a "no-modulation" condition.

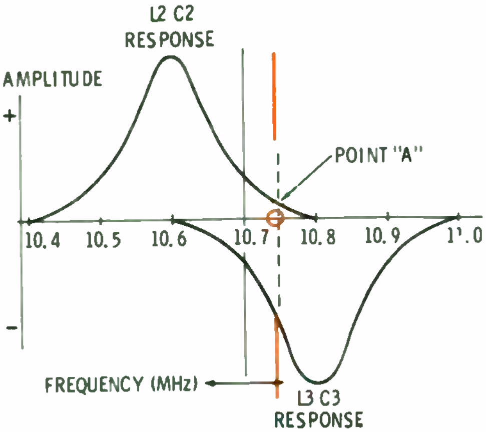

Figure 9—Superimposed response curves for the secondary tuned circuits of Figure 8.

Suppose now that the instantaneous frequency shifts to point "A" as a result of some instantaneous modulation. The voltage across L_3-C_3 will be greater than that across L_2-C_2 because the frequency is closer to the resonant point of the L_3-C_3 circuit. As seen in Figure 9, the instantaneous resultant voltage developed across the combination load of R_1 and R_2 will be negative. Furthermore, as the frequency of the carrier (and hence the IF stages) shifts back and forth at a rate determined by the audio tone to be reproduced, the output across this combination load will rise and fall through positive and negative values, effectively converting frequency variations into their corresponding amplitude or audio variations.

Since the output voltage is really the difference in voltage across R_1 and R_2, both curves can be represented as one continuous curve, as shown in Figure 10. This is the familiar "S" curve so often referred to in alignment instructions for FM sets. The central, linear portion of the curve must be at least 150 kHz from point 1 to point 2 if distortion-free audio demodulation is to take place. Generally, 250 kHz and even more of linear region is designed into these circuits to insure against slight mistuning away from the center of the channel and to further reduce audio distortion.

To summarize the action of this early form of discriminator, it may be said that two separate actions occur. First, the tuned sections convert frequency modulation to amplitude modulation at intermediate frequencies. Then, by inserting a diode detector, the audio-modulated intermediate frequencies are converted to the desired audio. From the foregoing, you can deduce that this form of discriminator is sensitive to AM variations, and it is for this reason that limiters must be used ahead of the discriminator, so that the discriminator input is "pure" FM with no AM content.

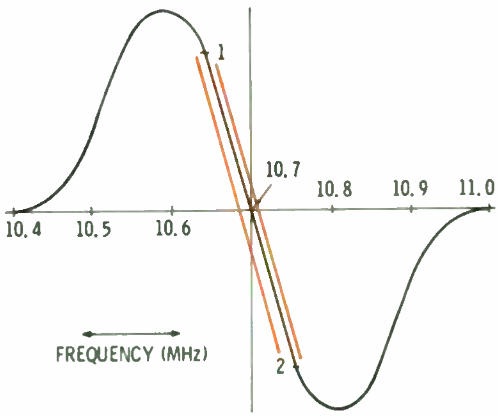

Figure 10 — Combined "S" curve of the discriminator shows linear portion from point 1 to point 2.

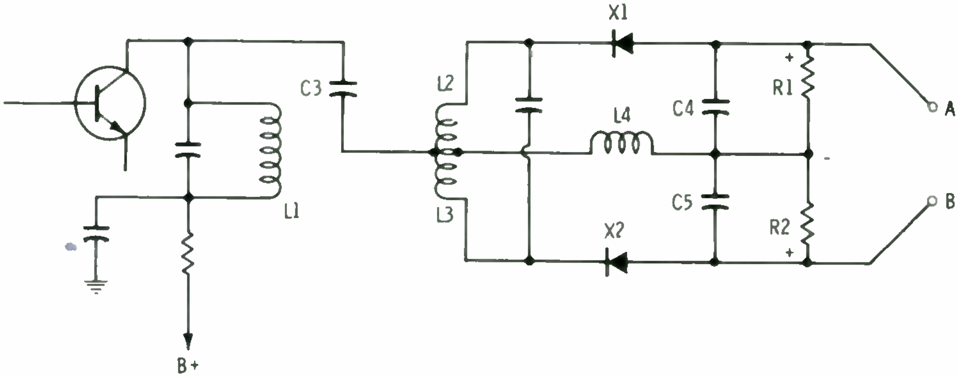

Figure 11 — One version of the Foster-Seeley discriminator circuit.

The Foster-Seeley Type

From the foregoing simple analysis we go on to the Foster-Seeley, shown in one of its many forms in Figure 11. In this circuit, both secondary windings are combined and a single capacitor is used to tune the circuit to 10.7 MHz. Inductive tuning of both primary and secondary is usually employed. The discriminator output voltage no longer depends upon the difference in response of two tuned circuits to various incoming frequencies. Instead, the voltage appearing at each diode will depend upon the *phase* of the secondary voltage as compared to the phase of the primary voltage.

Each different frequency (above and below 10.7 MHz) alters the phase response of the secondary network which, in turn, causes each diode to receive a different amount of voltage. From that point on, however, the action is as described before, in that the rectified voltages across R_1 and R_2 give the proper audio output.

To illustrate this "phase" of discriminator theory, let us consider what happens first when the incoming IF signal is at its mid-point (10.7 MHz) or when no modulation is applied. The voltage induced in the secondary E_{in} produces an in-phase secondary current, I_s, since, at resonance the impedance presented is purely resistive.

Vector Voltages

On the vector diagram of Figure 12, E_{in} and I_s are therefore drawn along the same straight line. The voltage developed in L_2 and L_3 due to I_s is 90 degrees out of phase with I_s. This, of course, is true of any inductance. In the vector diagram, E_2 and E_3 (the voltages developed across L_2 and L_3) are both drawn at 90 degrees from I_s. These two voltage vectors are drawn on opposite sides of I_s because of the reference center tap on the secondary coil. With reference to this center tap, E_2 and E_3 are 180 degrees out of phase with each other. Now, if E_{L4} (the equivalent primary voltage

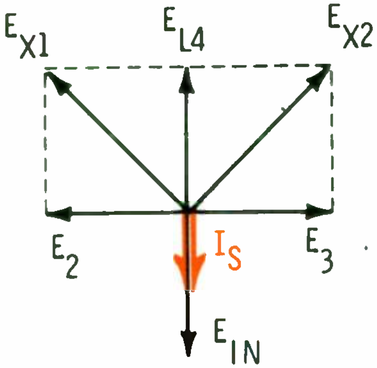

Figure 12 — Vector relationships in the discriminator of Figure 11 with no demodulation. Voltages E_{X1} (across R_1) and E_{X2} (across R_2) cause currents that cancel each other.

which can be shown to appear across L_4) is added vectorially to E_2 we obtain E_{x1}. By adding E_{L4} to E_3, we also obtain E_{x2}, the two respective voltages applied to the diodes X_1 and X_2. It is obvious from the diagram that E_{x1} and E_{x2} are exactly equal in amplitude. Therefore, there will be the same current through each diode, and similar voltages will appear across R_1 and R_2. Being out of phase, these voltages will cancel and there will be no audio output. Again, this is as it should be, since no modulation is applied to the signal, which remains static at 10.7 MHz.

By way of contrast, let us consider the case in which the FM signal, now modulated, swings towards a higher frequency. As shown in Figure 13, E_{in} and E_{L4} still bear the same reference relationship to each other (namely, 180
5 degrees apart in phase). At frequencies above resonance, however, X_L (the inductive reactance) exceeds X_c (capacitive reactance) and the current, I_s, will lag behind E_{in}. E_2 and E_3 still maintain a 90-degree relationship to I_s, however, since that relationship always exists between the voltage and the current in a given coil. If we once again add E_2 to E_{L4} and E_3 to E_{L4}, vectorially, we see that resultant E_{x1} is now greater than resultant E_{x2}. As a result, the voltage developed across R_1 will be greater than that developed across R_2, and the output voltage will be positive with respect to ground or the center tap.

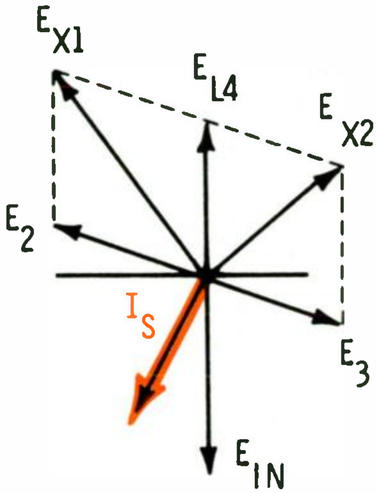

Figure 13 — Phase relationships when frequency is shifted above resonance cause E_{X1} to be greater than E_{X2}, and a net ouput voltage (+) will appear across R_1 and R_2.

A similar, but opposite phase analysis by means of another vector diagram could easily be drawn for the case in which the incoming frequency shifts below center, in which case the output voltage would be negative with respect to ground. The unbalanced condition that arises from the shifting frequency (either negative or positive) is made linear with respect to frequency by careful design of the discriminator transformer so that the audio output will be a faithful replica of the audio which caused the modulation at the transmitter. The S curve previously shown applies equally to this design; the linear portion can be made just as great as in the previous case.

A modification of the Foster-Seeley circuit is shown in Figure 14. At first glance you might suppose that voltage E_{L4}, the reference voltage needed for proper operation of the discriminator, has been eliminated with the removal of L_4. Actually, R_2 is now effectively in parallel with L_1 (thanks to coupling capacitor C_3); therefore E_1 appears across R_2. In this circuit, R_2 performs a double function—it develops the rectified voltage from the diode and serves to apply E_1, the reference voltage, to the opposite diode. The advantage of this configuration lies only in the fact that fewer parts are required. R_1 and R_2 must be high in value, however, because they are effectively in parallel with L_1. In the original Foster-Seeley circuit (Fig. 11), L_4 served as a choke, isolating R_1 and R_2 from L_1. For reasons which we shall go into when we discuss stereo FM, the higher output impedance can sometimes create problems in coupling to a stereo FM decoder.

Pre-emphasis and De-emphasis

In studies of the frequency and energy content of music and speech, it was determined long ago that most of the energy is contained in the low and middle frequencies. In addition, it is well known that the noise which irritates listeners most is that found at the higher audio frequencies, above 4 or 5 kHz or so.

These two facts clear the way for use of pre-emphasis and de-emphasis. Pre-emphasis involves boosting the relative level of high frequencies during the process of transmission in accordance with the curve shown in Figure 15. Bear in mind that this curve represents the response of some audio amplifier ahead of the transmitter. It does not mean that the high frequencies will overmodulate the transmitter because, remember, the high-frequency energy content of music and speech is

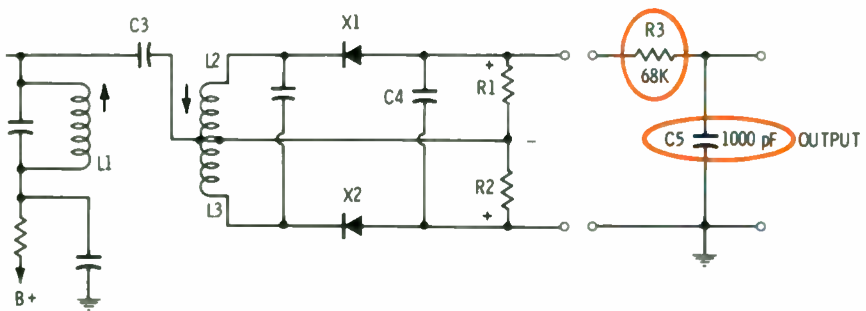

Figure 14 — Modified version of a discriminator, in which L_4 and C_5 have been omitted, also shows parts needed for proper de-emphasis.

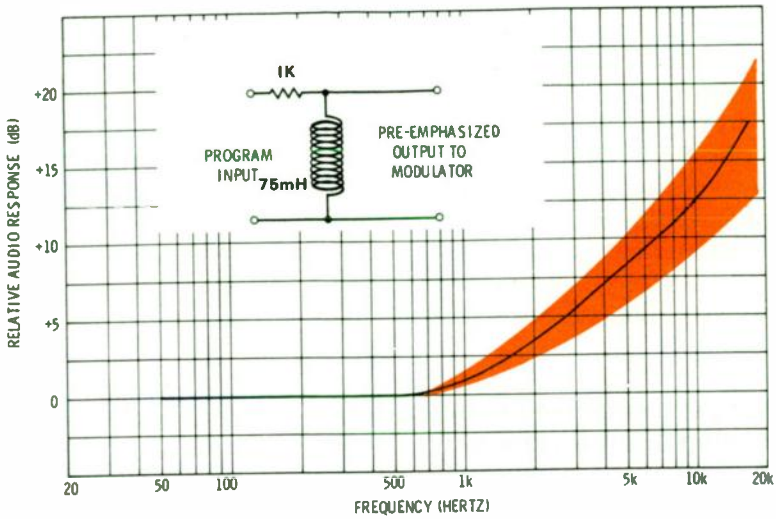

Figure 15 — Standard FM pre-emphasis, as practiced by FM broadcasters in the U.S.

generally so much lower than the low and middle tones that, left unaccentuated, they would never even come close to effecting a 75-kHz deviation of the main carrier.

A typical circuit for accomplishing the correct amount of pre-emphasis accompanies the response curve of Figure 15. Now, perhaps, you can understand why an FM tuner response curve is anything but "flat," and, rather, follows the curve shown in Figure 16.

By *de*-emphasizing the high frequencies in the receiver, the overall frequency response of the system

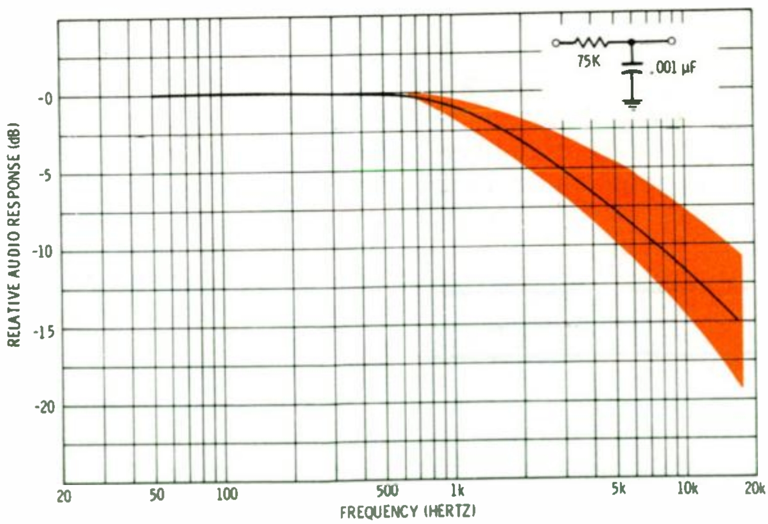

Figure 16 — Standard 75-μ s de-emphasis built into FM tuners to restore "flat" response.

(including transmitter and receiver) is restored to the desired "flat" or uniform characteristic which is a prerequisite to all high fidelity equipment. More important, however, is that by including de-emphasis, the objectionable high-frequency noise is considerably reduced, compared to what it would have been had we not bothered.

The circuit generally used to accomplish de-emphasis is shown in Figure 16. Note that it consists only of a resistor and a capacitor, chosen so that the product of R and C equals 75×10^{-6}. This product, referred to as a time constant, is expressed as 75 microseconds.

De-emphasis

Whether a discriminator or a ratio detector is used in a given design, one important job must be done before the demodulated audio can be applied to an audio amplifier. You will recall that the frequency response of the program material broadcast is anything but flat in the high-fidelity sense. Rather, the high frequencies above about 1500 Hz have been deliberately boosted to improve the signal-to-noise ratio of the overall received signal. The scheme is called "pre-emphasis." In order to
9 restore flat response, a de-emphasis network must now be introduced. R_3 and C_5 in Figure 14 serve this function. Note that the RC time constant, as shown, would be only 68 microseconds, as opposed to 75 microseconds used at the transmitting end. Usually, length of connecting shielded cable and/or stray wiring capacity make up the difference. Sometimes, less meticulous designers will *under*-de-emphasize recovered audio in order to create a more "brilliant" sounding output, but they are only deluding themselves and the public. Further, this causes inaccurate frequency response and a less-than-optimum signal-to-noise condition.

The Ratio Detector

The conventional form of FM detector, the Foster-Seeley discriminator, is sensitive to AM variations as well as to desired FM deviation or modulation. As a result, one or more limiter stage is required to remove all amplitude modulation and apply a pure FM signal to the input of the discriminator.

In the mid-1940's, a circuit was developed that was sensitive to frequency variations, though much less sensitive to amplitude variations. This circuit, dubbed the ratio-detector, may therefore be thought of as a combination limiter-detector. In widespread use today, the ratio detector, as used in high-quality tuner designs, is still preceded by one or more limiters. But this is done to afford even more AM rejection than would be possible if the same amount of limiting circuitry preceded a conventional discriminator.

In order to understand the limiting action of a ratio detector, let us refer to Figure 17, which is the schematic of the Foster-Seeley discriminator that appeared in identical form in preceding paragraphs.

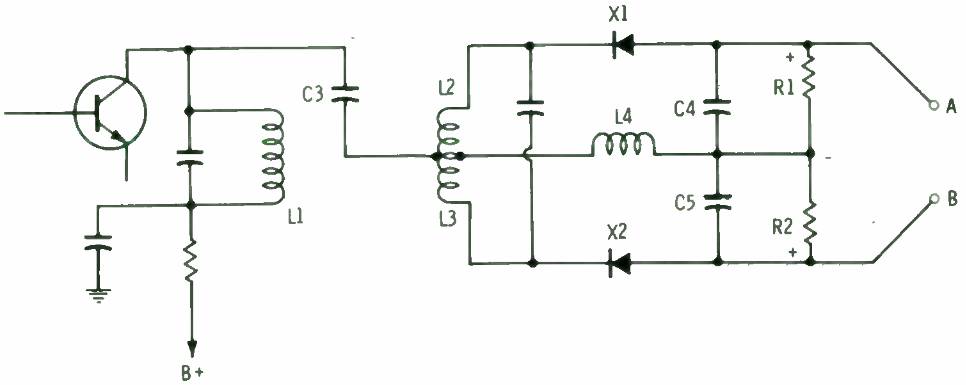

Figure 17 — Schematic of the Foster-Seeley discriminator.

As shown then, equal voltages appear across R_1 and R_2 when the incoming IF signal is centered at 10.7 MHz (no audio information being transmitted). Assume that, with a certain carrier strength and a given modulation, the voltage across R_1 increases from a quiescent value of 3 volts to 4 volts, and that the voltage across R_2 decreases from its static value of 3 volts to 2 volts. The net output voltage (instantaneous) would be the difference, or 2 volts. Now assume a stronger incoming IF signal, arising from a stronger carrier signal, so that the voltage across R_1 and R_2 is now 6 volts instead of 3 volts. With the same modulation applied as before, but with this stronger carrier, the voltage across R_1 will rise to 8 volts, while the voltage across R_2 will decrease to 4 volts, a net difference (and instantaneous output) of 4 volts.

Equal Ratios

Despite the fact that the same modulation has been applied in both cases, the amplitude of output in the second case is twice as large as in the case of the weaker incoming RF signal. This amounts to direct AM response as well as FM response and is the reason why limiting is needed with the discriminator circuit. There is, however, an interesting numerical relationship between the two examples cited. The ratio of voltages across R_1 and R_2 in the first example—4/2—exactly equals the ratio of voltages across these resistors in the second example—8/4. It is this equality of voltage ratios, regardless of incoming signal strength, that gives rise to the idea of the ratio detector.

The concept of ratio detector operation can be best understood by examining the circuit of Figure 18, in which each diode is associated

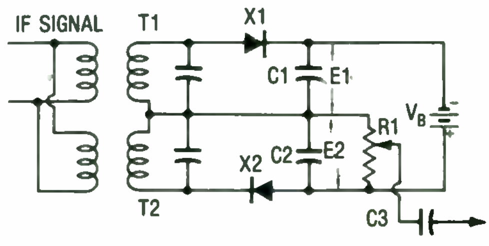

Figure 18 — Explanatory form of a ratio detector.

with a completely separate resonant circuit. Let us again assume that the circuit involving X_1 is tuned above 10.7 MHz, while that of X_2 is tuned below 10.7 MHz. The output voltage for the X_1 circuit will appear across C_1, while the output voltage for X_2 will appear across C_2. The battery V_B is a fixed voltage. Since C_1 and C_2 in series are directly across this battery, the instantaneous sum of their voltages must equal V_B. Also note that the polarity of the battery is such that under static or no-signal conditions, no current can appear in the circuit consisting of T_1, T_2, X_2, C_2, C_1, X_1 and T_1. Now, although $E_1 + E_2$ can never exceed or be less than V_B, E_1 does not necessarily have to equal E_2.

In other words, the *ratio* E_1/E_2 may vary! Output signal (recovered audio) can be taken from a variable load resistor connected across C_2, since the voltage across this capacitor will vary with the signal.

6 When the incoming signal is unmodulated (10.7 MHz), E_1 and E_2 will be equal. This is similar to the situation that prevails with the discriminators examined earlier. When the incoming signal rises in frequency because of modulation applied, it approaches the resonant frequency of T_1, resulting in a higher voltage across C_1 At the same time, a lower voltage is developed across T_2. Therefore the voltage across C_2 decreases. However, the sum of these two voltages must still equal V_B.

In other words, an instantaneous change in frequency alters the ratio of E_1/E_2, but not the total voltage. With a signal frequency modulated to a point below 10.7 MHz, E_2 will exceed E_1, but, again, the ratio of E_1/E_2 will remain constant because of the stabilizing effect of V_B. Desired audio information is obtained from the voltage variations across C_2. Since only audio variations are desired, C_3 serves to block the DC voltage present at all times across C_2.

The key to this explanation is, of course, V_B, which keeps the total voltage constant while permitting the ratio of E_1/E_2 to vary. Thus, in this elementary circuit, an output voltage is obtained that is purely a result of the FM signal. In actual practice, the use of a battery would severely limit the dynamic range of such a circuit. For example, if V_B were made very high, weak incoming signals would be lost entirely because they would not possess sufficient amplitude to overcome the negative "back bias" placed on diodes X_1 and X_2 by V_B. If V_B were to be made quite low, then more powerful stations would be severely limited in the amount of audio voltage that could be recovered from the circuit because the voltage across either capacitor (or even the sum of voltages across both C_1 and C_2) could never exceed the low value imposed by V_B.

In practical circuits, the value of V_B is not determined by a fixed battery, but by the average value of each incoming carrier. This idea will be better understood by examining Figure 19, a practical form of ratio detector.

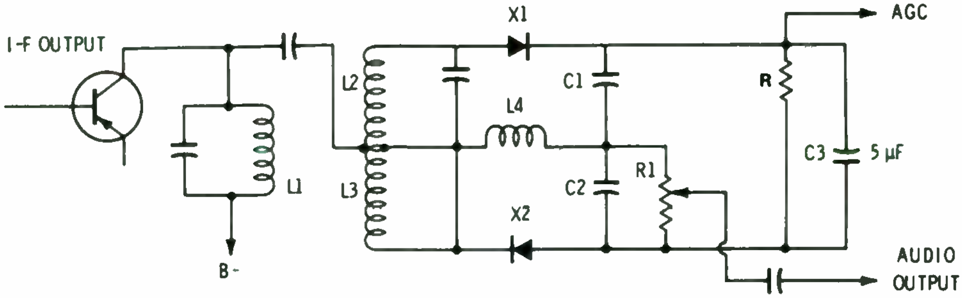

Figure 19 — Practical form of ratio-detector circuit.

This circuit uses the same phase-shifting properties as the discriminator of Figure 17. R and C_3 replace V_B, the battery, and the voltage developed across R will be dependent upon the strength of incoming signal. Notice that X_1 and X_2 are in series with R and all current through these diodes must go through R. By placing a 5-μF capacitor across R, a fairly constant voltage is maintained and momentary changes in signal amplitude are absorbed by this capacitor. It is only when the average value of the incoming signal changes (as when tuning from a stronger station to a weaker one) that the voltage across R changes significantly. Audio output is still taken from across C_2. Since the voltage across R is dependent upon incoming signal strength, it may be used as an AGC (automatic gain control) voltage. The ratio detector in this form does possess the disadvantage of being somewhat more difficult to align; also, great care must be taken to obtain a linear response characteristic during alignment, as well as in the initial design of the ratio-detector transformer.

8

A more symmetrical form of ratio-detector design (and one that is almost always used in preference to the form just discussed) is shown in Figure 20. Instead of the direct

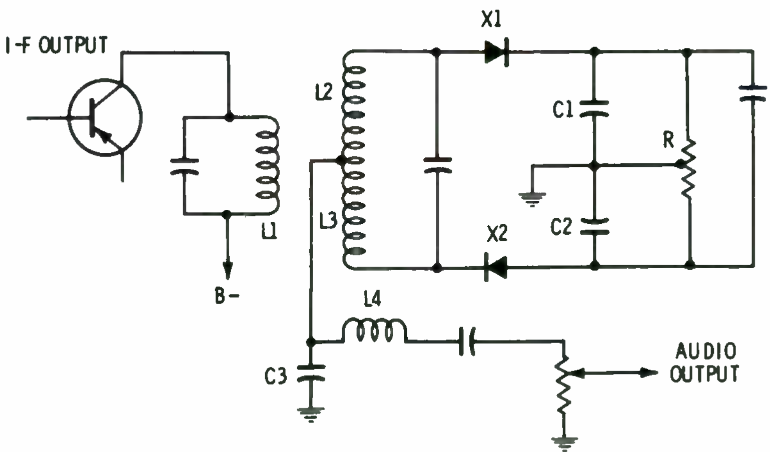

Figure 20 — Balanced or symmetrical ratio detector. (Note: "R" may consist of two fixed resistors in practice.)

capacitive connection between L_1 and the secondary tap, we now introduce L_4. Using the same reasoning as was applied in our earlier discussion of discriminators, we see that the voltage induced in L_4 (which is closely coupled physically to L_1) will remain constant as long as the primary voltage is constant. Since the voltage across L_4 depends upon the voltage across L_1, and not upon the secondary circuit, it can be used as the reference voltage in place of the previous capacitive-coupled arrangement of Figure 19.

The path from the center tap of the secondary to the junction of C_1 and C_2 includes L_4 and C_3 (Fig. 20). Voltage applied to X_1 consists of E_{L4} and E_{L2}, while voltage applied to X_2 consists of E_{L4} and E_{L3}. At 10.7 MHz (center intermediate frequency), both diodes receive the same voltage, with C_1 and C_2 reaching the same potential. The current path from X_2 is through L_3, through L_4 and C_3 to ground, and thence through C_2. (Note that L_4 and C_3 are connected in parallel!) Current continues until the voltage across C_3 and C_2 equals the voltage at the diode. Current from X_1 is from its cathode through C_1, C_3, and L_4, and up through L_2, and back through X_1 until C_1 and C_3 are charged to the voltage at the diode. The current path from X_2 is through L_4 and C_3 in the opposite direction from the current path produced by X_1. Therefore, these two currents in the common branch (L_4 and C_3) actually oppose each other and the resultant voltage is zero.

At frequencies above and below 10.7 MHz, the voltage applied to each diode will vary and a net current will take place through C_3 and L_4. When frequency varies in one direction, a positive voltage will be developed across C_3 and L_4; when frequency varies in the other direction, a negative voltage will be developed. The potential variations across C_3 will vary directly with frequency and, therefore, represent audio information.

Both the ratio detector and the discriminator have one advantage in common in that there is a point in each circuit at which there is a zero DC potential when the set is tuned accurately to the center of the channel. First, the popular zero-center tuning meter can be connected (with suitable impedance isolation) to this circuit point. When a station is properly tuned in, the meter pointer will rest at the center of the scale. When the station is detuned, the needle will indicate a positive or negative voltage, depending on which way the signal is detuned. This meter is the easiest to use, visually, and is often present in good-quality tuners or receivers.

Perhaps more important, the zero center feature of these circuits provides a convenient take-off point for some form of AFC (automatic frequency control) used to "lock in" FM stations, once properly tuned. Without detailing these AFC circuits at this time, it is obvious that a voltage that is zero when a station is properly tuned in and varies above and below zero when the station is detuned can be used to retune the receiver electronically.

To sum up the difference between the ratio detector and the discriminator, the latter operates on the difference of the output voltages of two diode detectors. Diode-load resistors are connected with their voltages in opposition. The resultant of the two voltages becomes the audio output voltage. Since the discriminator responds to amplitude modulation as well as to FM, it must be preceded by one or more limiters and requires a great deal of amplification in order to drive these limiters into saturation. Ordinarily, this requirement makes for a more costly design.

In the ratio-detector circuit, the two diodes are connected in series. Then the stabilizing or controlling voltage that is developed depends upon the strength of the incoming carrier signal. The controlling voltage sets the limit of maximum audio voltage that can be obtained. The ratio detector is more immune to AM variations than the Foster-10 Seeley discriminator (considered without limiter), and it is generally more economical since it requires fewer amplification stages ahead of it. Often, a limiter, or an IF stage acting as a partial limiter, will precede a ratio detector to further improve AM rejection. As a consequence of the foregoing, most Hi-Fi tuners today employ a ratio detector.

AUDIO SIGNALS

After the signal has passed through a limiter stage and the ratio detector, it has been converted to an audio signal. This audio signal varies in both amplitude and frequency, but is not yet powerful enough to drive a speaker. It must now be increased in strength in an audio amplifier.

One of the principal features of FM is its ability to faithfully transmit a wide range of audio frequencies; thus, the audio system used with FM tuners must be capable of amplifying this wide frequency range without distortion. This is the reason that high quality FM receivers specify the usable audio range that can be reproduced with a minimum of distortion. As an example, the specification might state that the audio range is from 20 to 15,000 Hz, with not more than 1% distortion. A receiver with this range of response would be considered to be among the higher class of receivers. There are receivers that have a wider range—both lower than 20 Hz and higher than 15,000 Hz—and also have even less distortion, but the price of achieving this higher quality sometimes becomes too costly for the average person.

Audio amplifiers that are designed to reproduce a wide range of frequencies, whether they are used in AM or FM receivers, have tone controls. These tone controls allow the listener to adjust the sound to accentuate either the bass or treble response of the amplifier. In addition, the volume control allows the proper sound level to be set for the room size.

SUMMARY

Limiters are used in FM receivers to remove any amplitude variations that are superimposed on the signal by electrical noise, such as electric motor or automobile ignition noise. Without any limiting action, this amplitude variation would appear in the final audio signal.

After the signal has been cleaned of any spurious amplitude variations, due to noise, it is fed to a discriminator or ratio detector circuit. Either system of detection will produce an audio signal that contains both a variation in signal strength (for loudness) and a variation in frequency (for different voices and musical instruments).

The audio amplifier used with FM tuners is designed to reproduce a wide range of audio frequencies with the least amount of distortion.

TEST

Lesson Number 66

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-066-1.

1. A limiter stage
- A. is a stage that always uses a diode for limiting.
- B. is effective against ignition noise.
- 1 C. always has a grid leak in the circuit.
- D. is another stage in the IF section.

2. Some of the new ICs can be used to perform limiter action if
- A. the input voltages do not overload them.
- B. they are used above certain required input voltages.
- C. they are always preceded by many prior stages of RF amplification.
- D. all of the above.

3. The linear portion of the S curve in high quality FM receivers might extend over a frequency range of
- A. 250 kHz.
- 7 B. 75 kHz.
- C. 50 kHz.
- D. 10.7 kHz.

4. The Foster-Seeley discriminator circuit depends upon the
- A. difference in response of two tuned circuits.
- B. equal vector voltages.
- 8 C. amplitude of the in-phase voltages.
- D. phase relationship of the secondary voltage to the primary voltage.

5. When the IF signal at the Foster-Seeley discriminator is above resonance, the
- A. inductive reactance equals the capacitive reactance.
- 9 B. current will lead the voltage.
- C. inductive reactance exceeds the capacitive reactance.
- D. capacitive reactance exceeds the inductive reactance.

6. In a ratio detector circuit at resonance, an unmodulated FM carrier will produce

A. a varying ratio of DC voltage.
14 B. voltage ratios that can be larger if the signal is stronger.
C. equal voltage ratios.
D. all of the above.

7. With no audio modulating an FM signal, the two DC voltages present in a discriminator circuit will be

A. more positive.
B. equal in value.
C. unequal in value.
D. more negative.

8. The strength of the incoming signal in the ratio detector of Figure 19

A. is determined by the value of capacitor C_3.
B. cannot be determined.
15 C. establishes the operating voltage across resistor R.
D. is determined by the value of resistor R.

9. The purpose of the De-emphasis network is to

A. restore the overall frequency response to a "flat" characteristic.
12 B. boost the high frequency energy levels.
C. boost the low frequency energy levels.
D. filter out RF frequencies.

10. The ratio detector is

A. more immune to AM signals than the Foster-Seeley discriminator.
17 B. not operated on the difference in voltage of two diode detectors.
C. not generally used in Hi-Fi tuners.
D. none of the above.

Notes

Notes

Portions of this lesson from
FM from Antenna to Audio
by Leonard Feldman
Courtesy of Howard W. Sams, Inc.

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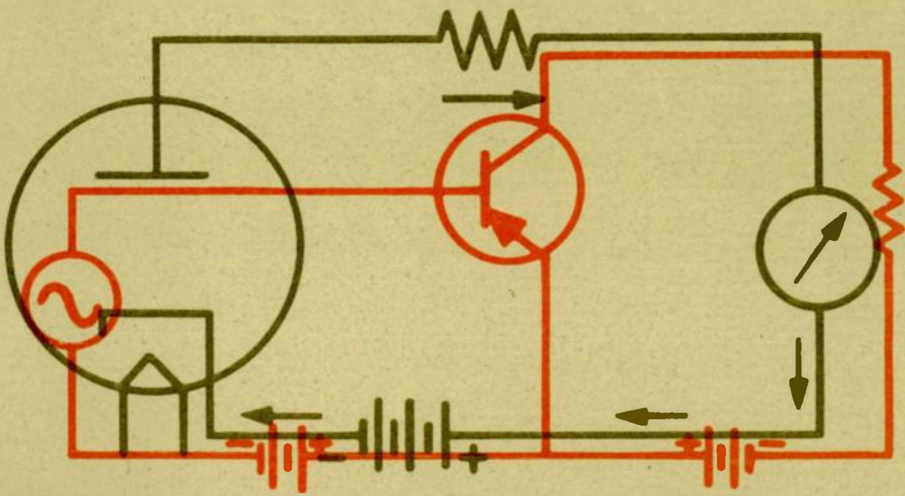
LESSON NO. 67

FM RADIO SERVICING



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-067
407

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 4/73
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CONTENTS

Advance Schools, Inc.

52-067

FM RADIO SERVICING

INTRODUCTION

There are three general methods currently used to align the FM circuitry of either an FM tuner or the FM portion of a complete receiver. The first involves the use of relatively inexpensive test equipment, such as an amplitude-modulated RF generator and a vacuum-tube voltmeter. The second involves the use of more sophisticated equipment such as a frequency-modulated RF generator and an oscilloscope. The final method will be mentioned once, and then quickly forgotten, we trust. This method involves the "ear-to-the-loudspeaker/screwdriver- to- the- alignment-points" approach which we have, regrettably, observed from time to time. A really experienced service technician can sometimes get away with this approach in aligning a simple AM transistor radio—using known stations as a signal source. Even then, the final alignment job will not equal that attainable with the use of proper instruments. In the case of FM receiving equipment, this hit-or-miss approach will lead to a "miss" 99 times out of 100—so don't even try it!

Before proceeding to the actual job of alignment, some generalizations can be made as to the order of the various alignment steps. Most manufacturers will advise that the detector (whether it is a discriminator or a ratio-detector) be aligned first. This is usually followed by a complete IF alignment. Finally, the RF or "front end" section is aligned. Often, the IF section and detector are aligned in a single procedure, depending upon circuitry, available test points, and the individual preferences of the manufacturer. If a service manual has not been supplied with the set, one should be obtained from the manufacturer. If this is not possible, a PHOTOFACT of this receiver should be purchased from an electric supply house, or from the publisher, Howard W. Sams & Co. Inc., in Indianapolis, Indiana. Having this manual is well worth the slight expense. We shall examine a typical example of manufacturer's alignment instructions after we have generalized the procedure.

IF AND DETECTOR ALIGNMENT

Figure 1 is a very generalized block diagram of an FM tuner. The receiver in question may be either

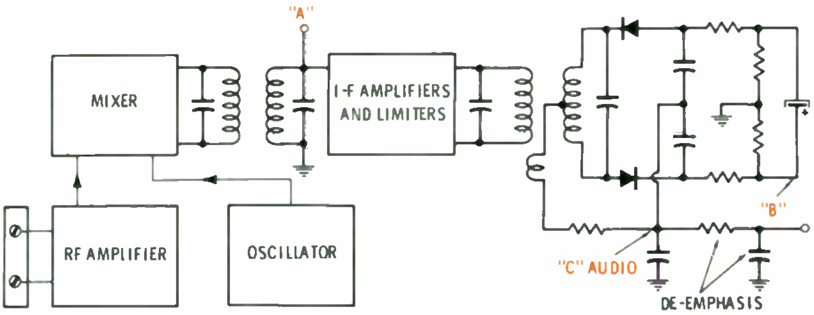


Figure 1 — Test points for IF and detector alignment.

of solid-state or tube construction. The detector in this diagram takes the form of a ratio detector, though that part of the alignment which involves the detector stage will be repeated, using a discriminator and detailing the differences in the procedure that is required.

To align the IF-detector portion of the receiver using just an AM RF generator and a VTVM, the generator is set to a frequency of 10.7 MHz. The output of the generator is coupled to point A of Figure 1 through an isolating capacitor (generally 0.01 μF or even smaller), so that the DC voltages at the input to the first IF stage will not be upset or altered. The VTVM is set to a low-voltage DC scale (5 volts, or even 1.5 volts full-scale) and connected to point B (one side of the charging or storage capacitor of the ratio-detector circuit).

It is assumed that this tuner has conventional IF transformers (as opposed to the newer crystal or ceramic filters), each of which has a tuning adjustment in the primary and secondary circuits. The signal generator should be adjusted to provide just enough RF output at 10.7 MHz to cause the VTVM to read part-way up the scale. As adjustments are made in each IF interstage transformer, the output of the generator should be backed off whenever a higher reading is obtained on the meter. Each transformer is adjusted until a maximum reading is obtained on the meter. Normally, it is usual to adjust the earlier IF transformers first, going right down the line towards the detector in the same way that the signal itself proceeds through successive IF stages. It is extremely important to keep "backing off" the output of the signal generator as each stage is adjusted for maximum gain at 10.7 MHz. If this is not done, the IF system will soon be well into full limiting and it becomes difficult to discern well-defined maxima as the adjustments proceed.

It is good practice after the IF transformers have been peaked, to repeat the process, trimming up each transformer primary and secondary to achieve absolute maximum reading on the VTVM. Only the *primary* of the ratio-detector transformer is adjusted at this time. The AM generator used in this procedure should be capable of being attenuated to only a few microvolts output and this part of the alignment is done with no modulation applied.

Once you are certain that the IF transformers have been peaked, move the VTVM probe to point C or to the point marked "Audio" in Figure 1. If your VTVM has facilities for moving the pointer to the center scale electronically, do so, still keeping the range setting on the lowest, most sensitive scale. Adjust the *secondary* of the ratio-detector transformer until precisely zero volts is read on the meter. Do not make the mistake of de-tuning the secondary so far as to be completely outside the frequency range, as such a setting will also result in a zero or near zero reading. The desired zero reading is one which occurs between a positive and a negative swing of the meter. That is why it is easiest to perform this adjustment with a zero-center meter. Even a slight movement of the tuning-adjustment slug in either direction will cause a rapid movement of the meter pointer to one side or the other, about zero center.

ALIGNMENT OF DISCRIMINATORS

One form of discriminator detector is shown in Figure 2. Points B and C are designated to correspond to the equivalent points used in the ratio detector of Figure 1. Procedure is pretty much the same. Point B is used for peak alignment of the IF transformer primaries and secondaries and the discriminator primary, while point C is used for zero-centering the voltage by adjustment of the secondary of the discriminator transformer.

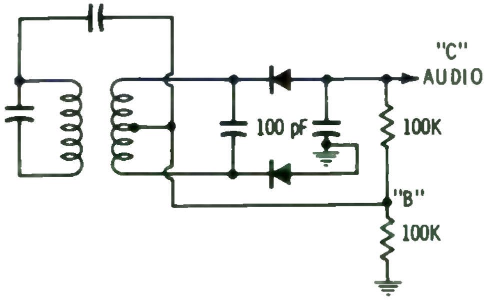


Figure 2 — Typical discriminator circuit with B and C test points corresponding to B and C points in Figure 1.

Figure 3 shows how a manufacturer might designate the above procedure in tabular form. Designations A11 through A18 refer to schematic designation points that correspond to the various primaries and secondaries of the IF transformers and the ratio-detector transformer.

ALIGNMENT USING AN OSCILLOSCOPE

The well equipped service shop generally will not align FM sets (particularly high-fidelity units) using the generator-meter method outlined above. For one thing, the simpler method presumes that each IF transformer is to be tuned to exactly 10.7 MHz when, in fact, some manufacturers require that specific stages be stagger tuned to specific frequencies other than 10.7 MHz. In this way they are able to achieve the wideband response so necessary for distortion-free audio recovery and good stereo-multiplex decoding. Even if the manufacturer were to list specific frequencies for

FM IF ALIGNMENT USING AM SIGNAL GENERATOR - SELECTOR IN FM POSITION

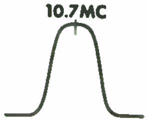
High side of generator thru .01mfd to pin 2 (grid) of FM Mixer, low side to chassis.				
GENERATOR FREQUENCY	DIAL SETTING	INDICATOR	ADJUST	REMARKS
10.7MC (Unmod.)	Point of non-interference.	DC probe of VTVM to point B, common to chassis.	A11, A12 A13, A14 A15, A16 A17	Adjust for maximum.  FIG. 1
"	"	DC probe to point C, common to chassis.	A18	Adjust for zero reading. A positive or negative reading will be obtained on either side of the correct setting.

Figure 3 — Alignment using an AM signal generator and a VTVM.

each IF transformer (e.g. T1—10.75 MHz; T2—10.67 MHz; T3—10.7 MHz), the usual inexpensive AM RF generator normally found in service shops is incapable of such accuracy. Normally, you're lucky if 10.7 MHz (as read on an inexpensive RF generator) is even close to 10.7 MHz in fact.

Visual Display

A much better method of alignment involves a visual display of the entire IF response, made possible by the use of an oscilloscope and an FM RF sweep generator. Figure 4 is a block diagram of the test setup required. The generator must be capable of producing FM output, variable in amplitude from perhaps just a few microvolts to several tenths of a volt. The modulating frequency, whether applied externally or provided by a built-in audio oscillator, must be able to shift the carrier frequency at least ±200 kHz. Notice that the audio modulating frequency is applied to the horizontal input of the oscilloscope. The vertical input to the scope is actually taking the place of the VTVM used in the previous discussion. The unmodulated AM RF generator used previously can now prove useful in providing a reference or marker frequency at 10.7 MHz, as will be shown shortly.

To view the overall IF response of the tuner in question, the vertical input to the scope may be connected to the final limiter grid (in the case of tube sets), to point B of Figure 1 (provided the storage or charging capacitor of the ratio detector is temporarily disconnected), or to an AGC (automatic gain control) voltage point, provided AGC voltage is developed from the last IF stage or limiter.

The oscilloscope sweep selector is set to "external", thereby defeating all internal horizontal-sweep circuits. Horizontal movement of the scope trace will be governed strictly by the positive- and negative-

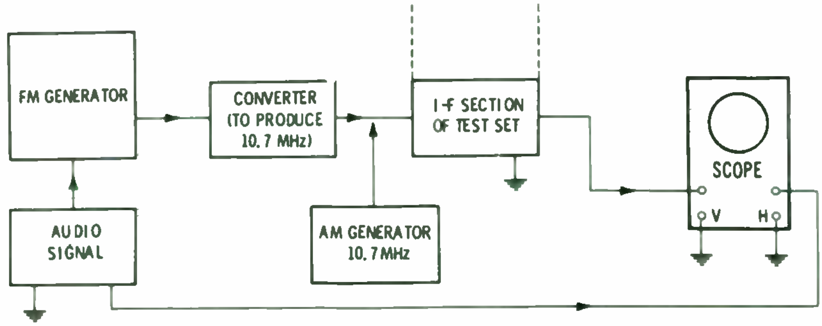


Figure 4 — Test setup for visual IF alignment.

swinging audio sinewave used to modulate the RF carrier. To clarify, let us suppose that positive-going voltage causes the trace to move to the right while negative-going voltage causes it to move to the left. Let us also suppose that positive-going audio voltage causes the RF signal in the generator to move *up* in frequency while negative-going audio causes a downward shift in carrier frequency. Figure 5 relates all these movements of scope trace and frequency in a graphic manner, showing where the trace will be for a given frequency (RF) and where the frequency will be at every point in the audio-modulating cycle.

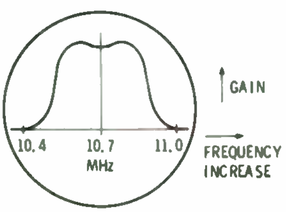


Figure 5 — Alignment response curve showing change in amplification (vertical) with change in frequency (horizontal).

We have noted, previously, that most IF systems have a bandpass characteristic that is about 200 to 300 kHz wide. That is, maximum gain occurs at exactly 10.7 MHz (when everything is properly tuned) and remains fairly constant (though not perfectly so) for about 100 kHz on either side of 10.7 MHz, falling off rapidly beyond these points.

Response Curve

By having the trace of the scope move along with the changing RF signal, and with the vertical input responding to amplification of the IF system, the scope trace is made to display the typical IF response curve that we have shown so many times (shown again in Figure 6). By coupling the RF generator loosely to the system, a marker "pip" is introduced on the curve as shown in Figure 6 and can be used as an aid in

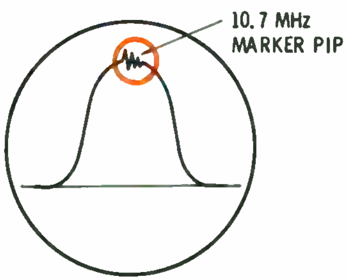
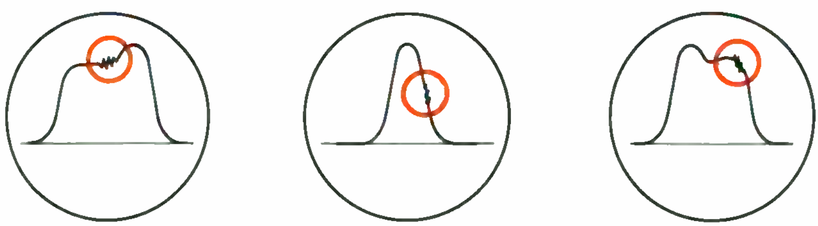


Figure 6 — IF response curve with 10.7 MHz marker.

determining that the system is, in fact, centered about 10.7 MHz. By altering the frequency setting of the unmodulated auxiliary generator, it is possible to move this "pip" along the response curve to determine just how wide the bandwidth is, etc. Energy from the marker generator should be just sufficient to create a small marker in the display. If the marker signal is too strong, it will fairly well obliterate the response curve trace by taking over completely. Usually, just holding the RF output cable near the system will provide sufficient marker indication. It should be noted that some FM generators have markers of fixed frequency built right in, as an added feature.

Now, it is easy to see that correct alignment can be discerned at a glance and, what is more important, incorrect alignment, as shown in various forms in Figure 7, is equally easy to spot. Such might not be the case in the generator-meter alignment method discussed earlier. Using this visual method, it is also possible to observe other important changes: the *effect* of varying signal strength on bandwidth; the *shifting* of the center frequency of alignment with increased signal strength, the *overload characteristics* of a given IF system (how does the response curve hold up when really huge RF signals are applied) and many, many more. In short, the FM-generator-oscilloscope method of IF and detector alignment is by far the more sophisticated and effective of the two practical methods discussed here. Why, then, do so few service shops and home labs use this method? Simply because a good FM generator costs a great deal of money—well over a thousand dollars, if purchased new. Considering the fact that most service shops have already had to spend a great deal of money in equipping their establishment, first for TV repair and then for color TV repair, it is not surprising that they don't all rush right out to purchase a $1500.00 generator. Too bad, since most shops have oscilloscopes equal to this particular task. The test equipment manufacturer who develops a good FM generator for under $200.00 will do the high fidelity industry a great service. While a great many FM generators do appear in the trade catalogs for even less than this figure, do not be misled. All they are good for is a spot-check of frequency calibration and a very minor kind of alignment usage. Their problem lies in their inability to provide an ac-



A - Improper flat top. *B - Narrow, off-center response.* *C - Off-centered, wideband response.*

Figure 7 — Displays of misaligned IF sections.

calibrated attenuator. What good is such a generator for use with an FM receiver claiming a sensitivity of 2 microvolts if the generator "leaks" a couple of hundred microvolts right out of its metal cabinet? To provide proper shielding and a calibrated attenuator costs a great deal of money and requires precision machining and assembly of parts.

RF OR FRONT END ALIGNMENT

Alignment of the RF sections of an FM tuner or receiver is surprisingly similar to the methods used for AM radio alignment. Most RF tuned circuits are single-tuned (or single-peaked) which requires that they simply be tuned for maximum output. This makes RF adjustment actually simpler in many respects than IF adjustment. RF alignment should never be attempted unless the IF system is known to be in perfect alignment. In addition, if an AFC circuit is present in the tuner or receiver, it should be defeated or deactivated before RF alignment is undertaken.

In most cases, alignment of the RF section will include making certain that the receiver, after alignment, meets its published specifications, particularly with regard to quieting sensitivity. For this reason, it now becomes imperative that the exact number of microvolts reaching the antenna terminals of the receiver under test be known. With today's ultrasensitive tuners and receivers, this means that the RF generator used must be capable of attenuation down to a fraction of a microvolt. Furthermore, when the generator output is reduced to its minimum, there must be no leakage or radiation of RF from the transmission cable, the generator metal housing, or even the AC power cord. These shielding requirements are part of what makes good FM generators so expensive.

Manufacturers involved in the design and production of FM receiving equipment often test their products in a magnetically and electrostatically shielded room, often called a "screen room," since tightly woven copper screening is usually used to cover walls, ceiling, and floor, as well as any doorways leading into the room. The use of such a shielded room prevents broadcast signals from nearby stations from interfering with the alignment and test process. The IHF standard for tuner measurement (and alignment) requires that tests be made at three frequencies: 90 MHz, 98 MHz and 106 MHz. Since there may well be stations within 100 kHz of all of these frequencies, it is important to block out reception of these stations and deal only with the RF produced by the signal generator.

As mentioned previously, the co-axial cable should connect RF energy to the antenna terminals by means of a matching network. Most generators have an internal output impedance of 50 ohms, while most FM tuners have input impedances of either 75 ohms or, more popularly, 300 ohms. In the case of a balanced 300-ohm system (the most popular type), the network shown in Figure 8 should be used to provide a proper match between generator and receiver or tuner. Since a

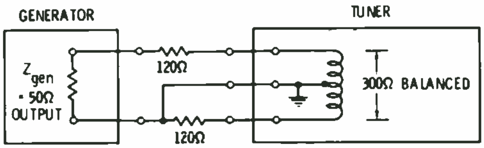


Figure 8 — Matching network required for connecting 50-ohm generator to 300-ohm balanced antenna input.

voltage drop will take place across the series resistors, however, the actual number of microvolts reaching the tuner or receiver antenna terminals will be *half* the number of microvolts read on the calibrated dial of the generator.

Test Procedure

Test points for connecting a VTVM or an oscilloscope are the same as those used for IF alignment, since the IF system, having been previously aligned, is now being used as a fixed amplifier. If using a meter as the indicator, the steps to be followed are these:

1. Set the tuner dial to 106 MHz and set the FM signal generator to the same frequency.

2. Adjust the oscillator section trimmer capacitor for a peak indication, rocking the trimmer adjustment back and forth a couple of times to make sure absolute peak has been achieved. Always work with the *least* amount of RF signal consistent with on-scale meter readings, using the lowest available scale of the VTVM.

3. Adjust trimmers of all RF sections of the variable capacitor for a peak reading. The number of trimmers will depend upon the number of tuned sections there are in the RF section of the set under test.

4. Repeat all adjustments, at a lower signal level, if possible. In many circuits, adjustment of one trimmer may affect the adjustment of others, and so the final adjustment points should be "zeroed in" by repeated adjustments—including even the local oscillator trimmer.

5. Set the tuner dial to 90 MHz and set the generator frequency to this frequency as well. Adjust the oscillator coil for a peak reading. Note that in many sets, the oscillator coil as well as all other RF coils consist simply of a few turns of wire wound in open air and having no tuning slug or supporting coil form. Such coils are adjusted by carefully compressing or expanding the turns a small amount, depending upon which action results in a higher reading on the meter. More sophisticated front ends will have RF coils wound on ceramic or other forms and may even provide tuning slugs, much like IF transformers and coils.

6. Adjust such other RF coils as may be present (again, depending upon the number of tuned RF stages) for a maximum indication on the meter. Repeat steps 5 and 6 as many times as needed, always reducing signal strength to min-

imum required, until an absolute maximum reading is obtained.

7. If considerable adjustment of the coils was required, it is necessary to return to a frequency of 106 MHz and touch up all the trimmers once more, repeating all of the above steps until no further increase in reading is attainable at either 90 MHz or 106 MHz.

VISUAL RF ALIGNMENT

Sweep alignment of the RF section of an FM tuner or receiver is quite similar to the procedures already outlined for IF alignment. We have found that it is best to observe the detector "S" curve for this procedure, rather than the limiter or AGC voltage, since by doing so it is possible to maintain the best overall output response and linearity. This procedure, too, has advantages over the static meter method, since it is possible, using just a meter as an indicator, to inadvertently tune the RF stages in such a manner as to reduce usable bandwidth. In observing the output "S" curve, on the other hand, the objective is to increase overall gain of the system without distorting or narrowing the "S" curve previously achieved during IF alignment.

The foregoing alignment procedures are necessarily general, since no two tuners or receivers are alike. Fortunately, just about every reputable manufacturer marketing high-fidelity tuners and receivers takes the trouble to prepare a detailed service manual. While individual procedures outlined in your service manual may differ somewhat from the general methods outlined here, the objectives are always the same—to bring performance up to "mint" condition. A bit of time spent studying specific suggestions of manufacturers will enable you to relate them to the discussion here.

We stressed, at the outset, the need for good test equipment in servicing FM equipment, and it bears repeating. Experience in dealing with these high-frequency, critical circuits is also a vital ingredient for successful servicing and alignment of these systems. It is NOT the kind of equipment one should attack with just a screwdriver and a pair of pliers. Without proper equipment and experience, you would be much better off letting a local service shop or the manufacturer's repair agency align the FM sets. However, if you have a small FM receiver of your own you can use the first method described —using an AM generator and a VTVM—to gain some initial alignment experience.

SERVICE MANUALS

Using Simple Test Equipment

An example of the kind of adjustment instruction furnished by a manufacturer of radio receivers is shown on the next few pages. Figures 9 to 12 are reproduced from the Montgomery Ward service manual for a 6-tube FM-AM Clock Radio. The type of tubes used plus other specifications are shown in Figure 9. Figure 10 is the complete circuit diagram and Figure 11 lists

SERVICE MANUAL

AND REPAIR PARTS

FOR REPAIR SERVICE DEPARTMENT

MANUAL 681A

Airline

FM–AM
CLOCK RADIO
WITH A.F.C.
MODEL
GEN–1826A

MODEL GEN – 1826A (WALNUT & WHITE)

GENERAL DESCRIPTION

This Airline radio is a 6 tube plus rectifier FM–AM superheterodyne receiver. The FM "front end" is a complete assembly using permeability tuning and a dual purpose tube. An A.F.C. circuit is included in the tuner. The radio uses a tone control circuit and a balanced ratio detector circuit. The walnut wood cabinet is interlocked for safety. A large air loop is used for AM and the line cord is utilized as a built-in FM antenna. Terminals for an external FM antenna are provided. The clock used in these receivers features automatic controls of radio on-off and use as an alarm clock. It starts as soon as you plug the radio cord to any outlet supplying 120 volts, 60 cycle alternating current. To set the clock to the correct time, set control in the rear.

ELECTRICAL SPECIFICATIONS

Power Supply:
105 to 120 volts
60 cycles A.C.
Approximately 40 Watts

Frequency Range:
FM – 88 to 108 MC
AM – 540 to 1600 KC

I.F. Frequency:
FM – 10.7 MC
AM – 455 KC

Loudspeaker:
6" P.M. Alnico V, V.C. Imp. 3.2 Ohms

Power Output:
Undistorted – .8 Watts
Maximum– 1.5 Watts

Tube Complement:
1– HCC85 FM Osc. & R.F. Amplifier
1– 12BE6 AM Converter
2– 12BA6 I.F. Amplifiers
1– 14GT8 2nd Detector, AF Amplifier
1– 50C5 Audio Output

M O N T G O M E R Y W A R D

Courtesy of Montgomery Ward

Figure 9 — A 6-tube FM-AM radio with clock.

the alignment instructions. The parts list is detailed on Figure 12 to allow an easy replacement of the conventional parts like resistors and capacitors, while the components that are specific to this list are also listed.

This FM-AM radio could be realigned using only an AM signal generator and a VTVM, as explained in the instructions in Figure 11. This list also contains the specific steps to be taken in servicing this receiver.

Figures 13 to 18 show a transistorized version of an AM-FM-PB Digital Clock radio. The PB stands for Police Band and has a frequency range of 148 to 175 MHz, which also permits the reception of the weather broadcasts from the stations of the United States Weather Bureau. Both sides of the printed circuit board are shown for easy identification and location of the parts (Figs. 15 and 16). The schematic wiring diagram is shown on Figure 17, and the complete alignment instructions on Figure 18. These instructrons only require the use of an RF signal generator and a VTVM.

Using Complex Test Equipment

An AM/FM signal generator, an FM IF sweep generator, an oscilloscope, and an output meter are specified as the test instruments required for the alignment of the FM-AM radio shown in Figure 19. With the schematic diagram of Figure 20 and the alignment procedure of Figure 21, the time required to repair and service a radio of this type is reduced considerably. Most radios of any given type, such as AM radios, AM-FM radios, AM-FM-FM stereo radios, etc., are all aligned following the same general steps. Each design of set, however, might require that a certain series of steps be followed that are different than for most receivers of that type, so it is always best to review the recommended alignment procedure before making any adjustments.

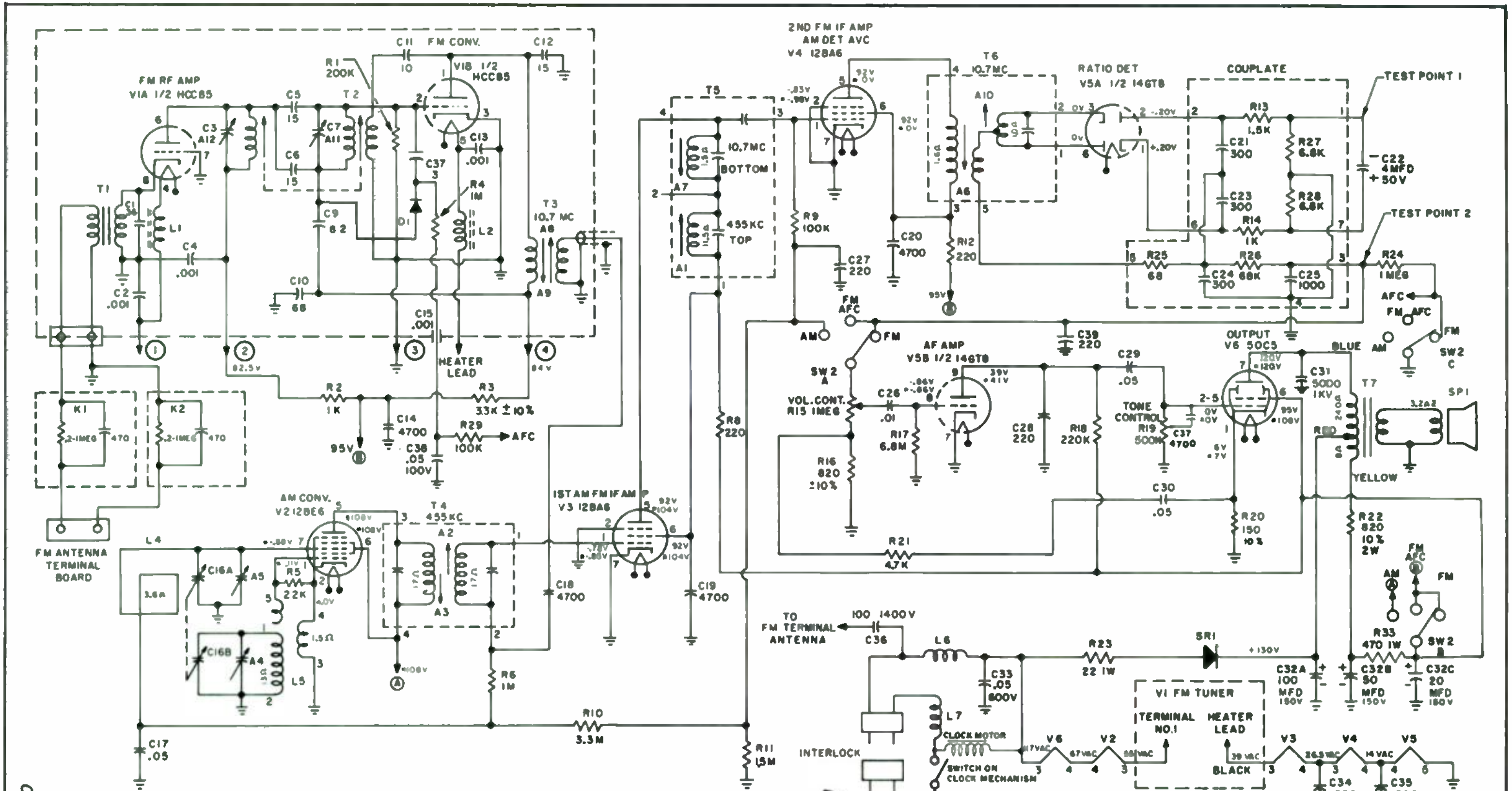
Localizing the Trouble

When the trouble in a receiver cannot be corrected by realigning it, it becomes necessary to determine where the trouble lies. Once the difficulty has been localized to a particular stage in the receiver, it becomes necessary to pinpoint the defective component(s). Even though a logical system of signal tracing is being followed, it is important to know and understand some of the causes that produce a specific effect in different types of circuits.

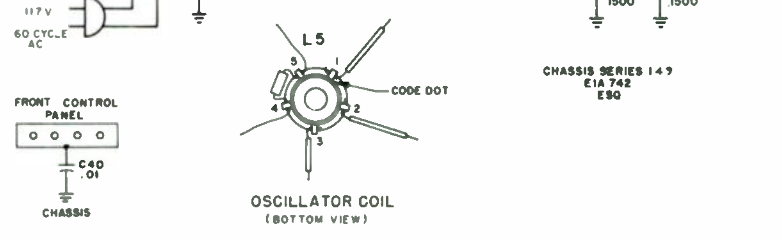
The remainder of this lesson is devoted to a review of five major circuits. The operation of each one of these circuits is analyzed, and then methods are listed for each one to help locate the component that produces that specific defect.

RF AMPLIFIERS

RF amplifiers are similar in many respects to other forms of electron tube amplifiers, but differ primarily in the frequency spectrum over which they operate. There are two general classes of RF



NOTES:
1. ALL VOLTAGES MEASURED WITH VTVM, REFERENCED TO CHASSIS GROUND, WITH VOLUME CONTROL AT MAXIMUM, NO SIGNAL APPLIED, AND BAND SWITCH IN FM POSITION, UNLESS OTHERWISE NOTED.
2. ✱ VOLTAGES MEASURED WITH BAND SWITCH IN AM POSITION.
3. ALL VOLTAGES SHOWN ARE DC UNLESS OTHERWISE INDICATED.
4. ALL RESISTORS ARE IN OHMS, ±20%, 1/2 WATT UNLESS OTHERWISE SPECIFIED.
5. DC COIL RESISTANCE VALUES UNDER 1 OHM NOT SHOWN.
6. CAPACITANCE VALUES LESS THAN 1 ARE IN MICROFARADS, MORE THAN 1 ARE IN MICROMICROFARADS UNLESS OTHERWISE INDICATED.
TOLERANCE ±20%, VOLTAGE RATING PAPERS 400 V, DISCS 500 V, UNLESS OTHERWISE SPECIFIED.



Courtesy of Montgomery Ward

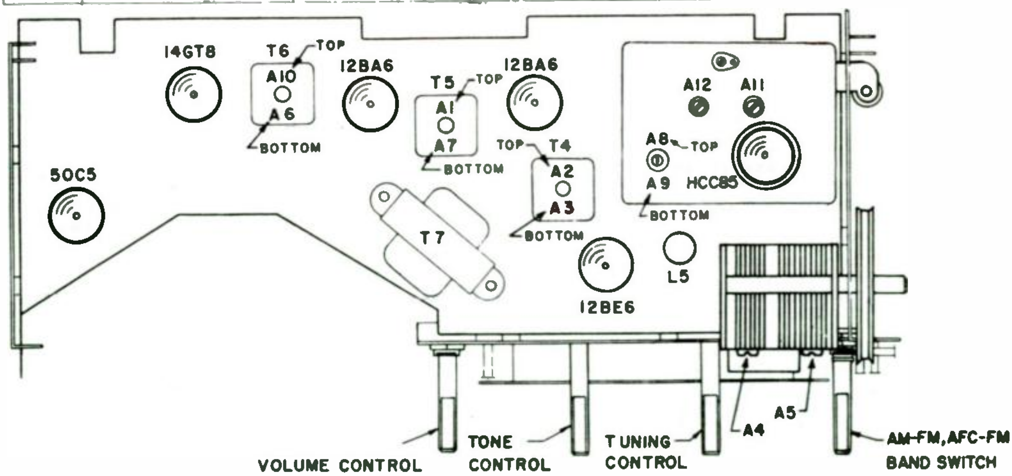
Figure 10 — Circuit diagram of a 6-tube FM-AM clock radio.

ALIGNMENT INSTRUCTIONS

NOTE: The chassis of this radio is connected to one side of the power line. Use isolation transformer to prevent dangerous electrical shock.

1. Volume control set at maximum.
2. Keep output of signal generator no higher than necessary to obtain an output reading.
3. Use an insulated alignment tool.

Dummy Antenna	Signal Generator Coupling	Signal Generator Frequency	Band Switch Position	Radio Dial Setting	Connect VTVM	Adjust	Remarks
FM IF ALIGNMENT USING AM SIGNAL GENERATOR AND VTVM							
Direct	Place a thin insulated metal strip between the FM Converter tube and tube shield. Connect the high side of generator to the metal strip. Low side to chassis.	10.7 MC (Unmod.)	FM	108 MC	D.C. probe to test point 1. Common to chassis.	A6,A7, A8,A9	Adjust for maximum negative deflection
Direct	Place a thin insulated metal strip between the FM Converter tube and tube shield. Connect the high side of generator to the metal strip. Low side to chassis.	10.7 MC (Unmod.)	FM	108 MC	D.C. probe to test point 2. Common to chassis	A10	Adjust for zero reading. A positive and negative reading will be obtained on either side of the correct setting.
FM RF ALIGNMENT							
Two 120 ohm carbon resistors	Across FM antenna terminals with 120 ohm in each lead.	104 MC (Unmod.)	FM	104 MC	DC probe to test point 1. Common to chassis.	A11 OSC.	Adjust for maximum deflection.
Two 120 ohm carbon resistors	Across FM antenna terminals with 120 ohm in each lead.	96 MC	FM	Tune to 96 MC signal	DC probe to test point 1. Common to chassis.	A12 RF	Adjust for maximum deflection.
AM ALIGNMENT							
.05 mfd	High side to antenna stator lug on tuning gang. Low side to B−.	455 KC (400 cycles mod.)	AM	Tuning gang fully open.	Across voice coil.	A1,A2 (Top) A3 (Bottom) of I.F.	Adjust for maximum output.
	Loop	1640 KC	AM	Tuning gang fully open.	Across voice coil.	A4	Fashion loop of several turns of wire and radiate signal into loop of receiver. Adjust for maximum output
	Loop	1400 KC	AM	Tune to 1400 KC signal.	Across voice coil.	A5	Fashion loop of several turns of wire and radiate signal into loop of receiver. Adjust for maximum output.

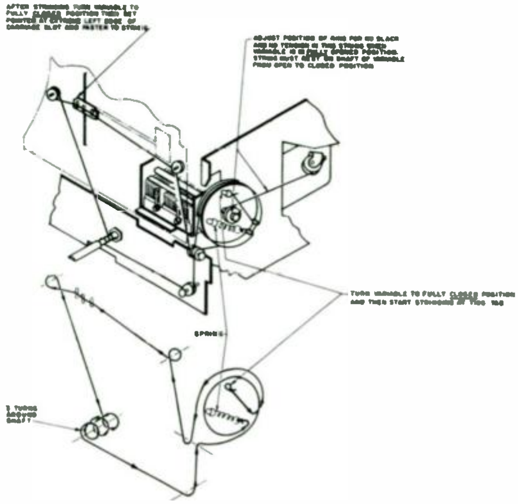


TO SERVICE CHASSIS OR CLOCK

1. Remove four screws from bottom of cabinet.
2. Slide chassis out from the front of the cabinet

Courtesy of Montgomery Ward

Figure 11 — Alignment instructions for the 6-tube radio.



PARTS LIST

REF. NO.	PART NO.	DESCRIPTION
RESISTORS		
R2	*CB1210	1K ohm +20% ½W
R3	*CB1233	3.3K ohm +10% ½W
R5	*CB1322	22K ohm +20% ½W
R6,R24	*CB1510	1 meg ohm +20% ½W
R8,R12	*CB1122	220 ohm +20% ½W
R9,R29	*CB1410	100K ohm +20% ½W
R10	*CB1533	3.3 meg ohm +20% ½W
R11	*CB1515	1.5 meg ohm +20% ½W
R16	*CB1182	820 ohm +10% ½W
R17	*CB1568	6.8 meg ohm +20% ½W
R18	*CB1422	220K ohm +20% ½W
R20	*CB1115	150 ohm +10% ½W
R21	*CB1247	4.7K ohm +20% ½W
R22	*CD1182	820 ohm +10% 2 W
R23	E2311	22 ohm +20% 1 W Glas ohm
R33	*CC1147	470 ohm +20% 1 W
R15	E2568A	1 meg Volume Control
R19	E2567	500K Tone Control
CAPACITORS		
C14,C18, C19,C20,C37	*DD-472	.0047mf +20% Ceramic
C16A&B	E3534B	Variable Capacitor
C17,C29,C30	*6TM-S50	.05mf +20% Molded Tubular
C22	E3244	4mf 50V Electrolytic
C26,C40	*6TM-S10	.01mf +20% Molded Tubular
C27,C28,C39	*DD-221	220mmf +20% Ceramic
C31	E3373	.005mf +20% 1KV Ceramic
C32A,B&C	E3251B	80/40/40 150V Electrolytic
C33	*6TM-S50	.05mf +20% 600V Molded
C34,C35	*DD-152G	.0015mf +80 −20% Ceramic
C36	E3371	100mmf 1.5KV Ceramic
C38	*DD-503	.05mf +20% 100V Ceramic

REF. NO.	PART NO.	DESCRIPTION
COILS AND TRANSFORMERS		
L4	E6051C	AM Loop Antenna
L5	E6146A	AM Oscillator Coil
L6,L7	E6148A	Line Antenna Choke
T4	E6256-3	1st AM IF Transformer
T5	E6284	FM & AM IF Transformer
T6	E6283	Ratio Detector
T7	E1137B	Audio Output Transformer
SPECIAL COMPONENTS		
K1,K2	E3410	Capristor 470 mmf & .3-1 meg ohm
Tuner	E3539C	Complete AFC Tuner w/HCC85 Tube
Couplate	E3038	Printed Network Balanced Ratio Detector
SW2A,B&C	E1216A	AM/AFC/FM Band Switch
Clock,SW1	E1321	Timer, Telechron #4403-001
SP1	E1064C	6" Speaker 3.2ohm V.C.
SR1	E146A	100ma Selenium Rectifier
CABINET AND ACCESSORIES		
	E70235D	Cabinet Shell Walnut Wood
	E70368D	Cabinet Face
	E50310C	Dial Window
	E10161C	Dial & Clock Face
	E4515A	Dial Pointer
	E50185B	Control Knobs
	E50212B	Switch Knob
	E50245B	Clock Knob
	E1361	Set of 4 Clock Hands
	E16155A	MW Nameplate
	E50220B	Namepad
	E5732C	Back Cover
	E8910A	Interlock Line Cord
	E4364	Time Set Shaft

E59599 EIA 742-149 PRINTED IN U.S.A.

Courtesy of Montgomery Ward

Figure 12 — Descriptive parts list for 6-tube radio.

MANUAL 997A

WARDS Airline

SERVICE NATIONWIDE

MONTGOMERY WARD

Service Manual and Repair Parts List

SOLID STATE AM-FM-PB DIGITAL CLOCK RADIO

MODEL GEN-1952A

MODEL GEN-1952A

GENERAL DESCRIPTION

The circuit used in this three band digital clock radio incorporates 12 transistors, 11 diodes, and 1 varistor.

A ferrite bar antenna feeds the AM signal to the AM converter, two IF amplifiers and a diode detector.

A line cord FM/PB antenna feeds the FM/PB signal to the FM/PB RF amplifier, FM/PB converter, three IF amplifiers and a ratio detector.

The audio signal passes through a four transistor audio amplifier circuit.

AM AGC voltage is fed back to the FM RF amplifier, and FM AFC voltage is fed back to the FM converter.

SPECIFICATIONS

Power Supply .... 120 V, 60 Hz, AC only

Power Consumption .... 13 watts

Tuning Range
- AM .... 540 – 1600 KHz
- FM .... 88 – 108 MHz
- PB .... 148 – 175 MHz

Intermediate Frequency
- AM .... 455 KHz
- FM, PB .... 10.7 MHz

Power Output
- Undistorted .... 1000 mW
- Maximum .... 1200 mW

Speaker .... 3" × 5", 8 ohms, 0.6 oz. mag. weight

Dimensions .... 12½" (W) × 3¾" (H) × 5⅝" (D)

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Courtesy of Montgomery Ward

Figure 13 — A 3-band transistorized receiver.

TRANSISTOR COMPLEMENT

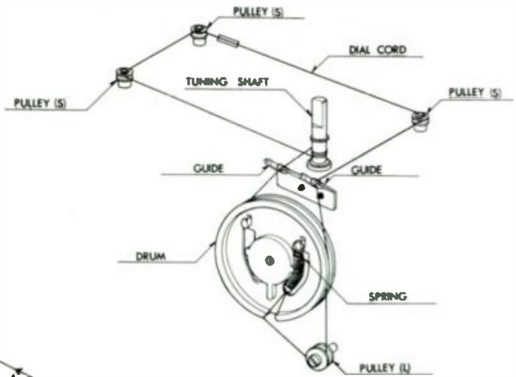
Q1	2SC535 (B)	FM/PB RF Amp.	NPN
Q2	2SC535 (B)	FM/PB Mixer	NPN
Q3	2SC535 (B)	FM/PB Osc.	NPN
Q4	2SC460 (C)	AM Converter	NPN
Q5	2SC460 (C)	VHF/AM 1st IF Amp.	NPN
Q6	2SC460 (C)	VHF/AM 2nd IF Amp.	NPN
Q7	2SC460 (C)	VHF 3rd IF Amp.	NPN
Q8	2SC458 (D)	PB AF Amp.	NPN
Q9	2SC458 (D)	AF Pre-Amp.	NPN
Q10	2SC458 (D)	AF Driver Amp.	NPN
* * Q11, 12		AF Power Amp. (matched pair, 1 ea. 2SC1209 (C), NPN, 1 ea. 2SC695 (C), PNP)	

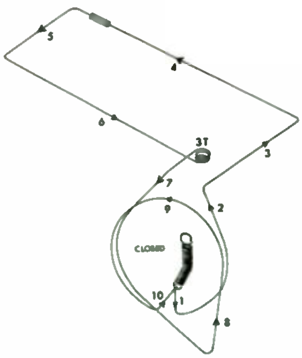
* * Replace with matched pair only.

CHASSIS REMOVAL

1. Remove the six front panel knobs.
2. Remove the five screws located around the outside portion of the front cabinet bottom.
3. Separate the cabinet back from the cabinet front.
4. Remove the two nuts and two screws holding the clock in place.
5. Remove the four screws holding the chassis in place.
6. Disconnect the speaker and clock leads.
7. Pull out the clock and chassis.

Dial Stringing

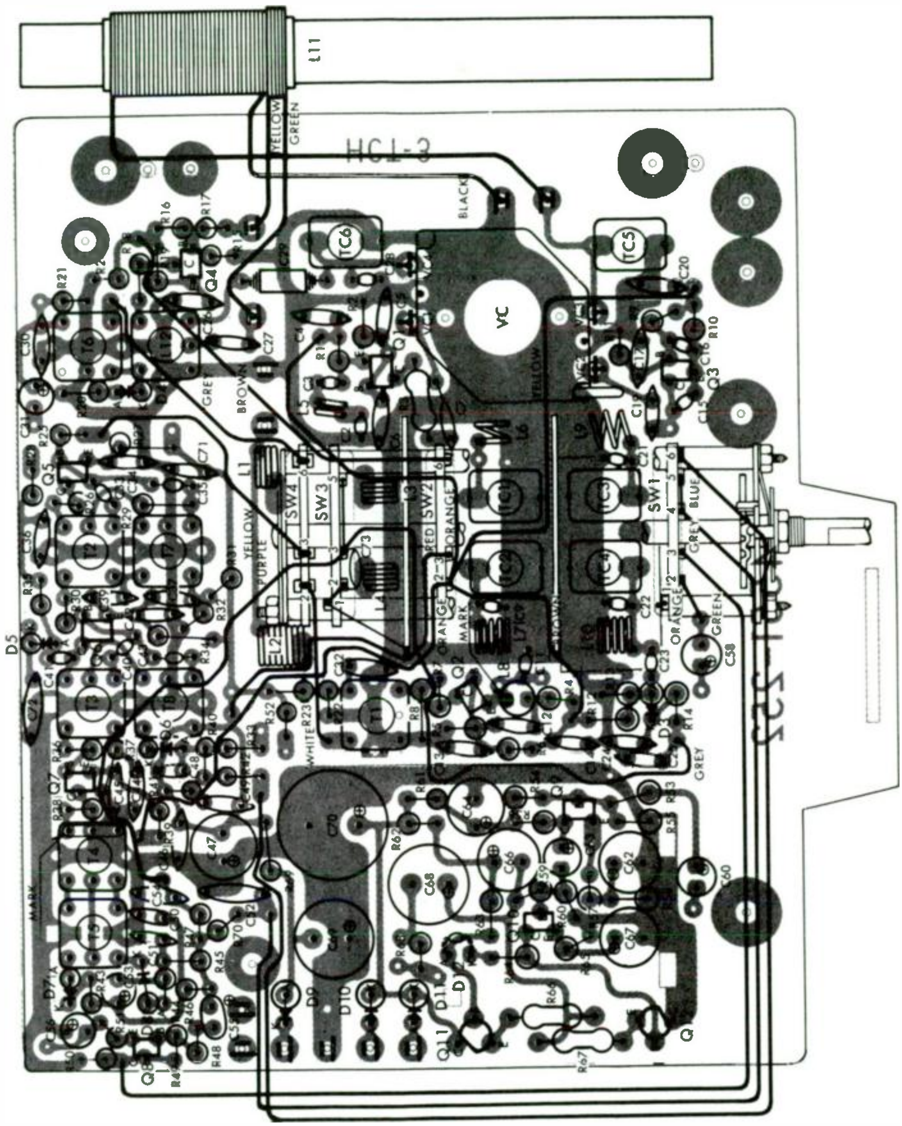




Approx. length of dial cord is 34 inches.
Start stringing gang in closed position.

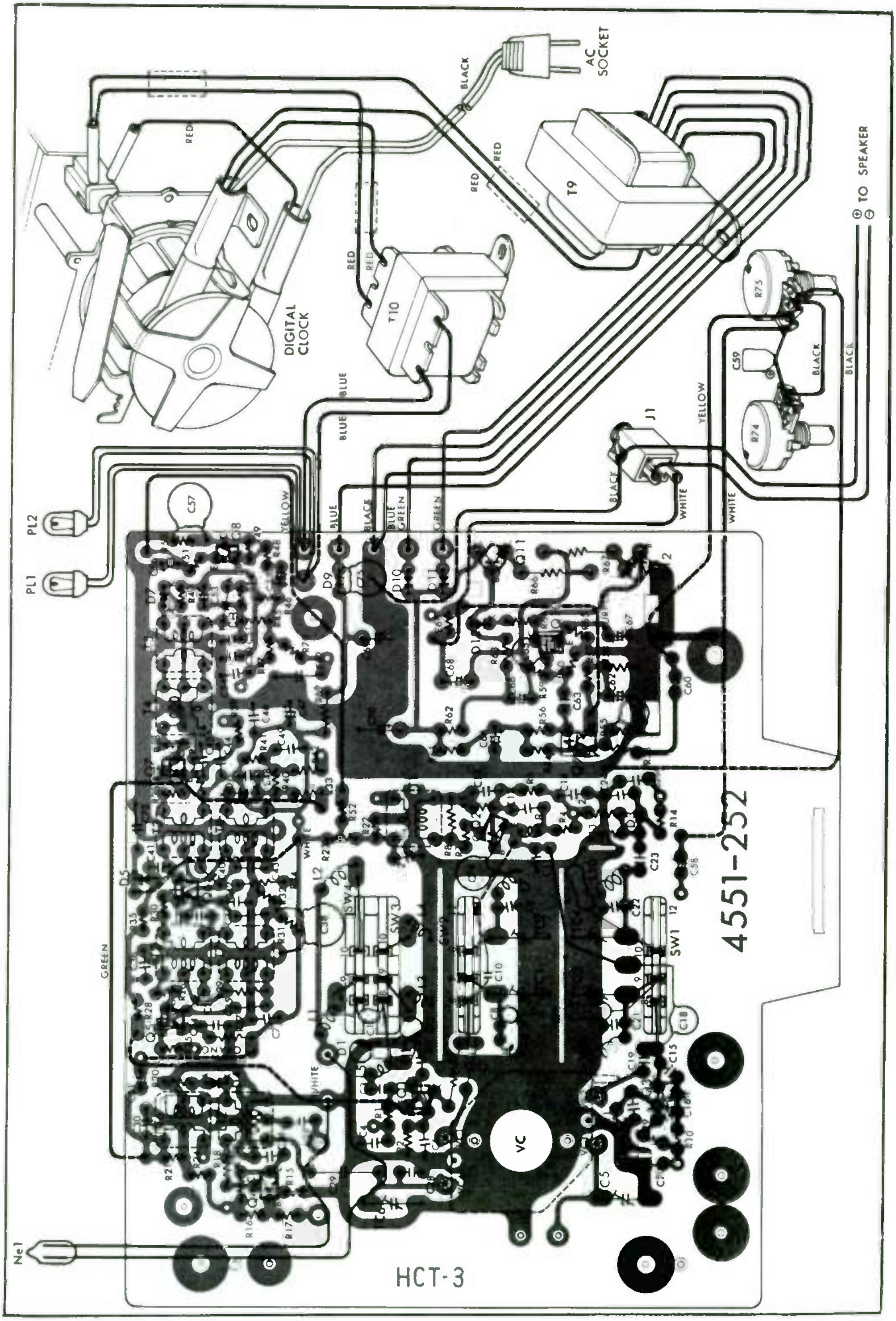
Courtesy of Montgomery Ward

Figure 14 — Repair and service instructions for the 3-band radio.



Courtesy of Montgomery Ward

Figure 15 — P. C. Board-Component Side.



Courtesy of Montgomery Ward

Figure 16 — P. C. Board-Wiring Side.

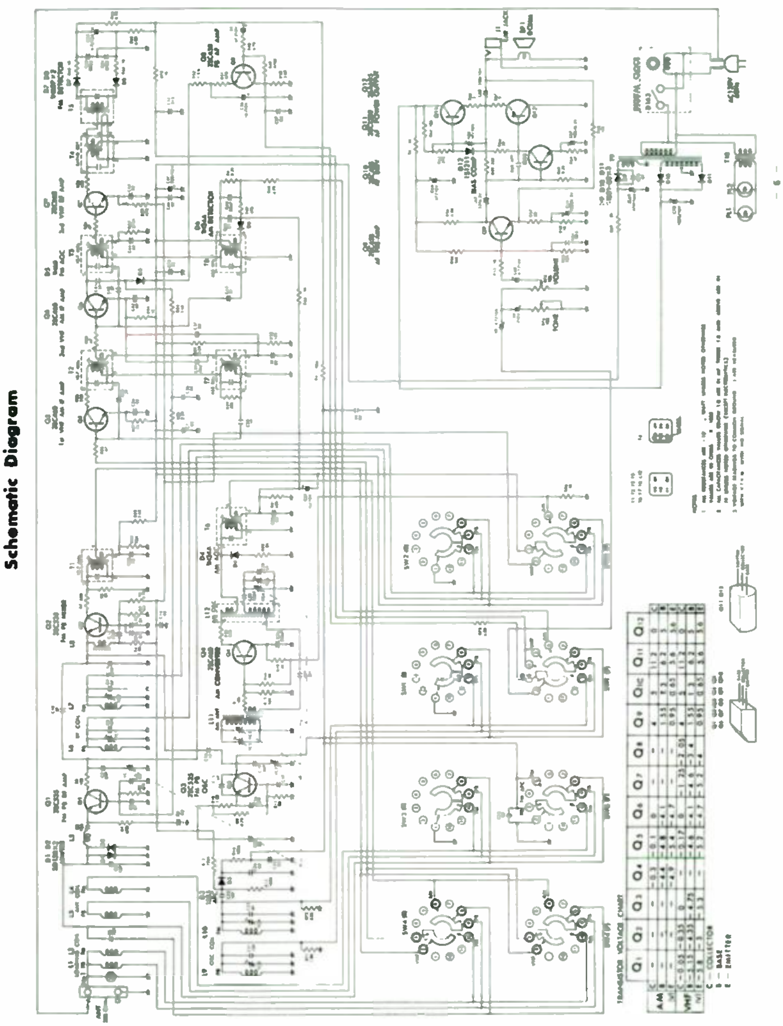


Figure 17 — Circuit diagram of 3-band radio. *Courtesy of Montgomery Ward*

ALIGNMENT

EQUIPMENT REQUIRED

1. RF Signal Generator
2. Electronic Voltmeter
   A.C.V.T.V.M.

GENERAL

1. Signal input must be as low as possible to avoid overload and clipping. (Use highest sensitivity of output indicator)
2. Volume control at maximum.
3. Standard modulation is 400 Hz at 30% amplitude.
4. Connect A.C.V.T.V.M. across voice coil.

Step	*Connect Signal Source To-*	*Connect Output Indicator To-*	*Set Signal Generator To-*	*Set Radio Dial To-*	*Adjust-*	*Adjust For-*	*Step*
	Set Function Switch to AM						
1	Loop of several turns of wire connected across gen. leads. Place loop close to the AM antenna.	A.C.V.T.V.M. across Voice coil	455 KHz	Tuning gang closed	T6, T7, T8	Maximum output on V.T.V.M.	1
2			515 KHz	Tuning gang closed	L12		2
3			1680 KHz	Tuning gang open	TC6		3
4	Repeat Steps 2 and 3 for optimum sensitivity						4
5	Same as above	A.C.V.T.V.M. across Voice coil	600 KHz	Tune for signal	L11	Maximum output	5
6			1400 KHz		TC5		6
7	Repeat Steps 5 and 6 for optimum sensitivity						7

	Set Function Switch to FM						
1	Place gen. leads across FM ant. terminals.	A.C.V.T.V.M. across Voice coil	10.7 MHz	Tuning gang closed	T1, T2, T3, T4	Maximum output on V.T.V.M.	1
2		DC probe across C52	10.7 MHz (Unmod.)		T5	Zero reading	2
3	Repeat Steps 1 and 2 for optimum sensitivity						3
4	Same as above	A.C.V.T.V.M. across Voice coil	87.0 MHz	Tuning gang closed	L10	Maximum output on V.T.V.M.	4
5			109.5 MHz	Tuning gang open	TC4		5
6	Repeat Steps 4 and 5 for optimum sensitivity						6
7	Same as above	A.C.V.T.V.M. across Voice coil	90 MHz	Tune for signal	L7	Maximum output on V.T.V.M.	7
8			106 MHz		TC2		8
9	Repeat Steps 7 and 8 for optimum sensitivity						9

	Set Function Switch to PB						
1	Same as above	A.C.V.T.V.M. across Voice coil	145 MHz	Tuning gang closed	L9	Maximum output on V.T.V.M.	1
2			180 MHz	Tuning gang open	TC3		2
3	Repeat Steps 1 and 2 for optimum sensitivity						3
4	Same as above	A.C.V.T.V.M. across Voice coil	150 MHz	Tune for signal	L6	Maximum output on V.T.V.M.	4
5			175 MHz		TC1		5
6	Repeat Steps 4 and 5 for optimum sensitivity						6

Courtesy of Montgomery Ward

Figure 18 — Alignment instructions for the 3-band receiver of Figure 13.

MANUAL 1021A

WARDS Airline

SERVICE NATIONWIDE

MONTGOMERY WARD

Service Manual and Repair Parts List

SOLID STATE
FM-AM CLOCK
RADIO
GEN-1911 A

SPECIFICATIONS

Frequency Range	
AM	535 to 1620 KHz
FM	88 to 108 MHz
Intermediate	
AM	455 KHz
FM	10.7 MHz
Power Output	
Undistorted	200 mW
Maximum	300 mW
Speaker	3" PM 8 ohms .02 oz. Mag. Wt.
Operating Voltage	105-120V 60 Hz AC only.
AC Power Consumption	10 Watts
Dimensions	10-7/8" (W) x 5" (H) x 3-1/8" (D)

TRANSISTOR COMPLEMENT

Q1	CS9016E	FM RF Amp.	NPN
Q2	CS9016E	FM Converter	NPN
Q3	T1340A3F	AM Converter	NPN
Q4	T9011H	1st FM IF	NPN
Q5	T9011H	2nd FM IF 1st AM IF	NPN
Q6	T9011J	3rd FM IF 2nd FM IF	NPN NPN
Q7	T1340A3J	Audio Pre-Amp.	NPN
Q8	T1340A3J	Audio Driver	NPN
Q9	CS1166D/ Beta 125-150	Audio Output	NPN
Q10	CS1166D/ Beta 125-150	Audio Output	NPN

GENERAL DESCRIPTION

Model GEN-1911A AM/FM clock radio consists of 10 transistors and 10 diodes. On the AM band, a built-in high gain ferrite bar antenna feeds the signal to a separate mixer stage. After passing through the two IF amplifiers and the diode detector, the signal is then fed to an audio amplifier and audio driver which feed a push-pull output stage.

On the FM band the signal is fed into the RF amplifier through the line cord antenna, which is followed by a mixer stage. After passing through the three IF amplifiers and ratio detector the signal then goes to the audio amplifier circuit. AFC and AGC circuits are incorporated to insure stable drift-free performance. The AFC circuit can be disabled by turning the function switch to the FM position.

CHASSIS REMOVAL

1. Remove four screws from the back of radio cabinet.
2. Remove one screw from the bottom of the radio cabinet.
3. The entire assembly including the chassis, clock and panel can now be removed through the front of the cabinet.

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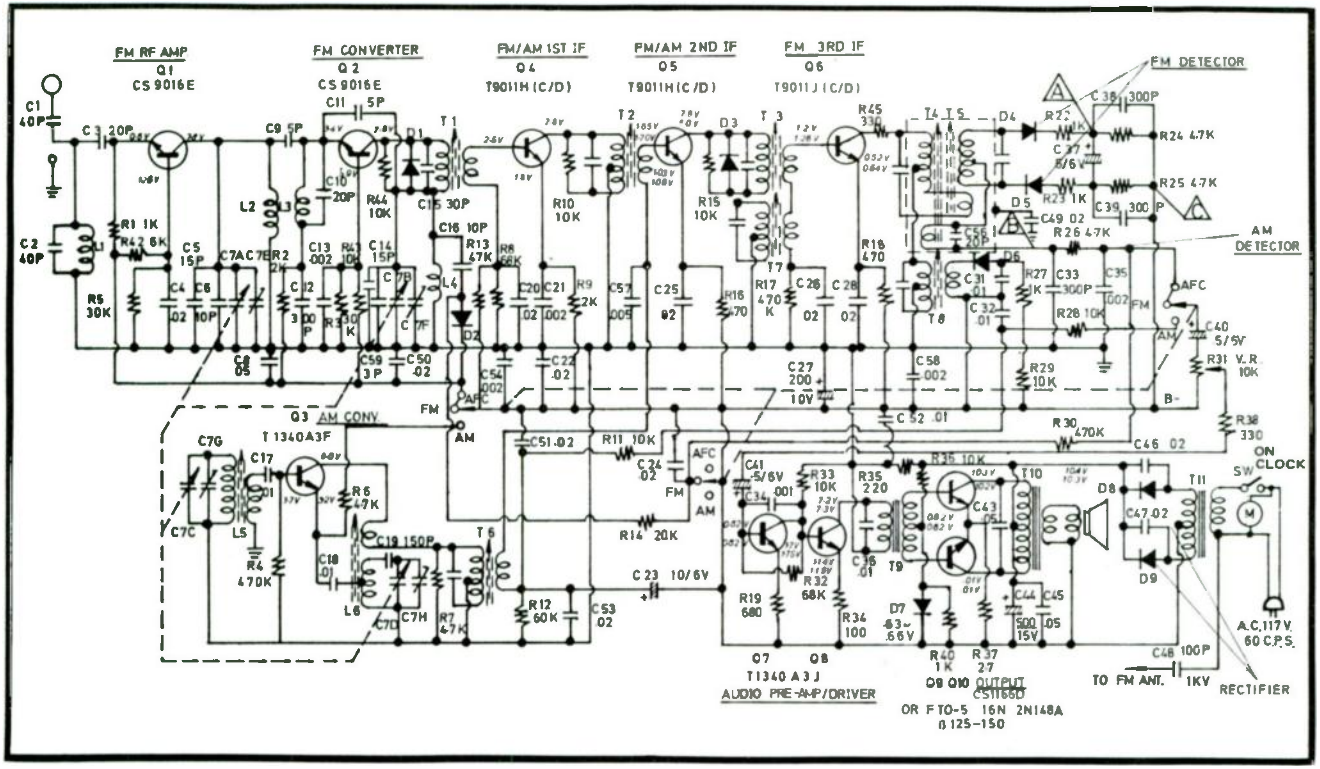
Courtesy of Montgomery Ward

Figure 19 — FM-AM clock radio.



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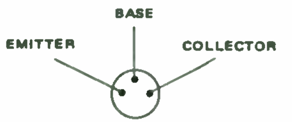
CUT "4"

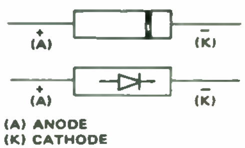


BOTTOM VIEW OF TRANSISTOR

ALL RESISTORS 1/8 WATT ± 10% UNLESS OTHERWISE NOTED.
K = 1000 OHMS.
ALL CAPACITORS IN MFD UNLESS OTHERWISE NOTED.
DC WORKING IS 50V UNLESS OTHERWISE NOTED.
⏚ CHASSIS GROUND.

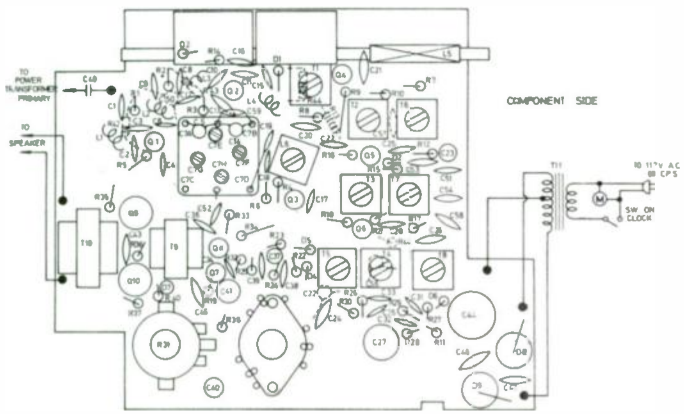
ALL VOLTAGE MEASUREMENTS TAKEN USING A VTVM.
VOLUME CONTROL SET AT MINIMUM AND NO SIGNAL AT FM ANTENNA TERMINALS OR AM CONVERTER (Q3) BASE. WHERE DUAL VALUES ARE GIVEN THE FIRST VALUE IS FOR FM AND THE SECOND VALUE IS FOR AM.

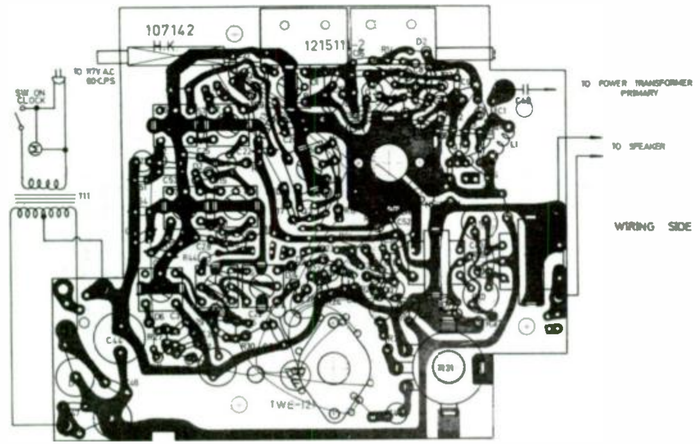
CUT "5"



KEY TO DIODE SYMBOL

Figure 20 — Circuit diagram of a 10 transistor and 10 diode receiver.





P/N 7005338

ALIGNMENT PROCEDURE

INSTRUMENTS REQUIRED:

1. RF AM/FM signal generator
2. FM IF sweep generator (10.7MC)
3. Oscilloscope
4. Output Meter

GENERAL ALIGNMENT CONDITIONS:

1. Signal input should be kept as low as possible.
2. Standard modulation is 400c/s 30% for AM.
3. Standard modulation is 400c/s 22.5KC dev. for FM.
4. Standard output is 250mW.

STEP	Signal gen coupling	Signal gen. frequency	Radio dial setting	Indicator - connect to -	Adjust	Remarks
FM IF aligament (switch @ position FM)						
1	Input signal directly to base of FM converter & ground	Sweep generator or center frequency @ 10.7MC	Point of non-interference (High end)	Oscilloscope Common to ground	T1 T2 T3	"S" curve of maximum symmetrical response @ equal heights.
2	..	..	..	..	T4 T5	Symmetrical "S" curve response centered @ 10.7MC
3	Repeat steps (1) and (2) as necessary to obtain "S" curve linearity					
AM-IF alignment (switch @ position AM)						
4	A standard radiating loop	Signal generator @ 455KC	Point of non-interference (High end)	Output meter Across the speaker voice coils	T6 T7 T8	Adjust for maximum and repeat as necessary
FM RF alignment (switch @ position FM)						
5	Input signal directly to FM antenna and ground	87 MC	87 MC (low end)	Output meter Across the speaker voice coils	L4	Adjust for maximum
6	..	109 MC	109 MC (high end)	..	C7F	Adjust for maximum
7	Repeat steps (5) and (6) as necessary					
8	Input signal directly to FM antenna and ground	90 MC	Equidistant between 88 and 92	Output meter Across the speaker voice coils	L2	Adjust for maximum
9	..	106 MC	106 MC	..	C7E	Adjust for maximum
10	Repeat steps (8) and (9) as necessary					
AM RF alignment (switch @ position AM)						
11	A standard radiating loop	Signal generator @ 525 KC	525 KC (low end)	Output meter Across the speaker voice coils	L6	Adjust for maximum
12	..	1650 KC	1650 KC (high end)	..	C7H	Adjust for maximum
13	Repeat steps (11) and (12) as necessary					
14	A standard radiating loop	600 KC	600 KC	Output meter Across the speaker voice coils	L5	Adjust for maximum
15	..	1400 KC	1400 KC	..	C7G	Adjust for maximum
16	Repeat steps (14) and (15) as necessary					

Figure 21 — Alignment instructions and parts location on the P.C. board.

Courtesy of Montgomery Ward

RESISTORS

Model 1911

ALL RESISTORS ARE 1/8W, ± 10%, CARBON UNLESS OTHERWISE NOTED

REF. NO.	PART NO.	DESCRIPTION
R1, 22, 23, 27, 40	CA1210	1K OHM
R2, 9	J23548	2K OHM
R3, 5	J23542	30K OHM
R4, 17, 30	CA1447	470K OHM
R6, 7, 24, 25, 26	CA1247	4.7K OHM
R8, 32	CA1368	68K OHM
R10, 11, 15, 28, 29, 33, 36, 43, 44	CA1310	10K OHM
R12	J23541	60K OHM
R13	CA1347	47K OHM
R14	J23543	20K OHM
R16, 18	CA1147	470 OHM
R19	CA1168	680 OHM
R31	J25497	10K OHM, VOLUME CONTROL
R34	CA1110	100 OHM
R35	CA1122	220 OHM
R37	CA12R7	2.7 OHM
R38, 45	CA1133	330 OHM
R42	J23545	6K OHM

CAPACITORS

REF. NO.	PART NO.	DESCRIPTION
C1, 2	J33881	40pf, 50V, ±10%, CERAMIC
C3, 10, 56	DD-200	20pf, 50V, ±10%, CERAMIC
C4, 20, 22, 24, 25, 26, 28, 46, 47, 49, 50 51, 53	CK-203	.02MF, 50V, +80-20%, CERAMIC
C5, 14	DD-150	15pf, 50V, ±10%, CERAMIC
C6, 16	DD-100	10pf, 50V, ±10%, CERAMIC
C7A-D	J35381	VARIABLE CAPACITOR WITH TRIMMERS
C7E-H	N.A.	TRIMMERS (PART OF C7A-D).
C8, 43, 45	CK-503	.05MF, 50V, +80-20%, CERAMIC
C9, 11	DD-050	5pf, 50V, ±10%, CERAMIC
C12, 33, 38, 39	DD-301	300pf, 50V, ±10%, CERAMIC
C13, 21, 35, 54, 58	J33886	.002MF, 25V, +80-20%, CERAMIC
C15	DD-300	30pf, 50V, ±10%, CERAMIC
C17, 18, 31, 32, 36, 52	DD-1032	.01MF, 25V, ±10%, CERAMIC
C19	DD-151	150pf, 50V, ±10%, CERAMIC
C23	J32838	10MF, 6V, +100-0%, ELECTROLYTIC
C27	J32839	200MF, 10V, +100-0%, ELECTROLYTIC
C34	DD-102	.001MF, 50V, ±10%, CERAMIC
C37	J32837	5MF, 6V, +100-0%, ELECTROLYTIC
C40, 41	J32835	.5MF, 6V, +100-0%, ELECTROLYTIC
C44	J32840	500MF, 15V, ELECTROLYTIC
C48	DD-101	100pf, 1KV, ±10%, CERAMIC
C57	CK-502	.005MF, 50V, +80-20%, CERAMIC
C59	J33933	3pf, 50V, ±10%, CERAMIC

COILS AND TRANSFORMERS

REF. NO.	PART NO.	DESCRIPTION
T1	J62642	TRANSFORMER, 1ST FM IF
T2	J62643	TRANSFORMER, 2ND FM IF
T3	J62644	TRANSFORMER, 3RD FM IF
T4	J62645	TRANSFORMER, RATIO DET. (PRIMARY)
T5	J62646	TRANSFORMER, RATIO DET. (SECONDARY)
T6	J62647	TRANSFORMER, 1ST AM IF
T7	J62648	TRANSFORMER, 2ND AM IF
T8	J62649	TRANSFORMER, 3RD AM IF
T9	J11362	TRANSFORMER, DRIVER
T10	J11363	TRANSFORMER, OUTPUT
T11	J11364	TRANSFORMER, POWER
L1	J61901	COIL, FM ANTENNA
L2	J61902	COIL, FM RF
L3	J61903	COIL, FM IF TRAP
L4	J61904	COIL, FM OSC.
L5	J61905	COIL, AM ANTENNA WITH FERRITE CORE
L6	J61906	COIL, AM OSC.

SEMICONDUCTORS

REF. NO.	PART NO.	DESCRIPTION
Q1	J24999	TRANSISTOR, FM RF AMP, CS9016E
Q2	J24999	TRANSISTOR, FM CONV., CS9016E
Q3	J241001	TRANSISTOR, AM CONV., T1340A3F
Q4	J241002	TRANSISTOR, 1ST FM/AM IF, T9011 H(C/D)
Q5	J241002	TRANSISTOR, 2ND FM/AM IF, T9011 H(C/D)
Q6	J241003	TRANSISTOR, 3RD FM IF, T9011 J(C/D)
Q7	J241004	TRANSISTOR, AUDIO PRE-AMP, T1340A3J
Q8	J241004	TRANSISTOR, AUDIO DRIVER, T1340A3J
Q9, 10	** J241005	TRANSISTOR, AUDIO OUTPUT, CS1166D (MATCHED (PAIR)
D1	1N60	DIODE, LIMITER
D2	J241007	DIODE, AFC, 1TW85A
D3	J241008	DIODE, LIMITER, GD3638
D4, 5	** J241000	DIODE, FM DETECTOR (MATCHED PAIR OF 1N60P)
D6	J241008	DIODE, AM DETECTOR, GD3638
D7	J241009	DIODE, VARISTOR SILICON
D8, 9	J241010	DIODE, RECTIFIER

** REPLACE WITH MATCHED PAIR ONLY

MISCELLANEOUS

REF. NO.	PART NO.	DESCRIPTION
	J70483	BACK COVER (INCL. LINE CORD RETAINER)
	J70482	CABINET FRONT (INCL. NAME PLATE)
	J56118	CLAMP, LINE CORD RETAINING
	J56117	CLAMP, SPEAKER MOUNTING
	E13175	CLOCK MOVEMENT (JD-11-54-1 TELECHRON)
	J50707	COVER, CLOCK (TRANSPARENT)
	J1329	HAND, ALARM
	J1326	HAND, HOUR
	J1327	HAND, MINUTE
	J1328	HAND, SECOND
	J64102	HOLDER, ANTENNA
	J50709	KNOB, BAND-SWITCH (WITH INSERT)
	J50705	KNOB, DIAL (WITH INSERT & SPRING CLIP)
	J50710	KNOB, TIME SET
	J50706	KNOB, VOLUME (WITH INSERT)
	J88113	LINE CORD, A.C.
	J497	NUT, HEX #6-32 (CLOCK MOUNTING)
	J56160	P.C.B. COMPLETE WITH COMPONENTS
	J50708	PLATE, CLOCK FACE
	J56116	RETAINER, LINE CORD (PLASTIC)
	J471016	SCREW, HEX HEAD (CLOCK MOUNTING)
	J43489	SHAFT, TUNING
SP1	J10136	SPEAKER, 3", 8 OHM
	J19326	SPRING, DIAL KNOB RETAINING
	J12349	SWITCH, 3 POSITION SELECTOR

Courtesy of Montgomery Ward

Figure 22 — Descriptive parts list for the radio of Figure 19.

amplifiers, the untuned amplifier and the tuned amplifier. In the untuned amplifier, response is desired over a large RF range, and the main function is amplification alone. In the tuned RF amplifier, very high amplification is desired over only a small range of frequencies, or at a single frequency. Thus, in addition to amplification, selectivity is also desired to separate the wanted from the unwanted signals. The use of the tuned RF amplifier is generally universal, while that of the untuned RF amplifier is relegated to a few special cases. Consequently, when RF amplifiers are mentioned, they are ordinarily assumed to be tuned unless otherwise specified. The tuning element usually consists of a parallel-resonant LC circuit. It may be inductively tuned by a movable slug, with the tank capacitance fixed in value or consisting of the stray and distributed capacitance existing in the circuit. Usually a fixed or slightly adjustable inductor determines the high-frequency limit, and a tuning capacitor is used to tune to the desired frequency or over a range of frequencies.

In receiving equipment, the RF amplifier serves to both amplify the signal and select the proper frequency; in addition, it serves to fix the signal-to-noise ratio. A poor RF amplifier will make the equipment able to respond only to large input signals, whereas a good RF amplifier will bring in the weak signals above the minimum noise level (determined by the noise generated in the receiver itself) and thus permit reception which would otherwise be impossible.

PENTODE RF VOLTAGE AMPLIFIER

The pentode RF voltage amplifier is universally used as the input stage in receiver RF amplifier stages to provide a high signal-to-noise ratio with maximum voltage amplification.

Circuit Analysis

The pentode RF voltage amplifier may be either tuned or untuned. When untuned, the stray wiring and distributed circuit capacitance plus the tube capacitance to ground limit the high-frequency response, and hence the highest RF frequency at which it can be used. On the other hand, the tuned RF amplifier uses a parallel-resonant circuit to supply a high impedance across which the load voltage is developed. In this instance, the stray, distributed, and tube capacitances merely add to the value of tuning capacitance so that higher frequencies and greater amplification (as compared with the untuned stage) at these higher frequencies is obtained. Therefore, the tuned RF amplifier is universally used, and the high gain of the pentode provides amplification not possible with a triode or untuned stage.

The use of the pentode, with its high transconductance and amplification factor, results in a high value of voltage amplification. In addition, the low grid-to-plate capacitance of the pentode reduces the tendency toward plate-to-grid feedback and self-oscillation. A lower effective tube input capacitance also increases the high-frequency limit of operation. By the use of coils with a high ratio of inductance to resistance (high-Q), the amplification provided by each stage of the tuned RF amplifier can be made greater than that of the amplification factor of the electron tube alone. Since the amplification of the RF amplifier depends greatly upon the transconductance of the tube, it is also possible to vary the grid bias for the stage in accordance with signal amplitude, and hence automatically control the gain.

Circuit Operation

The schematic in Figure 23 shows a typical pentode single-tuned RF voltage amplifier circuit. In the schematic, T_1 is an RF transformer which matches the antenna to the control grid of the pentode. Tuning the secondary of T_1 with C_1 permits a larger signal to be developed across the high-Q tuned circuit and therefore be applied to the grid than if no tuning at all were employed. Resistor R_1 and capacitor C_2 form the conventional cathode bias resistor and bypass capacitor. Resistor R_2 is the screen voltage-dropping resistor, and capacitor C_3 is the screen bypass capacitor, which stabilizes the screen voltage and prevents it from being affected by the signal. The suppressor element of V_1 is grounded directly. In some circuits the suppressor is connected externally to the cathode; in certain types of tubes it is connected internally to the cathode. RF transformer T_2 acts as the plate load and couples the output to the next stage. The output winding is tuned by C_4 to the desired RF output frequency. While C_4 could be placed across the primary of T_2 and the secondary left untuned, the conventional approach is to tune the secondary. With proper design the circuit is effective either way, and the secondary load is reflected into the plate circuit.

When a signal appears on the antenna, it is coupled through the primary of T_1 to the tuned secondary (grid input) circuit. With capacitor C_1 tuned to the frequency of the incoming signal, a relatively large RF voltage is developed

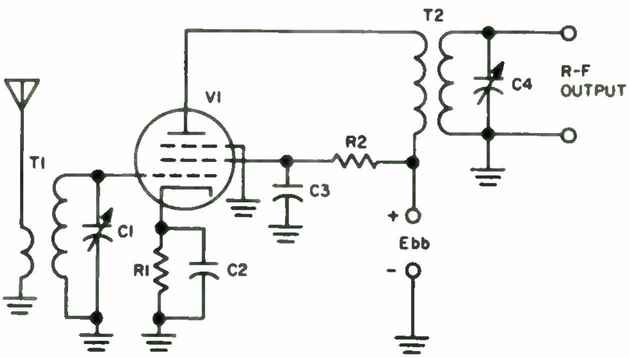


Figure 23 — Pentode RF voltage amplifier.

across the tuned circuit and applied to the grid of V_1. The RF signal, if unmodulated, consists of equal-amplitude positive and negative cycles occurring at the frequency to which the circuit is tuned. On the positive half-cycle the grid bias is decreased, causing a plate current increase. On the negative half-cycle the bias is increased, causing a plate current decrease. This changing plate current flowing through the primary of output transformer T_2 induces an output in the tuned secondary winding.

For ease of discussion, the signal is considered to be a sine wave with equal-amplitude positive and negative RF swings. The average plate current flow, therefore, will be constant, and cathode bias may be employed. It is important to note that the RF amplifier operating as the first stage in the receiver is usually a small-signal amplifier. That is, the input voltage is on the order of microvolts, except in strong-signal areas. Therefore, a small signal voltage change causes only a very small bias change, and it is necessary to employ high-transconductance electron tubes to produce effective amplification. The pentode tube is admirably suited for this purpose, since it has both a high amplification factor and a high transconductance. By using a large value of inductance and a small tuning capacitance for the frequency involved the tuning circuit exhibits a high-Q. Thus, its effective impedance is much larger than that presented by a tuning tank of low-Q. Hence, a large input voltage is developed between grid and ground across the tuned circuit. With a step-up turns ratio from transformer primary to secondary, if closely coupled, a still larger input voltage is produced. The step-up of voltage in the transformer and the high-Q tuned grid tank increase the small input voltage before it is applied to the tube for further amplification. Normally, Class A bias is used to produce linear swings and to minimize distortion. With very small input signals however, operation occurs over the curved portion of the plate-current grid-voltage characteristic. For example, typical bias values range from 0.5 to 1 or 2 volts maximum. Thus, the tube is clearly operating very close to zero bias, and the E_g-I_p curve in this region is never straight. This results in uneven positive and negative swings, and this produces distortion. For RF amplifiers where the input signal is large, as in cascaded or IF stages, a larger bias and a more linear portion of the curve are used.

When the input signal is modulated, each RF cycle may be of different amplitude. Considering each cycle to be amplified linearly, the modulation is likewise amplified proportionately producing an overall modulation envelope which is almost identical with that of the original modulation. A slight difference (usually a reduction in the modulation factor) exists; this is produced by distortion.

When small values of bias are used in the input stage and large signals are applied, distortion occurs because the signal is partially clipped off in the plate circuit. In addition, grid current flow creates a low-resistance (shunt) path between the grid and the cathode, which effectively lowers the grid tank Q. As a result, the input signal and over-all amplification of the stage are reduced. Therefore, it is common practice to employ a variable cathode resistor for manual gain control, or to provide some means of automatic bias (gain) control.

Circuit Failures

No Output. Loss of plate, screen, filament voltage, or a defective tube can cause no output. The voltages can be checked with a voltmeter, and an open filament can sometimes be observed by noting that the tube is not illuminated and feels cold to the touch. If the plate, screen, and filament voltages are normal, substitute a tube known to be good. If there is still no output, check the input transformer by applying a modulated voltage from a signal generator to the input terminal and observe whether there is an input voltage on the grid (use a VTVM or an oscilloscope and RF probe as the indicator). An open screen resistor (R_2) will be indicated by the lack of screen voltage. Similarly a shorted screen capacitor (C_3) will drop the screen voltage to zero and cause R_2 to heat abnormally. The short circuit condition may be observed visually by smoke from or discoloration of the resistor. An open or shorted cathode bypass capacitor (C_2) will not necessarily produce a no-output indication; however, an open bias resistor (R_1) usually will. In fact, on very small signals either trouble may not be obvious or may show only as a slight increase in distortion. If tuning capacitor C_1 or C_4 is defective, depending on whether it is short-circuited or open-circuited, there may be no output or a considerably reduced output, respectively. Since each capacitor is shunted by a coil, it will be necessary to disconnect one end to check for capacitance or a short. Where an open coil is suspected, it can be checked for continuity with an ohmmeter.

Reduced Output. When there is an open circuit in either transformer T_1 or T_2, if sufficient capacitive coupling exists between the windings (especially at the higher frequencies), the output will be reduced, rather than non-existent. On the other hand, at the lower RF frequencies the output may be reduced practically to zero. A check with an ohmmeter will determine whether there is continuity in the coils. A change in the value of screen resistor R_2 to a higher value will lower the screen voltage and reduce the output. Likewise, a reduced plate voltage caused by a high-resistance connection or winding will lower the output. Low output can also be caused by a defective tube, that is, a tube with low filament emission or an internal short. If the tube has an internal short, it will draw a heavy cathode current, thus producing a much greater than normal bias and reducing the output accordingly. A defective antenna or transmission line can cause a weak input signal and an apparent lack of output. In this instance the circuit will check normal in every respect, and changing tubes will make no difference. Substitute another signal from a different antenna, if possible, or apply an input from a signal generator with an attenuator. If a large value of attenuation is required to reduce the output signal to a low value or zero, the stage is operative and the trouble is external.

Distorted Output. Improper plate or screen voltage will cause a certain amount of distortion. While improper bias will also cause distortion, it will depend to a great extent on the tube used, the input signal amplitude, and the value of bias. Intermodulation between the side (modulation) frequencies of a modulated input signal will create a slight amount of distortion due to the curvature of the tube E_g-I_p characteristic.

Another prevalent form of distortion, which occurs when two strong modulated signals are nearby, is cross modulation. This actually causes modulation of the carrier of the desired signal by that of the undesired signal. Cross modulation is recognized as a form of "monkey chatter" heard in the background of broadcast stations, particularly where strong adjacent-channel signals are present. It is also recognized in voice communication by the clear, undistorted, but weak reception of the undesired station superimposed on the desired station. In the pause between syllables and words, the cross-modulating station can be heard clearly. The interfering signal may not be within the tuning range of the receiver used, although it usually is.

TUNED INTERSTAGE IF AMPLIFIER

The tuned interstage IF amplifier is universally used in superheterodyne receivers to supply high RF amplification and the desired selectivity.

Circuit Analysis

The tuned IF amplifier may consist of a single stage, or as many as six or more cascaded similar stages to obtain the desired amplificatron and selectivity. Generally speaking, one to two stages are used for radio broadcast reception, while two to four stages are used in selective communications receivers, television, and microwave reception. The intermediate frequency chosen usually determines the number of stages. The lower frequencies, such as 50, 175, and 250 hertz, produce more amplification and better selectivity than 450 kHz; at 21 or 44 MHz (as in TV applications) or at 30 or 60 MHz (as in radar applications), less gain per stage is obtained, and the response curves are broader, so that more stages are needed. In addition, the bandpass requirement introduces another factor, since a simple 5 to 10 kHz band pass can be obtained with a few tuned circuits, whereas a broad band pass of 4 to 5 megahertz with sharp cutoff, which is required in TV and radar receivers, requires a number of stagger-tuned stages. The band pass is measured at the half-power points of the receiver response curve, that is, at 70.7 percent amplitude on each side of the IF center frequency. For example, if we have an IF amplifier output of 100 volts at the center intermediate frequency, and it drops to 70.7 volts when the amplifier is detuned 5 kHz each side of resonance, the amplifier bandpass is 10 kHz, as illustrated in Figure 24. The manner in which the shape of the response curve (selectivity) is changed by stagger-tuning (each tank tuned to separate frequencies) is shown in Figure 25.

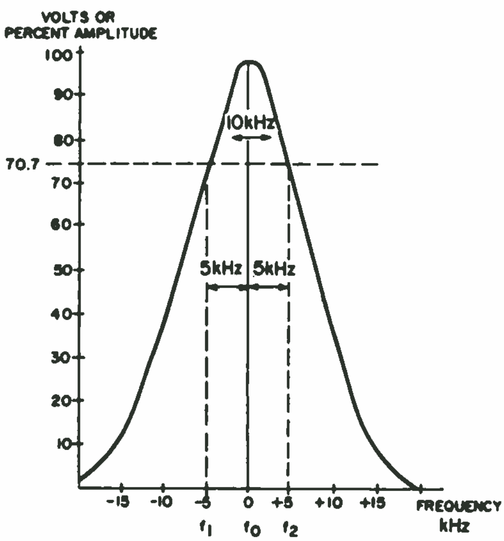


Figure 24 — Typical IF response curve.

Circuit Operation.

The schematic of a typical two-stage IF amplifier is shown in Figure 26. The dashed line divides the circuit into two separate stages. Note that in the inter-stage amplifier T_2 is common to both stages. Thus, T_2 matches and couples the output of V_1 to the input of V_2 for efficient signal transfer. Since the stages are operating Class A, no grid current flows and power transfer is not real concern; however, maximum voltage transfer is important. Transformer T_1 couples the grid of V_1 to the plate of the preceding mixer or converter stage, while T_3 usually supplies the IF signal to the detector. Any change in impedance between the primary and secondary circuits can be accommodated by changing the turns ratio in the transformers. Normally, a 1-to-1 ratio is used, and any difference in impedance between the plates and grids of the cascaded stages is usually of academic interest only, since the primary and secondary of each IF transformer are high-Q, parallel-tuned circuits and they both present a high impedance to the circuits in which they are connected. The high impedance produced by the plate circuit tank causes a large voltage drop across the primary, and by transformer action a large voltage is induced in the secondary. At the same time, the secondary presents a high impedance to the following tube grid circuit so that maximum voltage is developed on the grid, and grid losses are kept to a minimum. Thus, it is seen that double-tuning in itself always provides sufficient matching for efficient voltage transfer, provided that the coupling between the primary and secondary is optimum. It is also evident that the largest voltage is developed across either tank at the frequency to which it is tuned, since the tank presents the highest impedance at resonance. While there are some shunting effects due to grid-to-ground and plate-to-ground capacitance, plus internal leakage in the transformers, this is taken care of in design calculations.

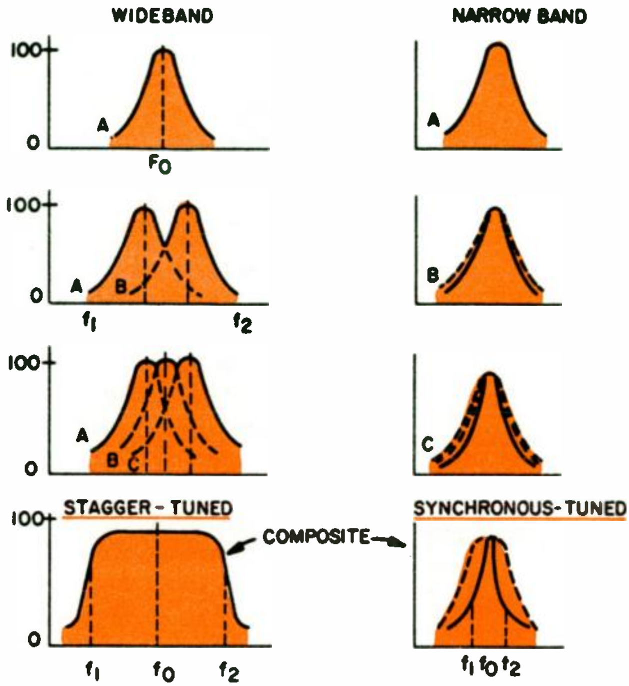


Figure 25 — Stagger-tuning and Synchronous-Tuning response curves.

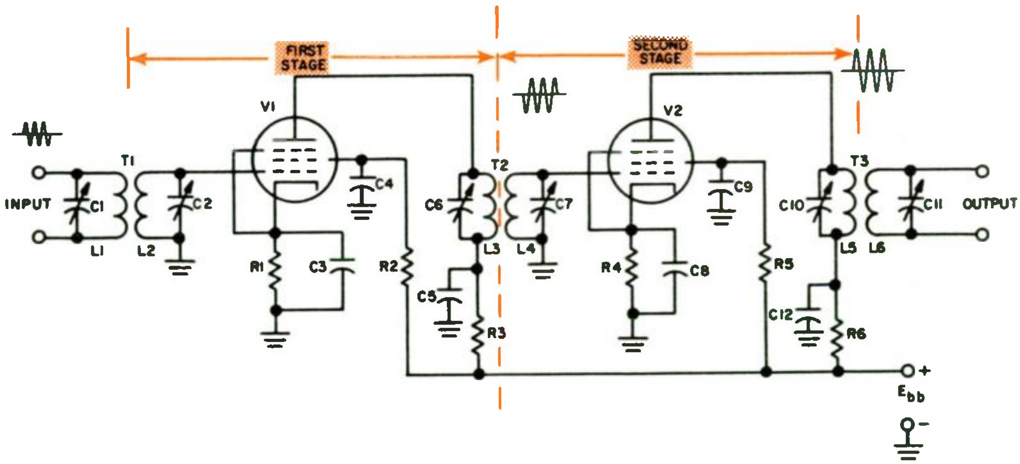


Figure 26 — Two-stage IF amplifier schematic.

Further examination of the schematic also reveals that the stages are simple pentode RF voltage amplifiers. Self-bias for the stages is provided by cathode resistors R_1 and R_4, bypassed for RF by C_3 and C_8, respectively. Screen voltage is obtained through voltage-dropping resistors R_2 and R_5, while plate voltage is supplied through R_3 and R_6. The screen resistors are bypassed to ground for RF by C_4 and C_9, and the plate resistors are bypassed by C_5 and C_{12}, which also form a decoupling network.

With no signal applied, both V_1 and V_2 are resting in their quiescent condition. Plate and screen currents flow steadily through cathode resistors R_1 and R_4, and develop a positive bias at the cathode, which is the same as a negative bias on the grid. Screen resistors R_2 and R_5 drop the supply voltage to the value of screen voltage necessary to provide sufficient plate current swing. Likewise, plate resistors R_3 and R_6 drop the plate voltage to the proper operating value. Since each of these resistors is bypassed to ground, any RF variations of plate current (when a signal is applied) are eliminated so that steady plate and screen currents flow throughout the cycle (with or without signal), and cathode bias can be used.

When an input signal is applied to T_1 primary, a high impedance is offered to the signal at the resonant frequency to which C_1 tunes L_1. With secondary L_2 tuned to the same frequency by C_2, a high impedance appears between the grid of V_1 and ground. When the input signal causes an increase in current through L_1, a corresponding increase in voltage is induced in L_2 by transformer action, and the increased voltage appears on the V_1 grid. As the grid of V_1 is made more positive on the first half-cycle of operation, a larger plate current flows through the primary of T_2. With tuned circuit L_3, C_6 tuned to the same frequency as the signal, a high impedance is presented to plate current flow, the plate voltage is reduced toward zero, and a large voltage drop occurs across L_3. This voltage drop induces a negative-going signal in the secondary of T_2 by transformer action. When tuned circuit L_4, C_7 is resonant at the signal voltage, a large negative voltage also appears between the grid of V_2 and ground.

Since V_1 and V_2 are biased at the center of their grid-voltage plate-current transfer characteristic curve, large positive or negative swings of voltage can be accommodated without causing any distortion. Thus, the amplified input signal from V_1, which appears on the V_2 grid, is reproduced in amplified form in the plate circuit of V_2. The operation of tube V_2 is similar to that of tube V_1 except that the signal is oppositely phased. The negative grid signal from the first stage causes the plate current of V_2 to decrease, and the plate voltage of the second stage rises toward the supply voltage (goes positive). At the same time, the primary of T_3 offers a high impedance to current flow. The reduction in plate current flow through tuned primary circuit L_5, C_{10} produces a large positive-going voltage and induces a voltage in the secondary of T_3. When secondary circuit L_6, C_{11} is tuned to the same frequency as the signal, it produces a high impedance, and a large output voltage is developed across it.

When the input signal at the first stage goes negative, on the remaining half-cycle of operation, the action of V_1 and V_2 is exactly the opposite of the action described above. As the plate current of V_1 is reduced by the input signal, a positive-going voltage is produced across the T_2 primary, and this voltage is applied to the V_2 grid. In turn, the V_2 plate current is increased, producing a negative output voltage across T_3. Since Class A bias is employed, a sine-wave input produces a larger and amplified sine-wave output. As long as the grid signal does not drive the grid of V_1 or V_2 to the point where it draws current, and the plate voltage does not fall below zero and cause plate current cutoff, no distortion occurs. The output waveform of the amplifier is the same as the input waveform, but is much larger in amplitude.

Since the grounded-cathode circuit inverts the input signal, the output of an even number of stages is of the same polarity as the input. Therefore, any feedback from output to input will produce regenerative oscillations. However, the very small plate-to-grid capacitance of the pentode reduces any such feedback to a negligible value, and neutralization is not required. The use of plate decoupling capacitors C_5 and C_{12} prevents feedback through common impedance coupling in the power supply. Thus, a stable, high-gain, and highly selective amplifier is produced by connecting the two double-tuned stages in cascade. From the discussion above it is clear that the operation is identical to that of the single-stage pentode RF voltage amplifier in all respects, except for the effects of the double-tuned circuits in providing higher gain and selectivity than is possible in a single stage.

Circuit Failures

The discussions of failure analysis for the Pentode RF Amplifier previously discussed are generally applicable to the interstage IF amplifier.

No Output. A defective IF transformer, an open bias resistor (R_1 or R_4), loss of screen or plate voltage, or a defective tube can cause loss of output. Check the plate, screen, cathode, and supply voltages with a voltmeter. Lack of plate voltage can result from a defective power supply, an open plate resistor (R_3 or R_6), a shorted plate bypass capacitor (C_5 or C_{12}), or a defective transformer (T_2 or T_3). If the voltage is zero at the junction of C_5 and R_3, or C_{12} and R_6, the cause is either an open plate resistor or a shorted plate bypass capacitor. A resistance check, using an ohmmeter (with the power off), will determine which is at fault. With plate voltage at C_5 and C_{12}, but not at the plate of one of the tubes, an IF transformer primary is defective, or the primary and secondary are shorted; in either case, replacement of the transformer is necessary. An open plate circuit in a screen-grid tube can usually be determined quickly by noting that the screen is red, because of an overloaded screen, which tries to take the place of the plate. In this case screen resistor R_2 or R_5 will be excessively hot; it may smoke, and will eventually burn out. Where voltage exists on the plate of one of the tubes, but not on the screen, bypass capacitor C_4 or C_9 may be shorted, or screen resistor R_2 or R_5 may be open. A resistance check from each screen bypass capacitor to ground (with the power off) will indicate zero if the capacitor is shorted, and a resistance check of the screen resistor will reveal the condition of the resistor. Since the screen voltage determines the plate current of a pentode, to a great extent, it is not always necessary for the screen voltage to be zero in order to cause loss of output. Since cathode resistor R_1 or R_4 is in series with the tube, if the resistor is open the circuit to ground will be incomplete and the tube will not operate. Likewise, if it increases in value sufficiently the tube can be biased off to almost zero plate current, and cause such a small output as to be considered practically no output at all.

If the tube is defective and no emission occurs, the cathode voltage will be zero. With C_3 or C_8 shorted, there will also be no cathode voltage, but the output will be distorted because of heavy plate and screen current; in this case the plates will get red and the tube may be damaged. Where the indications are otherwise normal, the tube should be suspected; replace the tube with one known to be in good condition. In simple receivers it is sometimes easier to first replace the tube to determine whether it is at fault. However, such a procedure can cause additional trouble in multi-tube IF amplifiers, particularly in those having a high intermediate frequency. This occurs because the IF tuning is affected by the tube capacitance, so that replacing the tube in a different socket (or with another tube) throws the set out of alignment, which can cause a large loss of gain; this condition can also be mistaken for no output. With normal plate, screen, and cathode voltages and no output, even with good tubes, it is certain that the secondary of output transformer T_3 is open or totally detuned. Usually such a condition will produce a slight output because of stray capacitive coupling between windings, but it could be mistaken for a no-output condition.

Low Output. Low output can be caused by a defective tube, low screen or plate voltage, or too high a bias. First check the tube element voltages with a voltmeter. A low voltage on the plate or screen indicates excessive current drain in that circuit (producing a large voltage drop through the series resistor), an off-value plate or screen resistor, or a leaky bypass capacitor. The resistors can be checked by means of an ohmmeter (with the power off), and the capacitors with an in-circuit capacitance checker. Larger than normal plate and screen current will also cause a corresponding increase in bias voltage, since cathode bias is produced by the sum of all currents flowing in the tube. A leaky screen or plate bypass capacitor will cause reduced plate or screen voltage, reduce the cathode current flow, and hence decrease the bias. Low tube emission is usually indicated by higher than normal plate and screen voltages, with reduced cathode bias. As the condition becomes worse, the output will continue to decrease progressively until the tube emission is insufficient to produce an output. When all voltages appear normal and the output is low, either a tube may be defective or the alignment may be at fault. Replace the tubes one by one, noting whether there is any slight increase in output. If very little or no increase in output can be obtained by tube replacement, recheck the alignment. If during alignment one of the tuning capacitors (or tuned inductors where inductive tuning is used) does not seem to have any effect, the transformer being tuned is defective; replace it with a good one.

When the set suddenly blocks on receiving a loud signal and becomes almost inoperative, the IF amplifier is probably oscillating and developing sufficient bias to cause the reduction in the output signal. Sometimes blocking will not occur, but a strong squeal or howl will occur instead. In either case a plate or screen bypass capacitor may be open. In some instances drying out of the last electrolytic capacitor in the power supply will cause loss of filtering ability, produce hum, and through common impedance coupling, cause a similar effect.

Distortion. Distorted output can be caused by an improper bias,
7 plate, or screen voltage. When the plate voltage drops below zero, plate current cutoff occurs, and this stoppage of plate current flow causes distortion. If the plate voltage is driven into plate current saturation no further change in plate current can occur, and a similar type of distortion will exist. Excessive bias will cut off the lower portion of the drive signal, reduce the plate current swing, and cause distortion. Likewise, excessive input (drive) voltage will cause the bias to be driven to zero (or above) and cause grid current flow; this will cause plate current saturation on one signal peak, and cutoff on the opposite signal peak. Both distortion and reduced signal output will occur. Usually, a voltage check for this condition will indicate improper or fluctuating voltages on the tube electrodes. However, it is easier to use a scope with an RF probe and observe the signal. A simulated (signal generator) input with modulation applied also provides a simple signal for observation on a scope. Localization of the trouble to a specific portion of the circuit will usually involve only those components in the circuit where the distortion is observed, so that further simple voltage or resistance checks of the parts involved will locate the defective part.

FOSTER-SEELEY DISCRIMINATOR

The Foster-Seeley discriminator is used in semiconductor receivers and particularly where automatic frequency control or high fidelity is required.

Circuit Analysis

The Foster-Seeley discriminator (also known as the phase-shift discriminator) uses a double-tuned RF transformer to convert the instantaneous frequency variations of the FM signal into instantaneous amplitude variations. The amplitude variations are then rectified and filtered to provide a DC output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output voltage is zero when the input frequency is equal to the *center frequency* (unmodulated carrier frequency). When the input frequency rises above the center frequency the output increases in one direction (for example, becomes more positive), and when the input frequency drops below the center frequency, the output increases in the other direction (for example, becomes more negative).

Since the output of the Foster-Seeley discriminator is dependent not only on the input frequency, but also to a certain extent upon the input amplitude, it is necessary to use one or two limiter stages before detection. When properly limited, and the input frequency is varied from a lower frequency through the resonant point of the discriminator, and is then raised higher in frequency, the typical discriminator response curve shown in Figure 27 is obtained.

The usable portion of the typical "S" shaped response curve is from point A to point B in Figure 27. Between these points, the curve is linear and the instantaneous output voltage is directly proportional to the instantaneous frequency deviation.

Circuit Operation

The circuit schematic in Figure 28 illustrates a typical Foster-Seeley semiconductor discriminator.

The collector portion of the preceding IF (limiter) amplifier Q1 is shown on the schematic with conventional emitter resistor R_E and bypass capacitor C_E. The collector circuit tank consisting of C_1 and L_1 is the primary tank of IF input transformer T_1, while L_2 and C_2 form the secondary tank circuit; both tanks are tuned to the center frequency. Choke L_3 forms the DC return for diode rectifiers CR_1 and CR_2. While CR_1 and CR_2 are shown by-passed by equalizing resistors R_1 and R_2, they are not always used (they are usually used when the diode back resistances are different). Resistors R_3 and R_4 are the load resistors bypassed by C_3 and

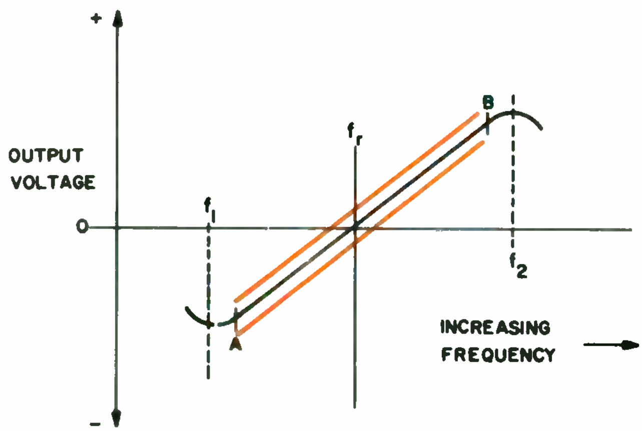


Figure 27 — Discriminator Response Curve.

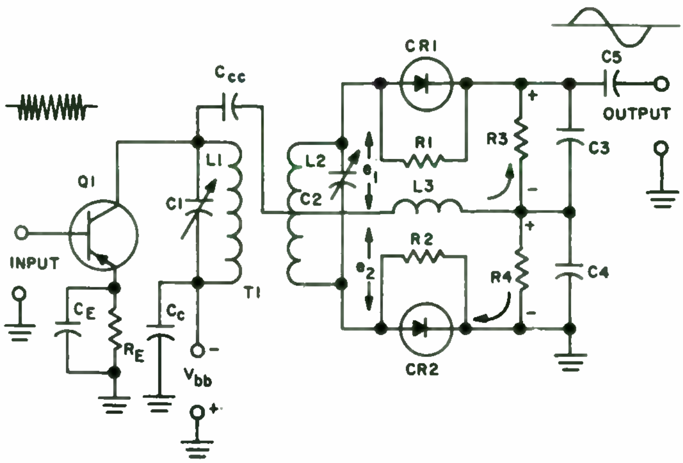


Figure 28 — Foster-Seeley discriminator circuit including the limiter stage.

C_4, respectively, for RF. Capacitor C_5 is the output coupling capacitor.

The center tap on coil L_2 is capacitively coupled through coupling capacitor C_{cc} to the primary, and the full voltage exists across choke L_3. At resonance (the center frequency) equal voltages e_1 and e_2 are produced across both halves of L_2, thus equal voltages are applied to the anodes of CR_1 and CR_2. Assuming these voltages are positive, conduction occurs and current flows through diode load resistors R_3 and R_4. This produces equal and opposing voltages across filter capacitors C_3 and C_4. Since the output is taken from C_5 to ground, the equal and oppositely polarized signals cancel and produce no output at the center frequency. However, as the frequency is raised above the center frequency, the phase relationships in the halves of the tank circuit cause a voltage change so that e_1 becomes larger than e_2. Since it is larger than the voltage across R_4, the voltage of R_3 dominates, creating a positive output voltage.

Conversely, when the input signal frequency drops below the center frequency, voltage e_2 is larger than e_1 and the voltage across R_4 dominates, creating a negative output. As long as the input frequency variations remain within the limits of peak separation marked A and B on the discriminator curve, a linear frequency versus amplitude relationship is maintained. That is, the higher the frequency the larger the positive output voltage becomes, and the lower the frequency the larger the negative output becomes. (If desired, the discriminator transformer can be wound and connected to produce opposite polarities from that described above.) In any event, the output voltage is always developed across both R_3 and R_4, and it is always the algebraic sum of these. Capacitors C_3 and C_4 are used to store the instantaneous voltages and develop an average output which varies at audio frequencies.

This output, in turn, is coupled to the audio amplifying stages by coupling capacitor C_5 (any coupling method may be used). Thus, while the input consists of a constantly varying FM signal of steady amplitude, the output is an audio frequency which varies linearly both in frequency and amplitude in accordance with the frequency swing of the input signal.

Circuit Failures

No output. A defect in the primary or secondary windings of T_1, in the RFC, or in tank tuning capacitors C_1 or C_2 as well as defective diodes can cause a no-output condition. It is also possible for coupling capacitors C_{cc} or C_5 to be open, or for bypass capacitor C_c, as well as C_3 or C_4,to be shorted and bypass the signal to ground. Use an ohmmeter to check the primary and secondary of T_1 and the RFC for continuity, and for shorts to ground. If these checks fail to locate the trouble, use an in-circuit capacitance checker to measure the values of C_1, C_2, C_{cc}, C_3, and C_4. Note also that both diodes must fail to cause no-output, since if only one fails there still will be an output. When possible, use an oscilloscope to observe the waveform at the input and follow the signal through the circuit, noting where the signal disappears to locate the source of the trouble.

Low or Distorted Output. A defect in nearly any component in the discriminator circuit may cause the output to be low or distorted. Use an RF Sweep Generator and an oscilloscope to isolate the trouble. Connect the sweep generator to the input and check the output with the scope on Q1 and at the anode of diode CR_1 or CR_2. Lack of signal at Q1 indicates a defective transistor or part in the transistor stage of Q1. A signal on Q1 but not at the diode anodes indicates C_{cc} is either open or shorted to ground. If the output signal does not change in amplitude as the input frequency varies, the trouble is most likely in the discriminator circuit. To determine if the discriminator is at fault, ground the base of limiter stage Q1 and connect the RF sweep input to the discriminator input, with the oscilloscope connected to the discriminator output. Adjust the sweep generator to produce an output which varies both below and above the discriminator center frequency and observe if the pattern on the oscilloscope is that of the typical "S" curve shown in the first illustration of this discussion. Defects in the circuit will cause either the entire curve or a portion of it to be distorted, or flattened.

If the entire response curve is distorted the trouble may be caused by either improper alignment or by a defect in transformer T_1. First check to be certain that both the primary and secondary tank circuits are tuned to the proper center frequency. If the discriminator is aligned properly, the trouble is most likely in the transformer.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode CR_1, capacitor C_3, resistor R_3 or transformer T_1. Use an in-circuit capacitance checker to check capacitor C_3 for value and leakage, and use an ohmmeter to check resistor R_3 for a change of value.

Conversely, if only the bottom portion of the discriminator response curve is distorted, the trouble may be caused by diode CR_2, capacitor C_4, resistor R_4, or transformer T_1. If the trouble persists use an in-circuit capacitance checker to check C_4 for value and leakage, and use an ohmmeter to check resistor R_4 for a change of value. If these checks fail to restore the output to normal, transformer T_1 is most likely defective.

RATIO DETECTOR

The semiconductor ratio detector is used in semiconductor type FM receivers to demodulate the received RF, FM signal, and in AFC control circuits to transform frequency changes into DC control voltages.

Circuit Analysis

The semiconductor ratio detector uses a double tuned transformer (discriminator) connected so that the instantaneous frequency variations of the FM input signal are converted into instantaneous amplitude variations. These amplitude variations are rectified by the diodes to provide a DC output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output is zero when the input is equal to the *center frequency* (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in one direction (for example, becomes more negative). The specific polarity of the output voltages obtained for an increase or decrease in input frequency is determined by the design of the circuits and may vary from circuit to circuit.

Circuit Operation

The schematic diagram in Figure 29 illustrates a typical semiconductor ratio detector.

The input tank circuit comprised of C_1 and primary winding L_1 of T_1 is tuned to the center frequency of the received FM signal. Secondary winding L_2 and capacitor C_2 also form a tank circuit tuned to the center frequency. Tertiary winding L_3 provides additional inductive coupling which reduces the loading effect of the secondary on the primary circuit of the detector. Solid state diodes CR_1 and CR_2 rectify the signal from the secondary tank. Capacitor C_5, in conjunction with resistors R_1 and R_2,determines the operating level of the detector, while capacitors C_3 and C_4 determine the amplitude and polarity of the output. Resistor R_3 modifies the peak diode current and furnishes a DC return path to ground. The output of the detector is taken from the common connection between C_3 and C_4 to ground, which is also the common connection of R_1 and R_2. Resistor R_L is the load resistor. A low-pass filter is formed by R_5 together with C_6 and C_7 to provide high frequency de-emphasis. Capacitor C_8 is the output coupling capacitor.

When input voltage e_p is applied to the primary, it also appears across L_3 since it is effectively connected in parallel with the primary tank circuit by inductive coupling. When voltage e_p is applied to the

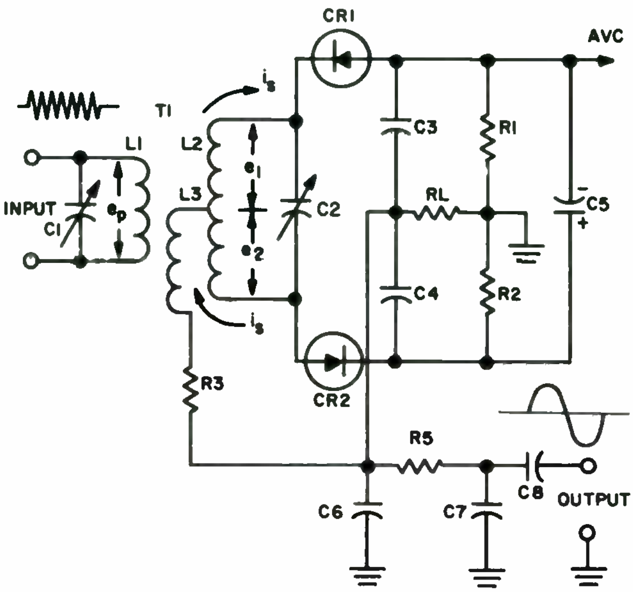


Figure 29 — Ratio detector circuit.

primary winding of transformer T_1, a voltage is also induced in the secondary winding and causes current to flow around the secondary tank circuit. When the input frequency is at the center frequency, the tank is at resonance, is resistive, and acts like a resistor. Therefore, tank current is in phase with primary voltage e_p. The current flowing in the tank circuit causes equal voltage drops to be produced across each half of the balanced secondary winding of T_1, which are of equal magnitude and of opposite polarity with respect to the center tap of the winding. Since the winding is predominately inductive, the voltage drop across it is 90 degrees out of phase with the current through it. At the same time, because of the center tap arrangement, the voltages to ground at each end of the secondary are 180 degrees out of phase and are shown as e_1 and e_2 on the schematic.

The voltage applied to the cathode of CR_1 consists of the vector sum of e_1 and e_p. Likewise, the voltage applied to the anode of CR_2 consists of the vector sum of voltages e_2 and e_p. Since at resonance there is no phase shift, both voltages are equal. Consider now the manner in which the diodes operate with the discriminator voltage discussed above. When a positive input signal is applied to L_1, a voltage of opposite polarity is induced into secondary L_2. As shown in the simplified schematic Figure 30, cathode of CR_1 is negative with respect to its anode and is forward biased, while the anode of CR_2 is positive with respect to its cathode and is likewise forward biased. Since both voltages are of equal magnitude at resonance, both diodes conduct equally. Hence current flow through CR_1 is in one direction, while the current flow through CR_2 is in the opposite direction. This direction of current flow causes a negative polarity at point A and a positive polarity at point B. Through R_L a positive charge is applied to C_3. In a similar manner current flow through CR_2 produces a negative polarity at point B and a positive polarity at C. Hence, capacitor C_4 is charged negatively. Since the polarities are additive, capacitor C_5 across the output charges to the series value of twice this voltage.

In the example shown in Figure 30 it is assumed that equal but opposite voltages of 5 volts exist across C_3 and C_4. Therefore, the total charge across C_5 is 10 volts. Since the voltages across C_3 and C_4 are equal in amplitude (5 volts) and of opposite polarity, the output across load resistor R_L is the algebraic sum or zero.

When the input signal reverses polarity, the secondary voltage across L_2 also reverses polarity. The cathode of CR_1 is now positive with respect to its anode, and the anode of CR_2 is negative with respect to its cathode. Under these reverse-bias conditions neither diode conducts, and there is also no output. Meanwhile C_5 retains most of its charge because of the long time constant offered by R_1 and R_2 and discharges very slightly.

The output of the ratio detector adjusts itself automatically to the average amplitude of the input signal. Through the action of resistors R_1 and R_2 together with capacitor C_5, audio output variations which would occur due to RF amplitude variations in the input (such as noise) are eliminated. Since C_5 charges to the sum of the voltages developed across R_1 and R_2, any amplitude variation at the input of the detector tends to change the voltages across R_1 and R_2, but because of the long time constant of C_5 across these resistors, these voltages are held to a minimum. Before C_5 can charge or discharge to the higher or lower amplitude variation, the impulse disappears, and the difference in charge across C_5 is so slight that it is not discernible in the output. Because the voltage across C_5 remains relatively stable and changes only with the amplitude of the center frequency, and since it is negative with respect to ground, it is usually used for automatic volume control (AVC) applications.

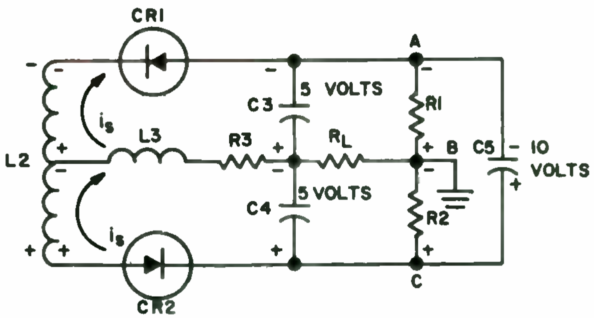


Figure 30 — Simplified schematic diagram of a ratio detector.

Capacitors C_6 and C_7 together with resistor R_5 form a low pass filter which attenuates the high audio frequencies and passes the lower frequencies. This is known as a de-emphasis network, which compensates for the pre-emphasis with which the high frequencies are transmitted, and returns the audio frequency balance to normal. When pre-emphasis is not employed these parts are not needed.

Circuit Failures

No Output. A defective discriminator transformer T_1, shorted tuning capacitor C_1 or C_2, an open output resistor R_5, an open coupling capacitor C_8, or shorted filter capacitors (C_6 or C_7) will produce a no-output condition. Check the continuity of the windings of T_1 with an ohmmeter. Check capacitors C_1, C_2, C_6 and C_7 for shorts and capacitor C_8 for an open with an ohmmeter, and measure the resistance of R_5. If any of these checks fail to restore the output, check all capacitors for value with an in-circuit capacitance checker. Note that while one defective diode will produce a partial loss of output, both diodes must fail to cause a complete loss of output.

Low or Distorted Output. A defect in nearly any component of the detector will cause the output to be either low or distorted. Therefore, it is good practice to use an RF sweep generator and an oscilloscope to locate the trouble. Ground the grid of the last IF stage and connect the RF sweep generator to the detector input, and connect the oscilloscope to the detector output. With the sweep generator set to produce an output which varies above and below the center frequency, the pattern observed on the oscilloscope should be similar to the discriminator response curve illustrated previously. Defects in the response curve will cause either the entire curve or a portion of it to be distorted or flattened.

If the entire curve is distorted, the trouble may be caused by improper alignment or by a defect in transformer T_1. First check to be certain that both primary and secondary circuits are tuned properly to the center frequency. If the detector is properly aligned, check capacitors C_1 and C_2 with an in-circuit capacitance checker. Check R_1 and R_2 for their proper value with an ohmmeter, and capacitor C_5 for value and leakage with an in-circuit capacitance checker. If the trouble is still not located, it is most likely caused by a defect in transformer T_1.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode CR_1, capacitor C_3, or transformer T_1.

Conversely, if only the lower portion of the response curve is distorted, the trouble may be caused by a defect in diode CR_2, capacitor C_4, or transformer T_1.

GATED-BEAM DETECTOR

The gated-beam detector is used in FM receivers to demodulate the IF signal. To convert instantaneous frequency variations into instantaneous DC voltage variations, it employs three tuned tank circuits and a special beam-power tube. This circuit provides both limiting and discriminator action in a single tube.

Circuit Analysis

The gated-beam detector uses a gated-beam tube to limit, detect, and amplify the FM signal. The output is a DC voltage which varies in amplitude and polarity as the input varies in frequency. This output voltage is zero when the input frequency is equal to the center frequency (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in a positive direction, and when the input frequency drops below the center frequency, the output increases in a negative direction.

Circuit Operation

Before attempting to explain the circuit operation of the gated beam detector, a brief review of the tube used in the circuit is essential. The illustration in Figure 31 shows a cross-sectional diagram of a typical gated-beam tube.

There are two major differences between the gated-beam tube and an ordinary pentode. First, the flow of electrons from the cathode to the plate is maintained in a concentrated beam formed by the elements of the tube, and secondly, cathode current flows at all times, even during the period of time during which no plate current flows.

The shield around the cathode, known as focusing plate No. 1, is internally connected to the cathode, and as the electrons leave the cathode they pass through a narrow opening in the shield, which is at cathode potential and repels electrons. Thus a narrow stream of electrons is formed.

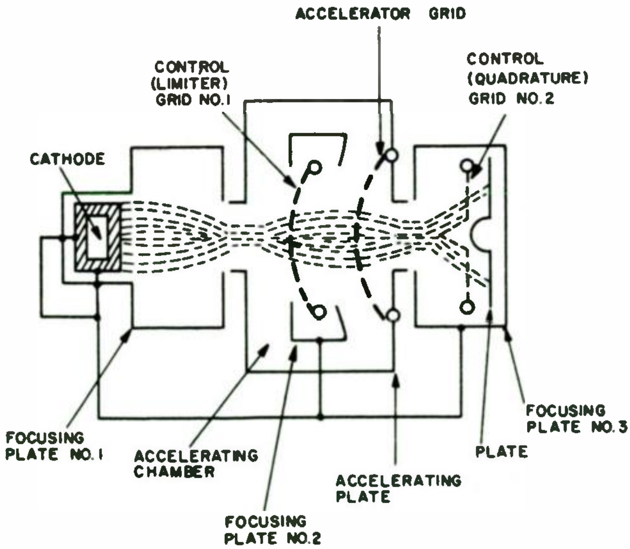


Figure 31 — Cross section of the gated-beam tube.

As the electron stream enters the accelerating chamber, which is at a high positive potential, it tends to spread, due to the attraction of the positive field. Ordinarily, the stream would continue to spread, but as it approaches the No. 1 control grid, it is prevented from spreading further by the repelling action of a second focusing plate, also connected to the cathode. Once the electrons pass through the first control grid, they are attracted towards the accelerator grid, which is at the same potential as the accelerator plate, and again the electron stream tends to spread. However, before the spreading becomes excessive, the stream enters the field of focusing plate No. 3 which is also at cathode potential, and further spreading is checked. The focusing plate is provided with a narrow opening, which concentrates the beam into a narrow stream again as it passes through this orifice. The electron stream then passes through a second control grid (referred to as the quadrature grid) and is attracted to the positive potential plate.

If a signal is applied to the first control grid, and it is sufficiently negative to prevent the electron stream from passing through it, the electrons approaching this grid rapidly build up a dense space charge in front of the grid. Because electrons repel each other, the accumulated space charge aids the control grid in quickly cutting off plate current flow, and accounts for the sharp cut-off tube characteristic. (This control grid is also referred to as the limiter grid for this reason.) The electrons cannot return to the cathode because of the narrow opening in the focusing plate, and they are attracted to the wall of the accelerator chamber instead, thus maintaining cathode current flow, as illustrated in Figure 32.

In a similar manner, when a signal of sufficient strength and of proper polarity to repel the electron stream is applied to the quadrature grid (No. 2 control grid), with the limiter grid above cut-off, plate current will not flow. Cathode current flow continues, however, because the electron stream is attracted to the accelerator wall instead (Fig. 33).

To summarize tube operation, both the limiter grid and the quadrature grid must be sufficiently positive at the same time to permit passage of the electron stream to the plate.

The circuit schematic (Fig. 34) illustrates the gated-beam tube connected as a typical gated-beam detector.

The input tank circuit, consisting of L_1, the primary of IF transformer T_1, and capacitor C_1, is tuned to the center frequency of the incoming FM signal. L_2, the secondary of the transformer T_1, and capacitor C_2, also comprise another tank circuit, which is also tuned to the center frequency. The first grid of the tube and the cathode perform the function of a limiter stage, with resistor R_1 and capacitor C_4 in the cathode circuit to provide a method of adjusting the limiter bias. The accelerator grid is connected to voltage-dropping resistor R_3 which establishes the proper

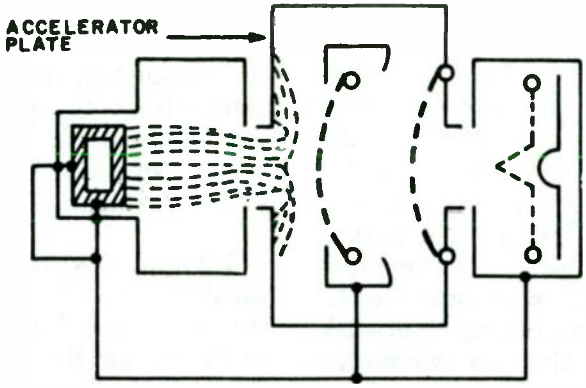


Figure 32 — First control (limiter) grid at cut-off.

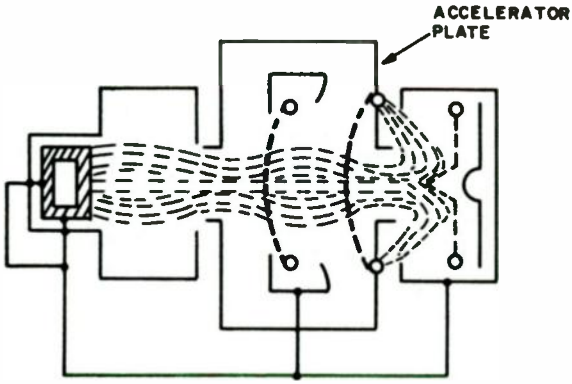


Figure 33 — Second control- (quadrature) grid at cut-off.

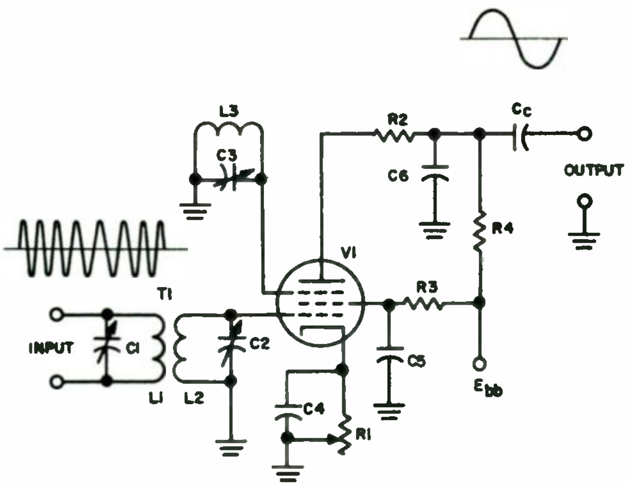


Figure 34 — Typical gated-beam detector circuit.

voltage on the accelerator grid, and C_5 bypasses it to ground. Capacitor C_3, together with L_3, forms another tank circuit also tuned to the center frequency, and is connected to the second control grid. Resistor R_2, (usually of a small value) is placed in the plate lead to increase output linearity. Resistor R_4 is the plate load, and together with capacitor C_6 forms an integrating network which produces the sine-wave output. The output is taken from across C_6, and applied to the audio stages through coupling capacitor C_c.

Circuit Failures

No Output. A defect in nearly any component in the circuit could cause a no-output condition to exist. Check the plate supply voltage at the tube socket; if plate voltage is not present, check resistors R_2 and R_4 and capacitor C_6. If plate and grid voltages are normal, the tube is probably defective.

Check for a signal on the limiter grid with an oscilloscope. If no signal is present, check for a signal on the primary of the transformer. If still no signal appears, the trouble is somewhere in the preceding stages, and the detector is probably not faulty. If there is a signal on the primary of the transformer, check the tuning capacitors with an in-circuit capacitor checker. If they are found to be good, the trouble is probably a defective transformer. Check cathode resistor R_1 for proper value and adjustment, and capacitor C_4 also, using an in-circuit capacitor checker. With the oscilloscope, check for a signal on the quadrature grid. If a signal is present, make sure it is at the center frequency. If no signal is present, check C_3 with an in-circuit capacitor checker, and L_3 with an ohmmeter. Check R_3 for proper value, and C_5 for a short to ground.

Low or Distorted Output. It is unlikely that a low output condition will exist, but if it does, R_2, R_4, or C_6 is most likely at fault. Check R_2 and R_4 for proper value, and C_6 with an in-circuit capacitor checker.

If the output is distorted, make the checks just mentioned above for a low output condition, and if the distortion still occurs, make certain that the three tanks are aligned properly, and contain no defective components. Also check R_1 for proper value and adjustment, using an ohmmeter and also check capacitor C_4 with an in-circuit capacitor checker.

SUMMARY

FM receivers can be aligned using simple test equipment, but the manufacturer's instructions on some FM sets specify the use of sophisticated test equipment. No matter what kind of test equipment is used, the manufacturer's instructions for alignment should be followed.

If alignment does not correct the trouble, a logical procedure should be followed when analyzing the possible cause of trouble. Once the trouble has been determined to be in a specific stage in the receiver, an understanding of the action of that part of the circuit will prove invaluable in locating the cause.

TEST

Lesson Number 67

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-067-1.

1. When aligning the IF and detector section of an FM receiver, it is extremely important to decrease the output of the signal generator because the

A. detector will cease functioning.
2 B. receiver may go into full limiting.
C. signal generator will become overloaded.
D. RF mixer will produce image signals.

2. The voltage across the secondary of the ratio transformer should read ________ when it is properly peaked on a 10.7 MHz signal.

A. zero volts DC.
3 B. maximum positive.
C. maximum negative.
D. zero volts AC.

3. To insure that the alignment of an FM receiver achieves the wide-band response necessary for good stereo-multiplex decoding a well equipped service shop uses

A. an amplitude modulated RF generator and a VTVM.
4 B. a screwdriver and an ear to the loudspeaker.
C. an FM RF sweep generator and an oscilloscope.
D. an RF sweep generator and a VOM.

4. The best overall output response and linearity can be obtained by

A. measuring the limiter voltage.
B. observing the detector S curve.
9 C. measuring the AGC voltage.
D. all of the above.

5. A tuned RF voltage amplifier uses

A. a parallel-resonant circuit to supply a high impedance.
25 B. a parallel-resonant circuit to supply a low impedance.
C. either a tuned or untuned stage to always provide a maximum voltage.
D. all of the above.

6. Stagger tuning of interstage IF transformers is used to achieve

A. a narrow bandpass.
39 B. increased selectivity.
C. synchronous tuning.
D. a broad bandpass.

7. Distortion in an IF amplifier can be caused.

A. only by a combination of improper bias voltage *and* screen voltage.
35 B. only by a combination of improper plate voltage *and* screen voltage.
C. by either improper bias voltage, plate voltage, *or* screen voltage.
D. only by a combination of improper bias voltage *and* plate voltage.

8. A Foster-Seeley Discriminator

A. does not require limiter stages.
B. cannot produce distortion.
36 C. cannot affect the shape of the S curve.
D. requires one or two limiter stages before detection.

9. A ratio detector

A. has a phase shift at resonance.
B. has current flow in the same direction through both diodes at resonance.
40 C. produces equal voltage drops across each half of the two secondary windings.
D. all of the above.

10. A gated-beam tube

A. requires a discriminator circuit.
B. will not allow the electrons to return to the cathode because of the
43 narrow opening in the focusing plate.
C. has to have one grid negative to operate properly.
D. is used only for AM detection.

Notes

Notes

Portions of this lesson from
FM from Antenna to Audio
Leonard Feldman
Courtesy of Howard W. Sams, Inc.

* * * * * *

Figures 9 to 22 are reproduced
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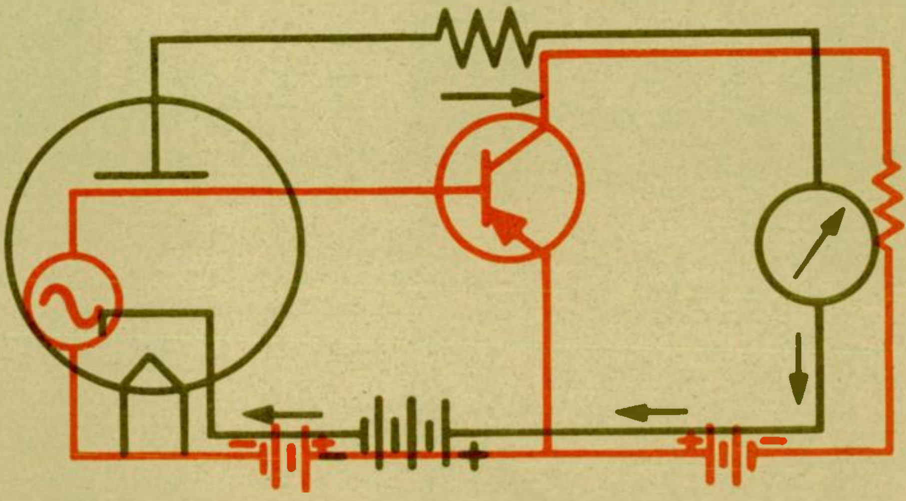
PERSONAL INVESTMENT

The Wall Street broker invests in stocks and bonds and then sits back and waits for the results. You, as an ASI student, are investing time, money, and energy in yourself. You're making it happen and not sitting around waiting for results. You're busy making your stock go up! The investment you're making will pay off.

S. T. Christensen

LESSON NO. 68

REVIEW FILM OF LESSONS 64 THROUGH 67



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-068
407

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 4/73
Reprinted July 1974

REVIEW FILM TEST

Lesson Number 68

The ten questions enclosed are review questions of lessons 64, 65, 66 & 67 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and Film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER: YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having the Test Code Number 52-068-1.

1. **Always test a battery**
   A. with a VTVM.
   —B. under load.
   C. disconnected from the radio
   D. none of the above.

2. **If power is available and an AM radio receiver has no sound output the first check should be a test of the**
   A. detector output.
   B. antenna.
   C. power supply.
   — D. speaker.

3. **Look for intermittent conditions**
   A. when the vacuum tube receiver is cold.
   B. with the radio turned off.
   —C. with the radio operating.
   D. with an oscilloscope.

4. **Carrier frequency limiters are used in**
   — A. FM receivers.
   B. both AM and FM receivers.
   C. FM signal generators.
   D. AM signal generators.

See page 199

5. A discriminator must be preceded by
A. a limiting amplifier.
B. a linear amplifier.
C. a DC amplifier.
D. an audio amplifier.

see page 411 - 19.9

6. The IF system for an FM receiver
A. has a wide frequency response.
B. is the same as for an AM receiver.
C. is narrower than for an AM receiver.
D. none of the above.

7. A ratio detector circuit can be easily identified
A. as the diodes are connected opposing.
B. as the diodes are connected series adding.
C. by the integrating circuit in the output.
D. by the capacitance coupling.

8. The purpose of the resistor-capacitor network in the output of a Quadrature detector is to
A. differentiate the output pulses.
B. provide self bias.
C. provide leak-off for the screen grid.
D. integrate the audio output pulses.

9. Most AFC circuits function by changing the
A. oscillator frequency.
B. AF gain.
C. audio output.
D. speaker impedance.

read page 415 19.3 Direct

10. FM signals can be demodulated by
A. discriminators.
B. ratio detectors.
C. quadrature detectors.
D. all of the above.

Notes

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OBSERVE!

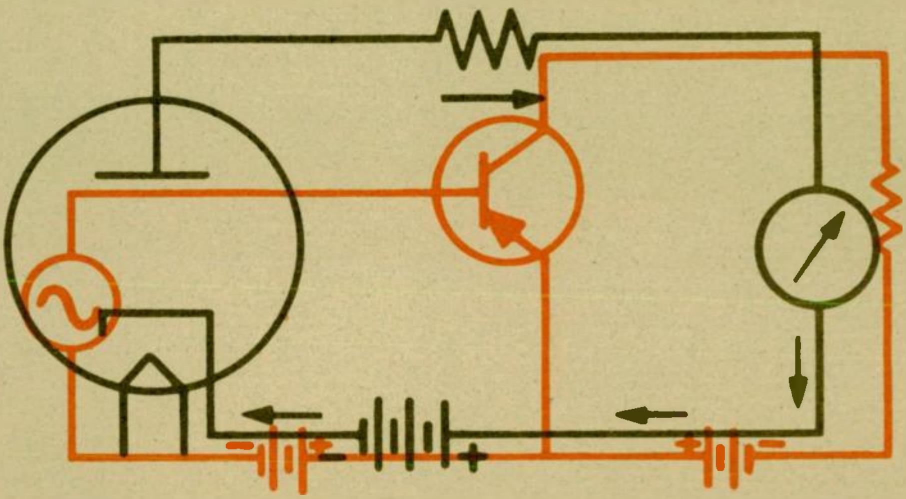
Observe what is happening around you. Keep alert and abreast of new developments in your business. To go around half asleep or with a closed mind is to live a life of emptiness.

Observe your fellow men and their activities. Gain experience from these observations and then apply your ASI training accordingly.

S. T. Christensen

LESSON NO. 69

AUTO RADIOS TUBE TYPE



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
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CONTENTS

Advance Schools, Inc.

AUTO RADIOS— TUBE TYPE

INTRODUCTION

The success of auto radios required solutions to many problems that did not occur with home varieties. First among these problems was the power source. Initially, vacuum tube auto radios required either dry cell batteries or a motor driven dynamotor supply. These sources were soon replaced by the vibrator supply.

Another problem was solved by developing special antenna systems and input circuits. This was necessary in order to provide adequate signal strength inside steel bodied cars.

Other problems were due to conditions under which the sets were required to perform with reasonable reliability. These conditions included temperature and weather extremes, vibration, and shock. Solutions to all these problems were found and the auto radio became a success.

VIBRATOR POWER SUPPLY

It is convenient to operate auto radios from the car's DC battery just as it is to operate a home radio from house current. To do so (in both cases) requires a power supply that can provide all voltages necessary to operate a receiver's circuitry.

For the home radio, AC is available from the wall plug and its voltage can be easily altered with a transformer. Only DC is available to the auto set. Therefore, some method must be used to make the available DC look like AC before it can be applied to a transformer for step-up or step-down.

To cause DC to look like AC to a transformer it must either be varied or interrupted (chopped) at some regular rate. The interruption method is used since it can be done with a simple electromechanical device called a "vibrator".

Figure 1 shows a simple electromechanical arrangement that can be used to interrupt current flow. Notice that it contains a set of open contacts with the movable contact spring loaded and placed in proximity to a field coil. When the switch is closed the movable contact is pulled toward the fixed contact by the electromagnetic field developed in the coil. When the contacts meet, they short circuit the coil and the field begins to collapse. The field now

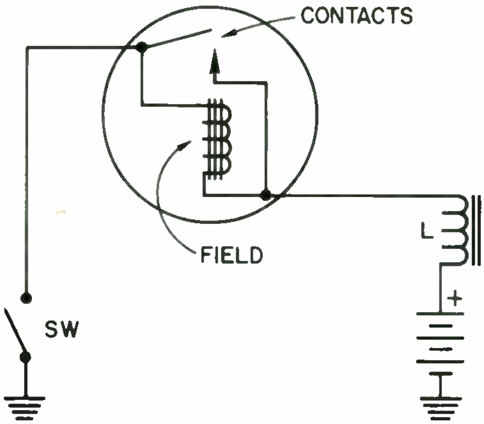


Figure 1 — Vibrator at rest.

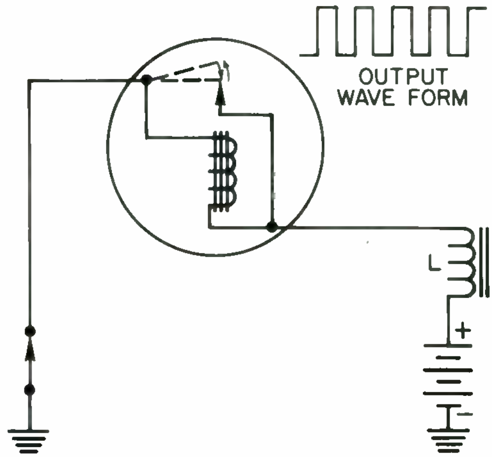


Figure 2 — Activated vibrator.

lacks sufficient strength to hold the contacts closed and they separate. Once again, the electromagnetic field builds in the coil until it eventually overcomes the spring tension of the movable contact, causing the contacts to again close. This action continues in rapid succession.

In Figure 2, we see an output developed across L that is almost a square waveform. A transformer will respond to this interrupted waveform almost as if it were AC.

Two kinds of vibrators are commonly used in tube-type auto radio supplies. One is the *nonsynchronous* type that requires a separate rectifier while the other, a *synchronous* type, does not require a rectifier.

The schematic in Figure 3 shows a typical nonsynchronous vibrator supply. It is powered from the automobile battery through terminals marked A+ and A−. Notice that the vibrator has two contacts; this is typical of nonsync vibrators. The transformer used has center tapped windings (both primary and secondary).

When the switch is closed current flows from terminal A- to ground, from ground through contact 1 of the vibrator, through section 1 of the transformer primary, the A-line filter, the switch, the fuse, and returns to terminal A+. A small amount of current will flow through the vibrator coil and section 2 of the transformer primary. The vibrator coil will develop a magnetic field which will pull the movable contact into position 2. The entire circuit current now flows through contact 2 and section 2 of the transformer primary. The vibrator coil is now bypassed and it's field collapses allowing the movable contact to return to position 1. The sequence is then repeated in rapid succession.

The current through section 1 is in an opposite direction to current through section 2 and they will induce opposite polarity voltage in the secondary. Thus, the rectifier's plates will be subjected to alternate positive voltage peaks and each plate will conduct during its associated positive alternation. In this illustration (Fig. 3), an LC pi-section network is used for filter-

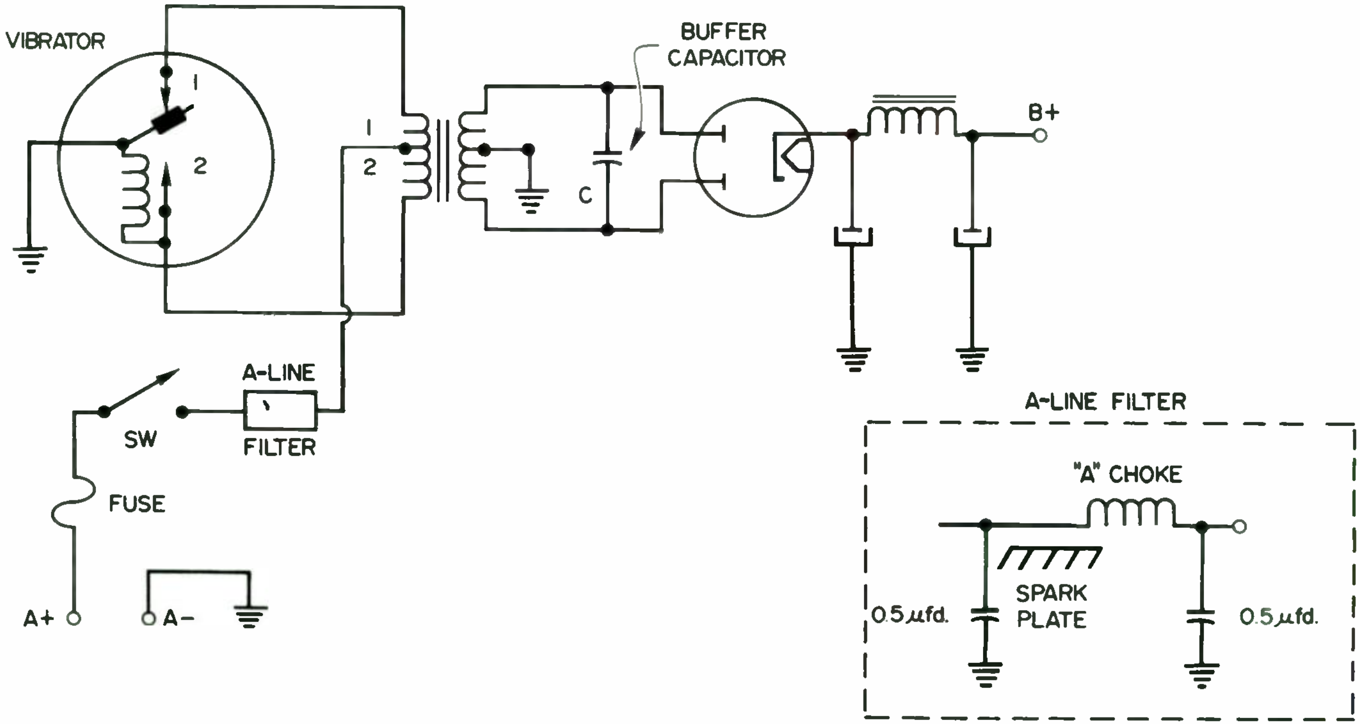


Figure 3 — Nonsynchronous vibrator supply.

ing, although RC filters are quite common. The purpose of the A-line filter is to prevent ignition disturbances or charging circuit variations from entering via this path.

An A-line filter consists of a series choke and bypass capacitors arranged as shown in the insert in Figure 3. In addition to these components another component called a "spark plate" is used for added suppression. It consists of two square metal plates separated by a sheet of mica, thus forming a capacitor. They are installed with one plate mounted flush to a flat surface on the radio's case. Since the radio is mounted to the body of the car, the spark plate will effectively bypass interference to the car's body.

Figure 4 illustrates a spark plate and its wiring. Notice that the leads are attached directly to the isolated plate eliminating the separate leads and associated lead resistance of ordinary capacitors.

Returning to Figure 3 for a moment, you will notice that a capacitor (C) is connected across the secondary of the transformer. This is a high voltage unit with a rating of 1000 VDC or greater. Its purpose is to remove the hash or noise that is generated as the vibrator contacts open and close.

In Figure 5, the conventional filament-type rectifier tube has been replaced with a cold-cathode gas-filled rectifier. This tube (usually an OZ4 type) does not require heater excitation and conserves battery current. It conducts by ionizing the gas between cathode and

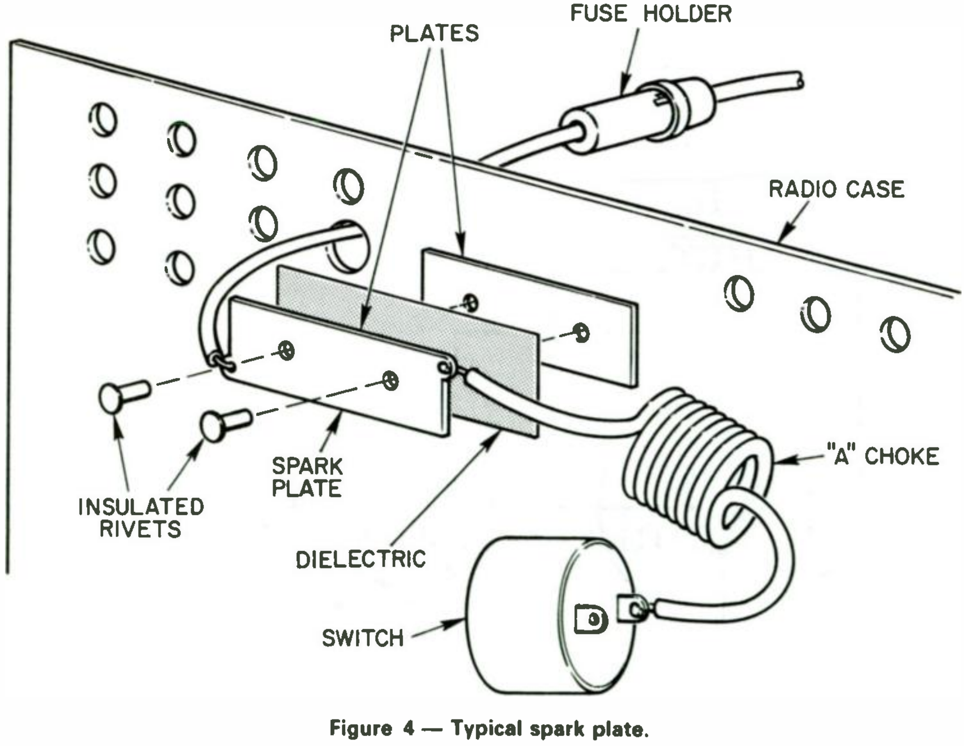


Figure 4 — Typical spark plate.

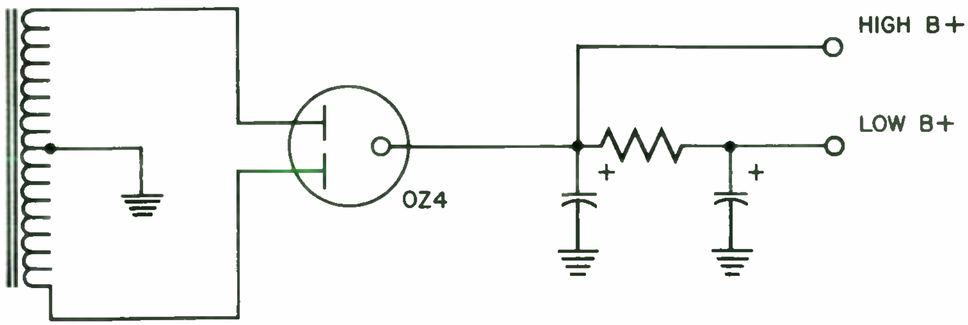


Figure 5 — Cold cathode rectifier (OZ4) does not require filament current.

plates whenever a plate becomes highly positive. The OZ4 cold cathode rectifier was widely used in Delco radios installed in General Motors automobiles.

SYNCHRONOUS VIBRATOR

Figure 6 shows a synchronous vibrator power supply; the use of a synchronous vibrator, as in this case, eliminates the need for a separate rectifier.

Synchronous vibrators are commonly said to be *self rectifying*. Notice that the vibrator in Figure 6 has two sets of contacts. One set performs the normal interruption function while the additional set alternately contacts opposite ends of the secondary winding and

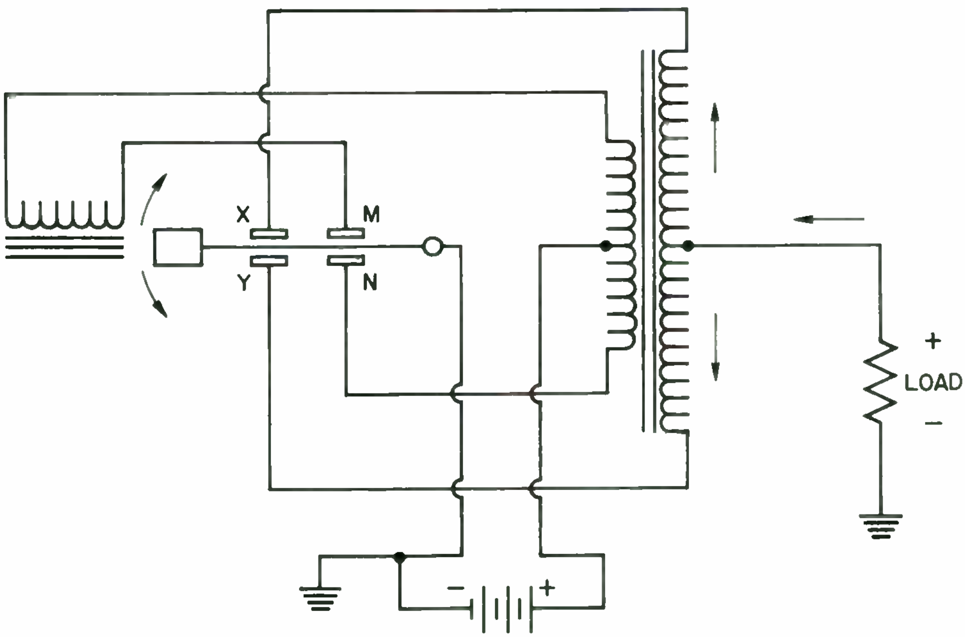


Figure 6 — Synchronous vibrator supply.

shorts them to ground. By this action, current flow in the output is always in the correct direction through each section of the secondary winding to produce positive DC at the center tap.

Synchronous vibrators are seldom used because of a number of disadvantages. Chief among these are:

1. synchronous vibrators are more complicated and have a higher failure rate.

2. the wiring sequence of the contacts must be correct for the battery polarity in the auto. Wiring must be changed for it to operate on a reversed polarity system.

3. synchronous vibrators develop considerably more contact hash than nonsynchronous types.

ANTENNAS AND RF-AMPLIFIER

Very early auto radios received their signals from antennas placed beneath wooden running boards. A short time later some manufacturers installed their radio antennas inside the fabric top covers. Two developments occurred in the mid 1930's that drastically altered both placement and styles of auto antennas.

1. the running board disappeared.

2. all steel bodies were adapted.

As a result of these developments, whip or vertical rod antennas became standard throughout the industry.

To reduce the objectionable ignition interference, shielded cable between the antenna and radio became the standard method of coupling. This brought about another serious problem. Shielded or coaxial cable contains considerable capacitance and in early installations much of the received signal was shunted to ground through this capacitance. To overcome this effect engineers designed input-antenna systems in which all capacitances became a part of the resonant input circuit. Thus, a once objectionable characteristic now became an aid to good reception.

Permeability tuning has replaced variable capacitance tuning in nearly all car radios. Movable powdered iron slugs are inserted into the RF, mixer, and oscillator coils. They are attached to a mechanism that varies their depth in the coils as the tuning knob is rotated. Resonances of the antenna, mixer, and oscillator circuits vary with slug position due to the variation of coil inductance with slug position.

Figure 7A shows a conventional antenna coil in which the cable capacitance shunts part of the received signal to ground. In Figure 7B, the coax lead is connected directly to the tuned circuit which puts the cable capacitance directly across the resonance components of the circuitry. Thus, the antenna and cable capacitances have become part of the resonant circuit.

Numerous input circuit schemes are used to attain optimum results.

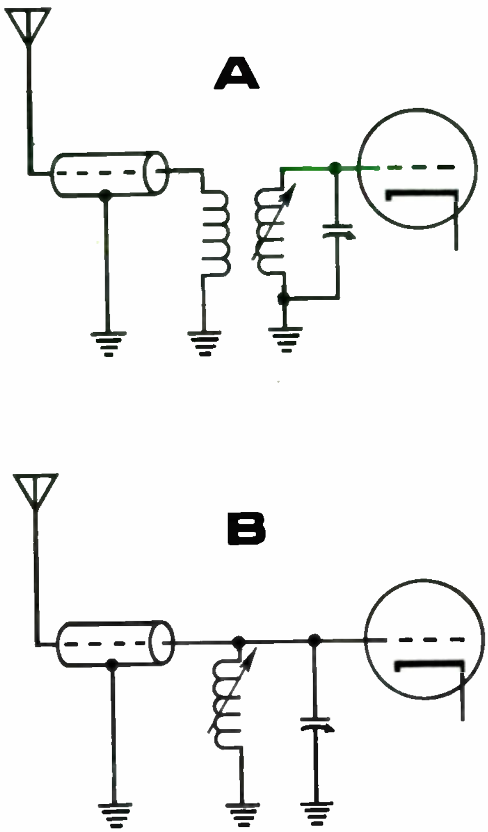


Figure 7 — Antenna and lead capacitance become part of the tuning in the input resonant circuit.

A basic RF input circuit is shown in Figure 8. Of particular interest are three systems that have been adopted by leading manufacturers.

The first input coupling system to be discussed uses *direct capacity coupling* into the RF tuned circuit. Figure 9 illustrates a typical capacitvely coupled system. RF signal currents generated in the antenna develop an RF voltage across RFC that is capacitively coupled into the RF coil through capacitor C_a. This capacitor is a trimmer that also serves to resonate the antenna system with the tuned RF circuitry to enable maximum signal transfer. Notice the presence of an antenna choke in the diagram of Figure 9. This choke is broadly resonant at frequencies above the broadcast band. It rejects these frequencies thus preventing them from causing interference to received signals.

The input circuit of Figure 10 uses a *double tuned RF transformer*. It has the antenna connected directly to the primary winding with it's capacitance being a part of the primary's resonant circuit. Capacitor C_a is the antenna trimmer and it is adjusted to compensate for capacity variations in the antenna and lead-in wire. Both the primary and secondary are resonated to a desired station signal with movable powdered iron slugs whose positions are varied by a tuning mechanism. Signal transfer takes place through mutual inductance between the primary and secondary. This particular input system is widely used in both vacuum tube and transistorized sets.

The third coupling method is called ***bandpass tuning*** and is illustrated in Figure 11. The two inductances involved (L_1 and L_2) are completely shielded to prevent inductive coupling. All coupling takes place due to the voltage developed across the .004 μfd capacitor. Signal currents in the antenna flow through L_1, C_a (the antenna trimmer), and the common .004 μfd capacitor (C_c). A signal voltage is developed across C_c that is coupled through L_2 and C_d into the signal grid of the RF amplifier.

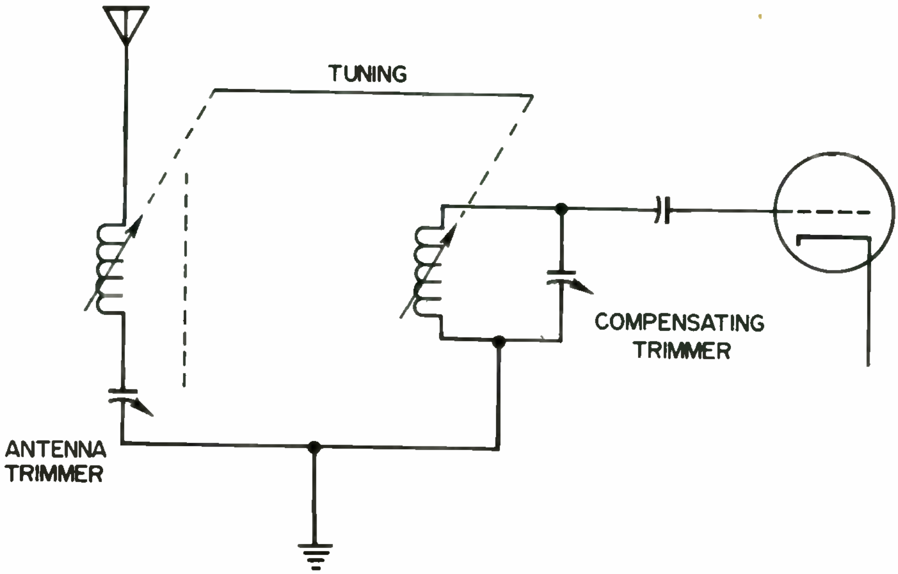


Figure 8 — Basic RF input.

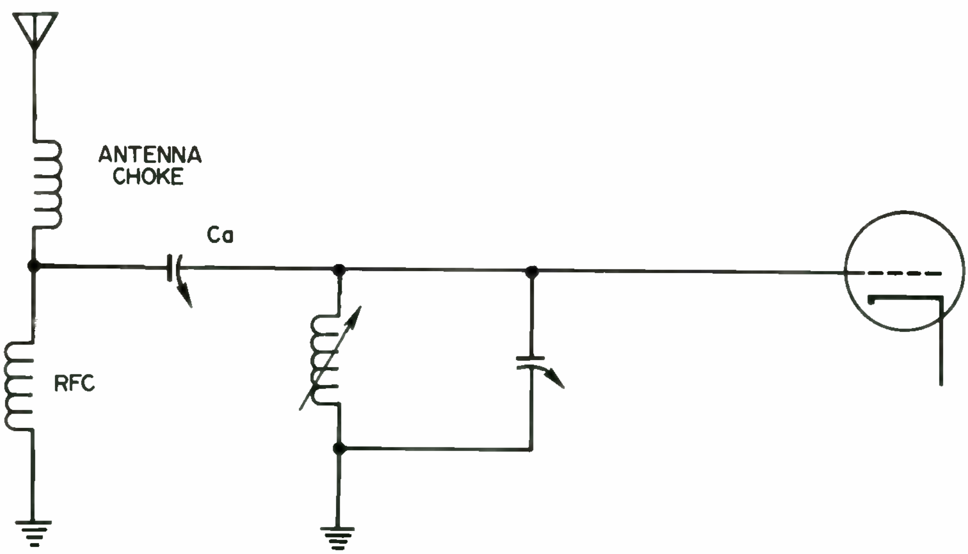


Figure 9 — Capacitively coupled input.

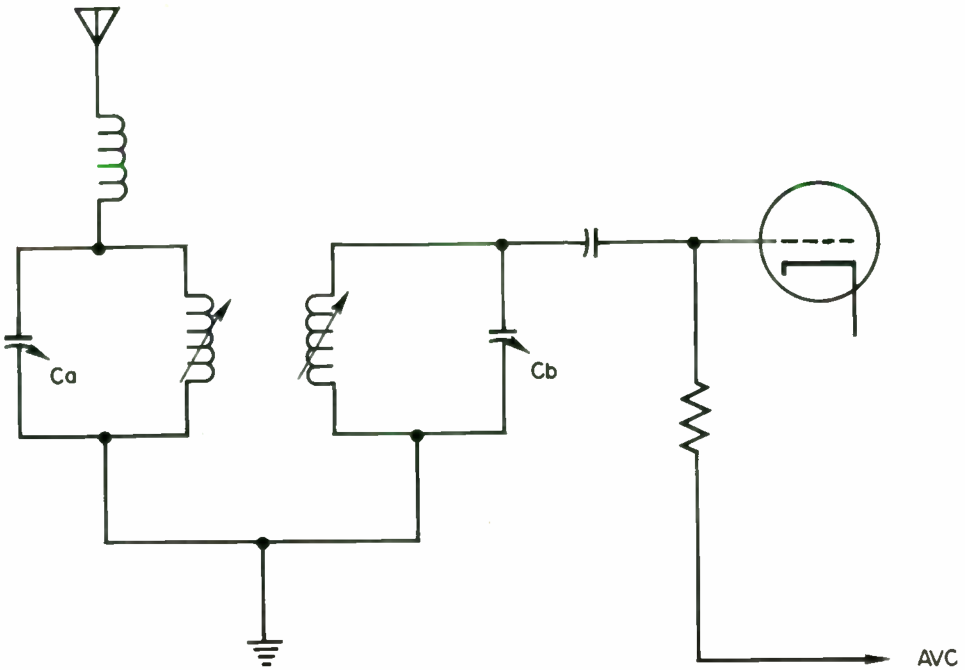


Figure 10 — Typical double-tuned RF input.

6 Bandpass tuning is particularly selective making it effective in eliminating images and other kinds of interference signals.

RF INTERSTAGE COUPLING

Several methods are used to couple the signal from the RF amplifier to the mixer. A very common method is RC coupling as shown in Figure 12. This method contributes nothing to selectivity but it does contribute signal gain.

The circuit of Figure 13 uses a tuned inductor (L) to improve selectivity. RF signal voltage is connected to a tap on the inductor in the converter's grid circuit. This nullifies some of the effects of capacitances in the preceeding stage . . . on the tuned circuit.

In Figure 14, coupling is through trimmer capacitor C_T. Isolation capacitor C_I blocks the DC voltage that appears on the RF tube's plate and prevents it from upsetting the grid bias on the converter tube.

Illustrations in Figures 15 and 16 are pi-networks. The basic difference between them is that the circuit in Figure 16 uses an RF choke as an RF plate load; whereas in Figure 15, the plate load is a resistor. The resistor that parallels the plate choke in Figure 16 broadens its response for equal signal transfer at all broadcast frequencies.

Although a few car radios have separate oscillator tubes, most use the same basic converter circuit as in home radios. Figure 17 shows

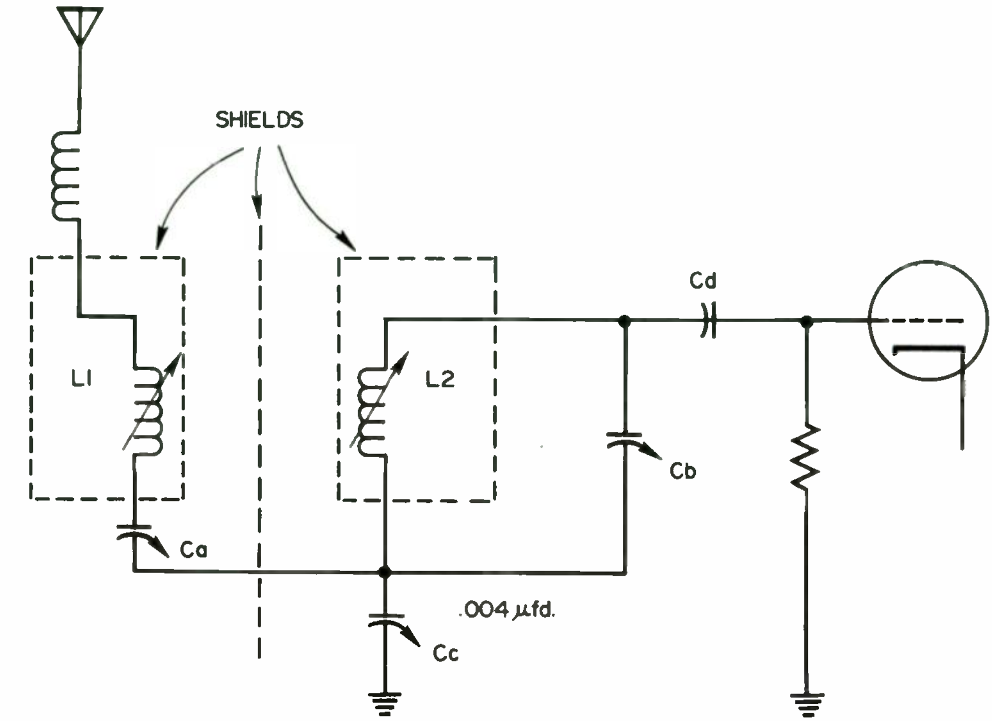


Figure 11 — Bandpass RF.

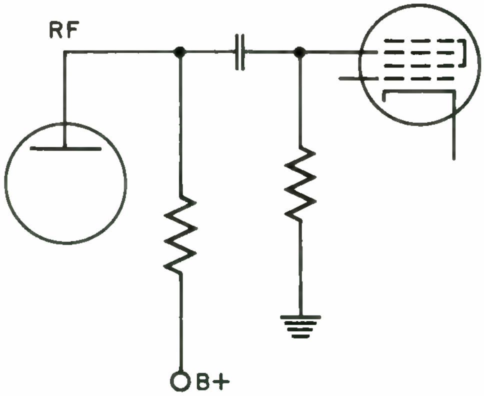


Figure 12 — RC coupling.

one such converter stage. This particular circuit uses a 6BE6 pentagrid converter tube. The only difference between it and the version used in home radios is that the IF frequency in this, as in most auto sets, is 262.5 kHz instead of 455 kHz.

INTERMEDIATE FREQUENCY AMPLIFIER

The IF amplifiers associated with auto radios are more than similar to those in home radios; the circuitry is almost identical. One difference that exists is the IF frequency which is 262.5 kHz in most auto radios. This lower frequency provides greater gain and better selectivity than the 455 kHz frequencies used in home variety radios.

9

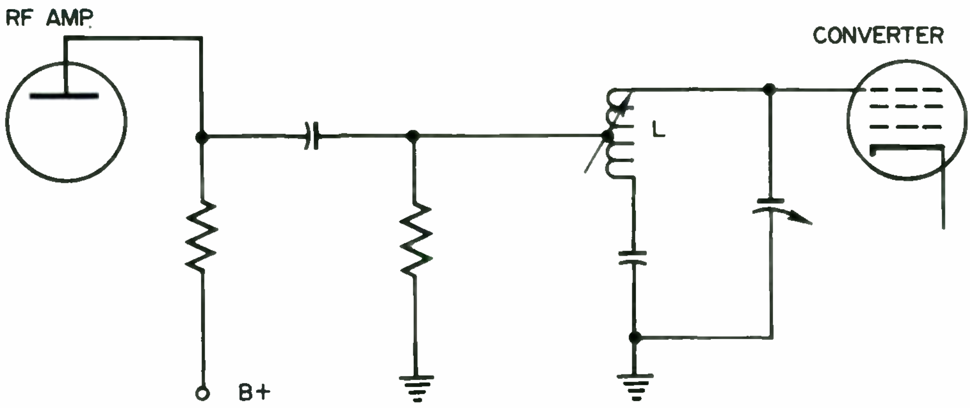


Figure 13 — Capacitive coupling into tuned mixer coil.

The major disadvantage in using a lower intermediate frequency is that many of the image frequencies fall within the broadcast band. Thus, if the set is receiving a 600-kHz station its oscillator frequency is 862.5 kHz or

600.0 kHz	Station signal
+262.5 kHz	IF frequency
862.5 kHz	Oscillator frequency

The resulting image will be

862.5	Oscillator frequency
+ 262.5	IF frequency
1125.0	Interfering image frequency

Images are purposely made to fall between assigned stations frequencies. In the above case 1125 kHz is between assigned station frequencies at 1120 kHz and 1130 kHz. A strong local station at either of these frequencies, however, could cause interference in the form of squeals, low pitched howls, or a rapid variation in volume.

Because of their susceptibility to image interference, good quality auto radios have highly selective RF amplifiers to reduce image response.

DETECTOR AND AUDIO SECTIONS

The detector circuit in tube-type auto radios is nearly identical to those in home sets. Frequently, however, the audio voltage amplifier is a pentode (Fig. 18) rather than a triode. Pentodes are often necessary to produce adequate drive for the high power audio output stage. Tone controls are generally included along with compensated volume controls. Inverse audio feedback is also occasionally included to improve fidelity.

The audio output sections of auto radios are most often push-pull stages although some are single ended. The driving signal for push-pull audio sections is often supplied from centertapped interstage transformers but RC-coupled paraphase circuits are also employed.

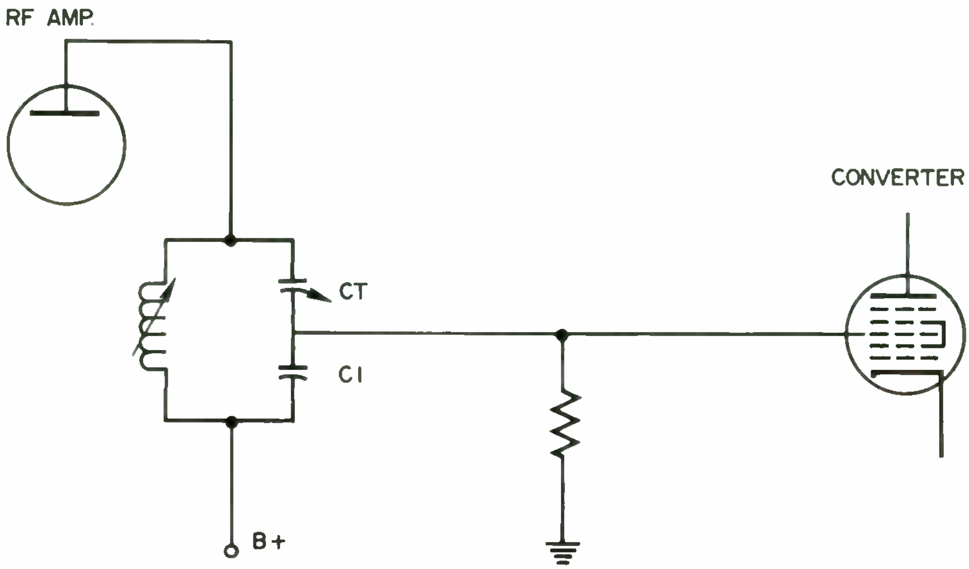


Figure 14 — Capacitive coupling with capacitive isolation.

SEARCH OR SIGNAL-SEEKING TUNERS

Delco introduced their signal-seeking tuner more than 15 years ago. Mechanically and electrically these tuners have been modified and refined, but the basic station-stopping circuit idea, for making the tuner stop right "on the nose" regardless of station strength, has never been improved.

It's Not AVC

At first thought it might seem easier to develop a search tuner than it really is. Why not just monitor the AVC voltage, amplify it, and let it trip a relay? This sounds like a good idea, except that it won't work. The reason is that AVC differs for different stations with different signal strengths so that the tuner would not know when the station was tuned in. For example, take two stations—one with a weak signal and developing only 2 volts of AVC voltage, the other a stronger station developing 5 volts of AVC when it is correctly tuned in. How shall the signal seeker be set? If it is set to stop on 2 volts of AVC, it will stop correctly for the weaker station, but on the strong station the tuner will stop before the station is correctly tuned in because the strong station will develop 2 volts of AVC before it reaches the middle of its passband. The tuner could be set to stop on 5 volts AVC; this would take care of the strong station but would miss the weak station altogether. In addition, the strength of each and every station will vary as the car travels from one location to another (especially on long trips). Thus, the ideal conditions could never be met with a small voltage setting.

How can the problem be solved?

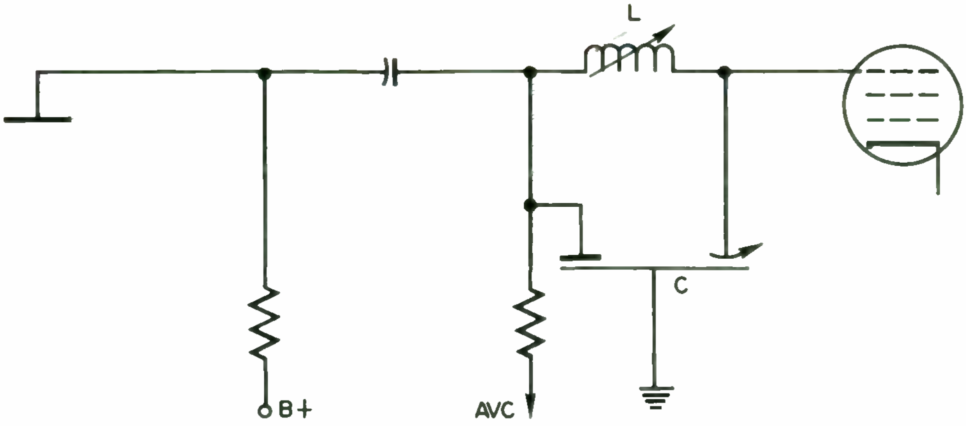


Figure 15 — Split capacitor used for coupling in a pi-network.

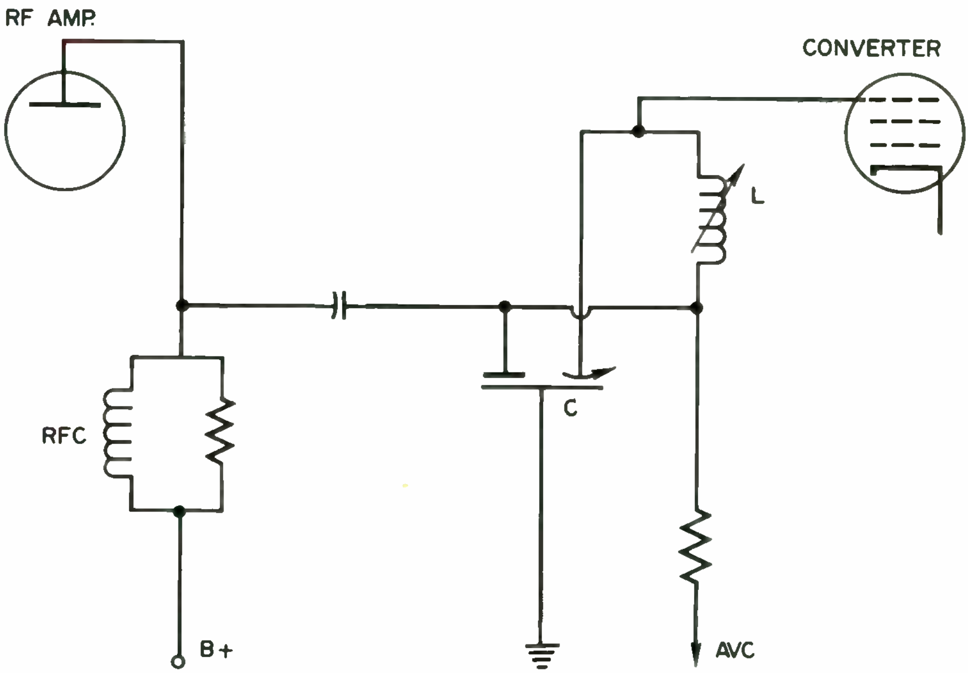


Figure 16 — Pi-network interstage coupling.

What is needed is something that will automatically "level" every station to a particular output and use this output to trigger the tuner stopping circuits.

The Solution

To solve this problem the engineers came up with an ingenious answer. Why not supply an AVC-

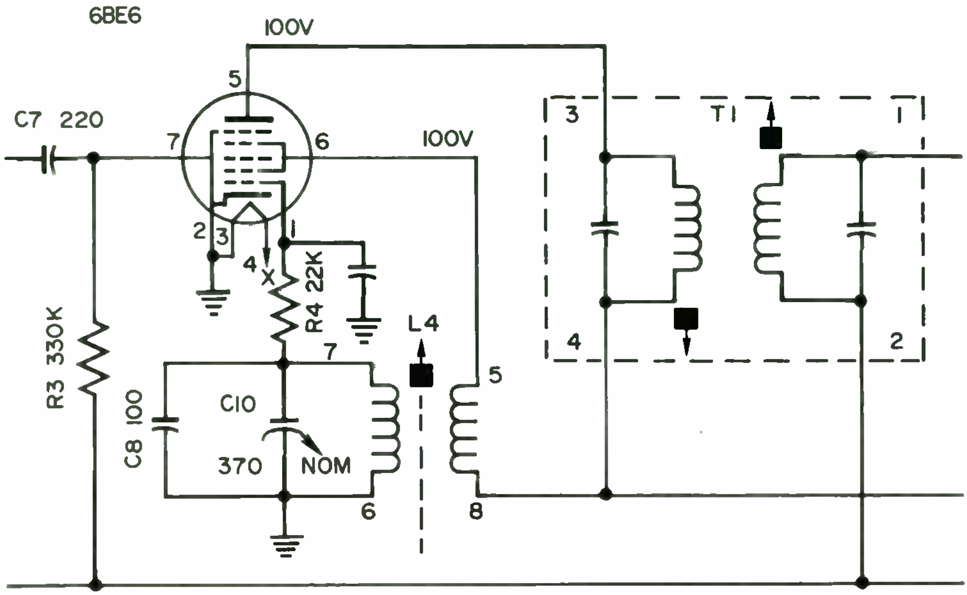


Figure 17 — Typical frequency converter in a tube type auto radio.

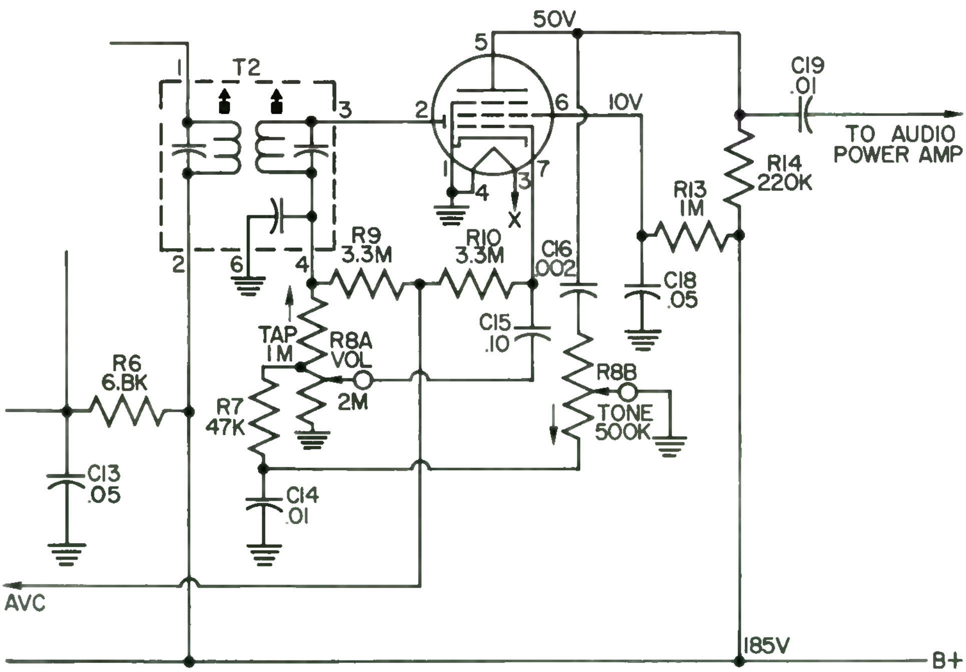


Figure 18 — Detector-AVC-1st audio stage-typical of many tube type auto sets.

controlled "bucking" or cancelling voltage so that triggering would be harder on strong stations and proportionately easier on weak stations? In addition, if the triggering voltage could be made to occur only near the center of the selectivity curve, the tuner would always stop with the station properly tuned in with no sideband distortion. You need only to operate a search tuner radio to find out how well they have succeeded.

How It's Done

In Figure 19 are somewhat idealized selectivity curves that will be referred to in explaining the signal triggering action. To understand this better, also refer to the circuit of Figure 20. This is a simplified schematic of an early Delco signal seeker, showing the circuits pertinent to this discussion. Note that C_2, a 100-mmf capacitor, is tied from the IF amplifier plate to the AVC diode plate. This will develop a negative AVC voltage, and it is fed back to the RF and IF tubes for just this purpose. But the AVC developed here is also fed through a 1-meg resistor (R_7) to the grid of the 12AU7 trigger tube. (Note: this is not the trigger voltage as can be seen by tracing this voltage through the trigger tube. The negative voltage on the first grid would be positive on the plate, and positive on the second grid. This would make the relay draw more current and hold in tighter—it must drop out to stop the tuner.) Also coming into the grid of the trigger tube through a 100-mmf capacitor (C_3) is "raw" IF voltage from the secondary of the IF transformer. This is the trigger voltage. Since the trigger tube is biased to near cutoff by the AVC voltage, only a strong positive voltage could make it conduct (plate detection). This causes a sharp drop in plate voltage (negative) and reduces the plate current in the output section, and the relay falls into the paddle wheel and stops the tuner. Here then you can see how the AVC voltage actually bucks out most of the trigger voltage. Since stronger stations will have stronger AVC, they will be cancelled out more than the weaker stations which give the levelling action on the triggering voltage. Now look again at Figure 19. These are the selectivity curves (also AVC voltage curves) for the primary and the secondary of the second IF transformer. The sharper curve represents the voltage from the secondary and the boarder curve that from the primary. This shows then

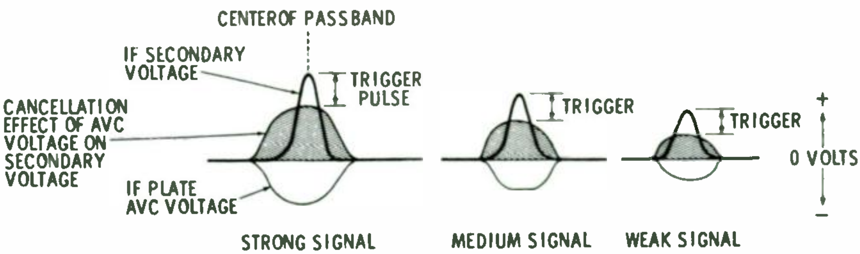


Figure 19 — Composite grid signal on trigger tube that stops tuner "on the nose" regardless of signal strength.

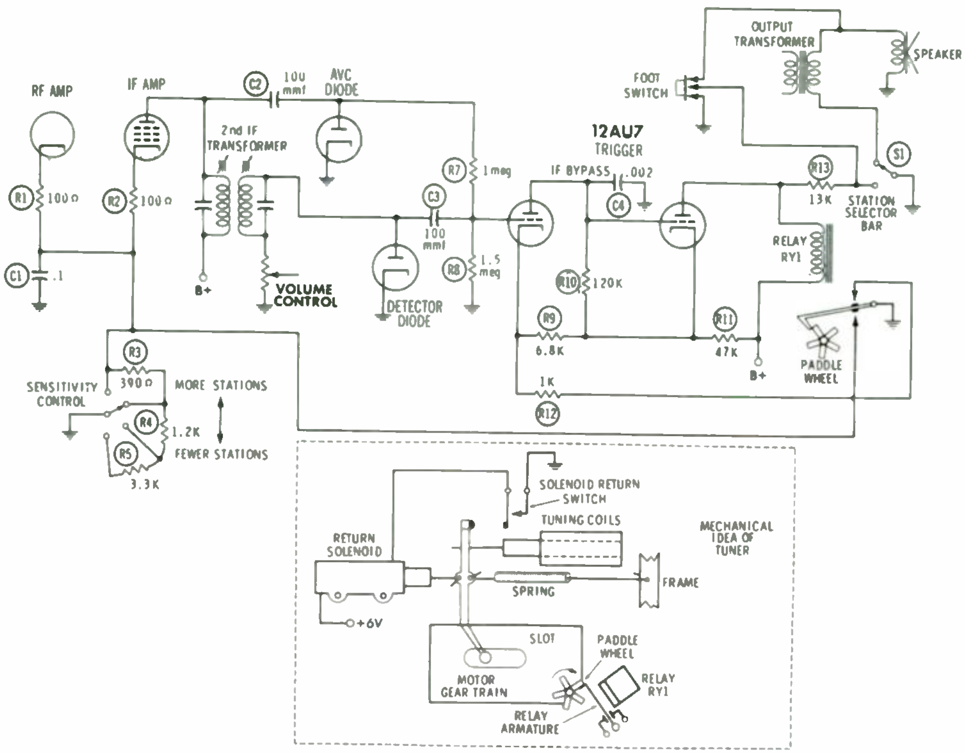


Figure 20 — Simplified schematic of signal-seeking circuit used in early Delco radios.

that triggering comes near the center of the curve, and the station will be tuned in. But why is there more output voltage from the secondary than from the primary? There isn't necessarily; the AVC voltage from the plate is deliberately reduced by the bleeder resistance of 1 megohm and 1.5 megohm in the trigger grid circuit (R7 and R8) so that the secondary trigger can "overtake" the primary AVC.

Complete Sequence

Now with the method of triggering in mind, let's go through the whole sequence of signal seeking from the time the owner decides to change stations.

First, the station selector bar (S1) is depressed to start the seeking action. This energizes relay RY1 through the 13K resistor (R13) to ground. The relay pulls up the relay armature and releases the paddle wheel. (The dial mechanism is a spring motor that is rewound by a solenoid. When the tuner reaches the high-frequency end of the scan, it is snapped back by the solenoid, placing tension again on the spring to drive the dial motor again to the high end. The paddle wheel is at the end of a gear train, and it picks up air as it spins to restrain the spring motor from running away and keeps the sweep from the low to high end of the dial slow and steady.) Now that the armature has been pulled up, the paddle wheel is released and is free to spin, and the radio starts its seeking process. The armature also shorts the cathode of the trigger tube through a 1K resistor (R12) so that the trigger tube will be ready to conduct when a signal is received. When a signal reaches the trigger grid, the trigger output section releases the relay armature which falls into the paddle wheel, stopping the tuner on station. Cathode resistor R12 is removed, biasing the trigger tube so that it will not false trigger. Now a strong noise pulse can increase the AVC voltage without pulling in the relay and starting the scan again. When the scan has stopped, it must be again manually started by pushing the station selector bar or foot selector button.

Sensitivity Control

Obviously, we might not want the search tuner to stop on every station since many would be too weak to listen to satisfactorily. This is the reason for the sensitivity control on signal-seeking radios. It can be set to receive all stations or just the strongest stations. Here's how it is done: Note when the RY1 relay armature pulls up, disengaging the paddle wheel during seeking, it also breaks a ground circuit going to the RF and IF amplifier cathodes; the only return for the cathodes at this time is through the sensitivity control. If the control is adjusted for "fewer stations," there is more resistance in the cathode circuit and the sensitivity of the IF and RF amplifiers is reduced accordingly. This means that only the stronger stations can develop enough voltage to trigger the stopping relay (RY1). As soon as the station does trigger the relay, however, the radio is returned to its maximum sensitivity again by the grounding of the cathodes through the relay arm. This ensures the best reception possible after the radio stops on the selected station.

Speaker Muting

When the selector bar is depressed (in this model), the voice coil to the speaker is open so that for as long as you have the bar depressed you will hear no audio. However, if you just touch the bar and release it, you will sometimes hear weak stations being tuned across because they are too weak to stop the tuner. Some tuners mute the speaker during the whole search—one of these will be covered later on in this lesson.

Foot Switch

This is an added convenience for the driver so that he can change stations without taking his eyes off the road. Pushing the foot switch starts the seeking sequence. In the circuit of Figure 20 the foot switch mutes the speaker by shorting it out.

FORWARD AND REVERSE SWEEP SEARCH TUNER

As we noted previously, the signal-seeking tuner makes a sweep of the dial from the low-frequency to the high-frequency end and then is quickly snapped back by a solenoid to the low-frequency end to start a new scan. Figure 21 is the simplified circuit of a tuner that sweeps and searches in both directions; that is, it moves slowly from low to high, reverses direction, and scans slowly from high to low. This uses a regular DC motor to drive the dial mechanism through an electromagnetic clutch. When the tuning mechanism reaches one end of the dial, it trips a switch that reverses the motor and starts the scan in the opposite direction.

The trigger circuit works on the same principle as discussed for the signal seeker, even though the trigger tube is AC coupled instead of DC coupled in the Delco circuit. A pulse of IF voltage causes the plate current of the triode section of the 12DY8 to go less positive or negative; this sudden negative voltage (pulse) is transferred to the tetrode grid, and the relay is released as the plate current drops. When the relay releases, 12 volts is removed from the magnetic clutch assembly and the tuner stops while the motor coasts to a stop. When the relay armature drops out, it also removes the screen voltage from the tetrode trigger tube so the circuit cannot false-trigger. The emitters of the audio-output transistors are returned to +12 volts so that there will be audio output.

Sensitivity

Only two sensitivity positions are used with this tuner. The sensitivity is selected each time the tuner is started searching. If you push the local (LOC) button, the relay is

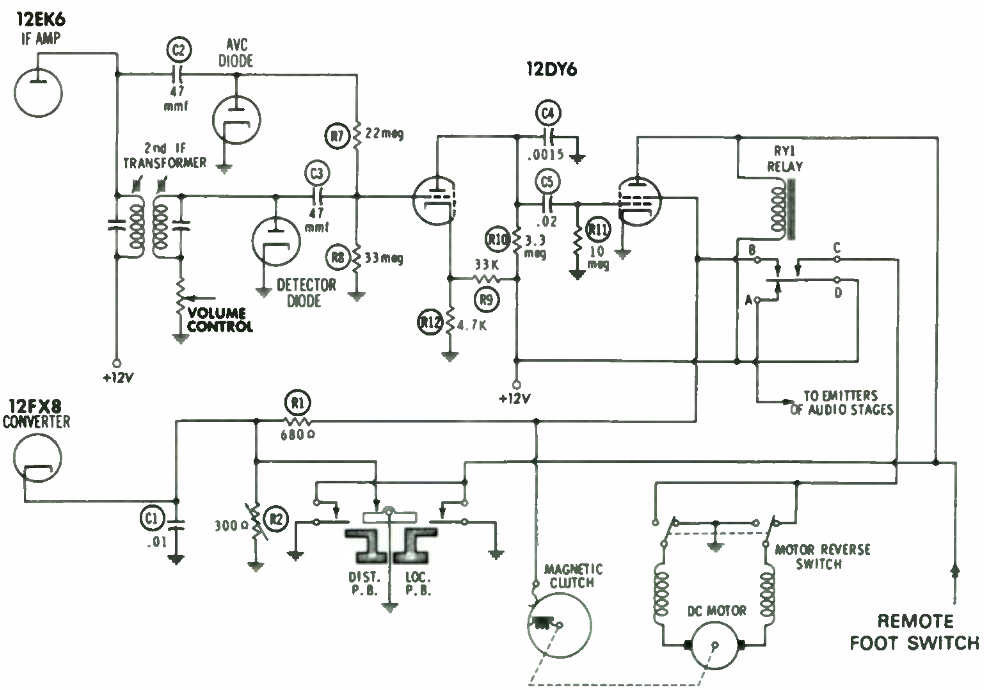


Figure 21 — Signal-seeking tuner that sweeps and searches in both directions.

grounded to start the search and the screen circuit of the trigger tube is connected to keep the relay locked in. This same +12 volts that supplies the trigger tube screen is also fed through a 680-ohm resistor to the cathode of the converter tube to increase its bias and lower its sensitivity. If, however, the distance (DIST) button is pushed, this moves a lever switch in, to ground out the cathode and make the radio more sensitive. This lever switch remains in this position until the local button is again depressed to move it back away from it's contact. The remote foot switch on this model simply starts the search by energizing relay RY1. The sensitivity of the search depends on which button was last pushed on the radio dial—whether local or distance.

In this circuit the radio remains at a slightly less sensitive position in the LOC position after the search is stopped. This is because the resistance of R2 is still in the cathode circuit. This resistor is adjusted in the LOC position so that the radio will stop on the desired number of stations.

TRANSISTOR SIGNAL SEEKERS

When the state of the art advanced far enough, and especially with the coming of silicon transistors, the transistorized signal seeker was developed. (Tubes were used in trigger circuits for quite a while after the all-transistor radio was common.)

Figure 22 is a three-transistor signal-seeking amplifier and control. This circuit works on essentially the same principle as the tube circuit. A signal is taken from both the primary and secondary of the last IF transformer and is used as the input signal for the seeker. The signal from the primary goes direct to an AGC diode while the secondary signal goes to the base of the trigger amplifier. The AGC diode automatically sets the bias level of the trigger amplifier so that it reacts only at the midpoint of a strong or weak signal just as is done in the tube circuit.

There is a slight difference in some parts of the circuit mainly in the muting circuit.

Sequence of Transistor Seeker

When the signal reaches the trigger amplifier it is amplified as a pulse and sent on to the relay amplifier. The relay amplifier receives a negative pulse which, in turn, reduces the current through the 1k emitter resistor. The reduced current through the 1k resistor reduces the positive voltage on the base of the relay control transistor reducing the collector current and allowing the relay to drop out. When the relay drops out it drops a tab into the motor governor fan and stops the tuner motor.

Muting

The muting circuit uses a diode. When the relay closes, the mute diode has 12 volts on the anode. This causes the diode to conduct and this does two things: *first,* +12 volts is applied to the cathode of the detector diode biasing it to cutoff so that it can no longer detect, and

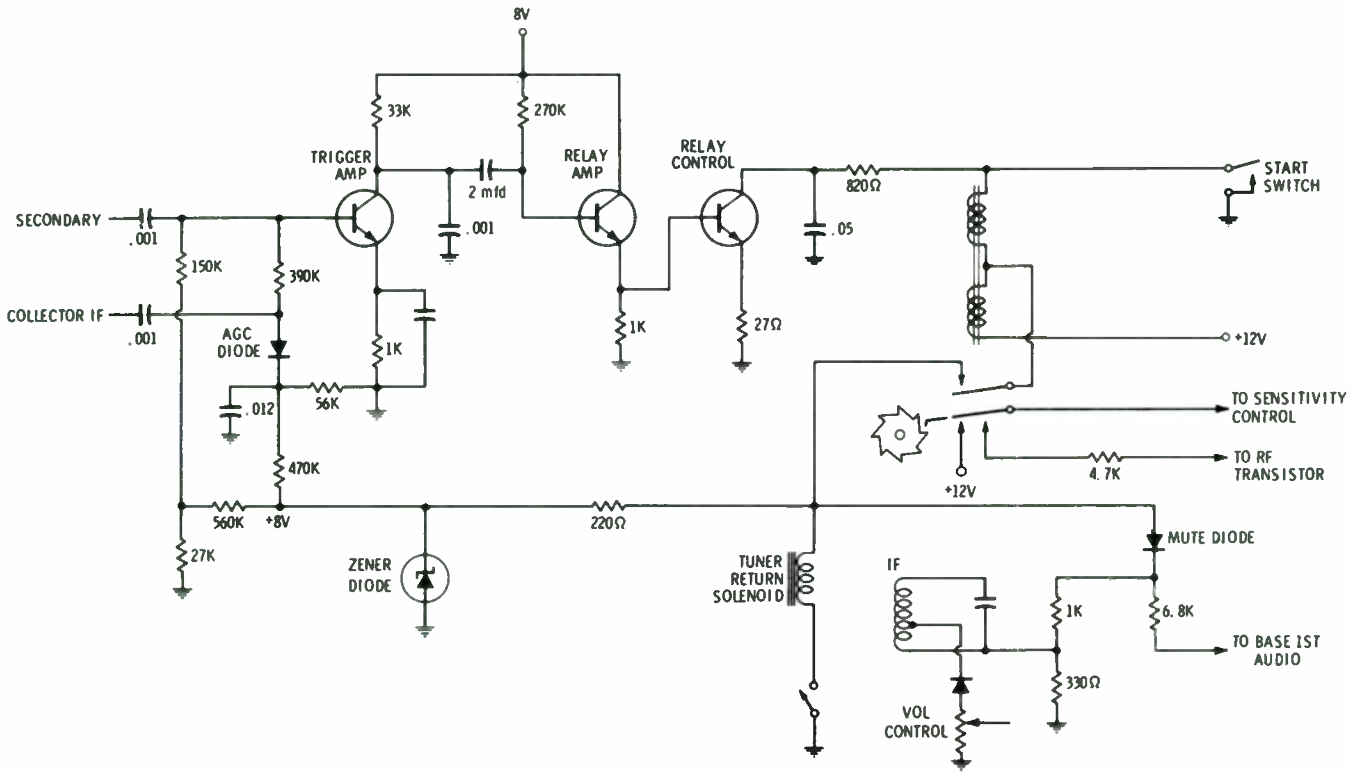


Figure 22 — A transistorized signal-seeking circuit.

second, a positive voltage is applied to the base of the 1st audio transistor and since this is a direct-coupled circuit the output transistor current drops to zero.

Sensitivity Adjustment

The sensitivity adjustment is almost the same as the tube circuit except that the emitter bias of the RF amplifier is adjusted instead of the cathode bias in the tube circuit. The sensitivity of the radio is maximum except during the seeking process. By adjusting the sensitivity control the operator can make the radio stop only on strong signals, strong and moderate signals, or on all signals.

REVERBERATION UNITS

A gadget that has been popular in some areas is the reverberation unit. This "reverb" makes the sound from the auto speaker appear to have more "presence" because of the slight delay that is added. This makes listening to a car radio sound a bit like you're listening to the same music in a large hall. As a general rule, reverberation can be used successfully only with music. The voice is usually 10 delayed enough so that it is harder to understand (about 30 milliseconds in a typical reverberator).

How It Works

The reverberation unit has a time delay transducer especially made for this purpose. Figure 23 shows the idea. A signal from the car radio speaker is fed to another magnetic transducer that instead of being fastened to a speaker cone is tied to two springs. The transducer arms move in accordance with the sounds twisting the springs. This tension is transferred down the spring to another part of the transducer—a pick up mike device. The springs move the mike diaphragm back and forth but because of the length and resiliency of the springs the sound from the driving unit is delayed getting to the mike unit. A small amplifier is used to boost the signal so that the reverberation speaker has a signal of the same approximate power as the auto speaker already in the car.

SUMMARY

Automobile radios are of necessity designed and built from more rugged material and components

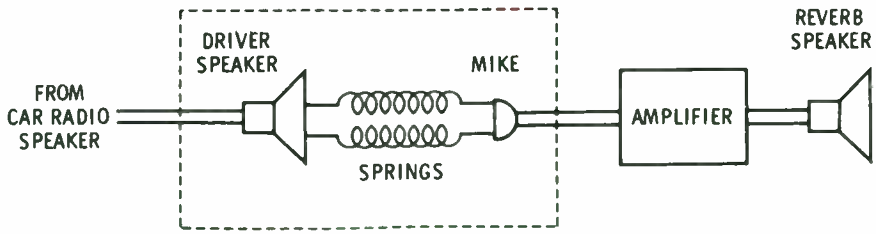


Figure 23 — Simplified diagram of reverberation unit.

than home sets. They are also available with features that have largely disappeared from home sets. A series of push buttons are frequently included that allow you to easily select your favorite stations. Deluxe models have motor driven search tuning systems that will (at the push of a button) advance the tuner to the next station within range.

Auto radios have other noteworthy differences from other types of sets. In general, any circuitry that is subject to ignition generated interference is shielded in a metal case. Filtering is provided where all wire leads enter to prevent interference.

The most difficult part of servicing auto sets is removing them from the car.

If you have trouble removing one, check with your local auto dealer's service agency for the make of car involved. The service agency will normally be glad to supply you with removal instructions.

TEST

Lesson Number 69

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-069-1.

1. The power supplies used in tube-type auto radios are __________ those in home radios.
- A. identical to
- B. unlike
- C. sometimes like
- D. rarely like

2. Power supplies in tube-type auto radio cause DC to appear like AC by interrupting it with a
- A. transistor.
- B. fullwave rectifier.
- C. vibrator.
- D. none of the above.

3. A nonsynchronous vibrator power supply ________ uses a separate rectifier.
- A. never
- B. sometimes
- C. rarely
- D. always

4. A synchronous vibrator power supply __________ uses a separate rectifier.
- A. never
- B. sometimes
- C. rarely
- D. always

5. Auto radios _________ have RF amplifiers.
- A. usually
- B. never
- C. cannot
- D. rarely

6. Bandpass RF tuning is desirable because it

A. is highly selective.

9 B. is highly sensitive.

C. improves fidelity.

D. conserves battery current.

7. Losses due to capacitances in the antenna and shielded lead are minimized by

A. shorting them to ground.

B. isolating them from ground.

6 C. making them a part of the resonant circuit.

D. shunting them with resistance.

8. One common type of RF coupling to the mixer in good quality auto radios is through

A. direct coupling.

B. a pi-network.

C. direct coupling with an inductor.

D. a resistor.

9. The most common IF frequency in tube-type auto radios is ______ kHz.

A. 455

B. 600

10 C. 862.5

D. 262.5

10. Auto radios are ________ than home types.

A. less selective

21 B. more rugged

C. less sensitive

D. easier to service

Notes

Notes

Portions of this lesson from
Auto Radio Servicing Made Easy
(2nd Edition)
by Wayne Lemons
Courtesy of Howard W. Sams, Inc.

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

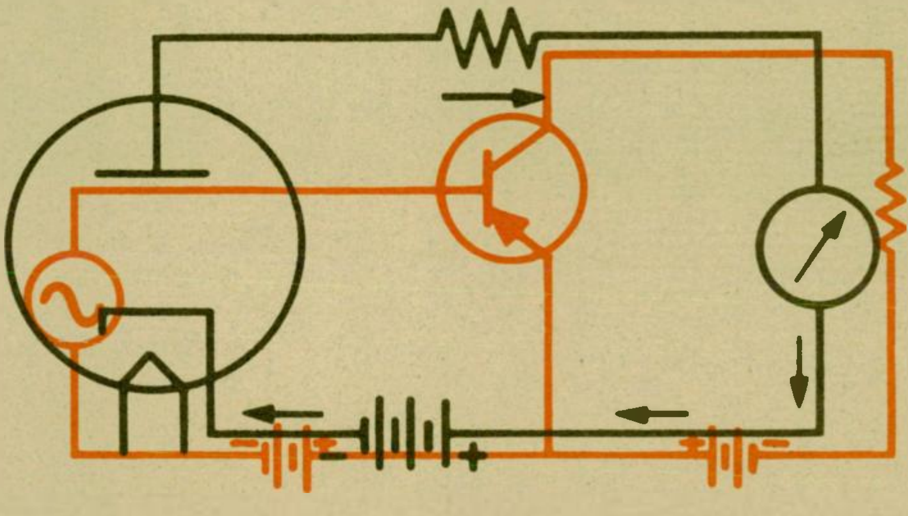
GO ON THROUGH

"The standard of manhood is not strength alone,
It isn't a measure of sinew and bone;
Your brain and your brawn aren't worth thirty cents
If you don't go on through with the things you
commence.
Reward is for the plodder, the bulldog-jawed fellow,
Who never grows blue and who never turns yellow,
Who learns how to suffer without yelp or bellow,
And smile all the while as he faces his trial—
Success is far more than a matter of wit;
It can't be achieved without courage and grit."

Herbert Kaufman

LESSON NO. 70

AUTO RADIOS TRANSISTOR TYPE



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE NO. 52-070

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CONTENTS

Advance Schools, Inc.

52-070

AUTO RADIOS —TRANSISTOR TYPE

INTRODUCTION

Transistors have replaced vacuum tubes in nearly all auto radios in current use. Rarely does the serviceman encounter an all tube auto radio. If he does it is from a foreign import car with a 6-volt electrical system.

The transition from vacuum tube to transistor was neither smooth nor instantaneous. Although fully transistorized sets were desirable, early transistors failed the challenge. They lacked sufficient gain and generated excessive noise and, therefore, were unsuited for RF and IF circuitry. A strong plus in their favor was the fact that they could operate from 12V DC eliminating the necessity for an expensive and bulky vibrator power supply. Almost equally important was the absence of a heat producing, power wasting heater element and the resulting long life of the transistor.

Since early transistors were well suited for audio stages and could perform from a 12V DC source a mixture of tubes and transistors appeared in auto radios in the late 1950's. A special series of RF-IF and converter tubes were developed that could operate with 12V DC on their screens and plates.

The product of this mixture was the *hybrid* (combination tube-transistor) radio. This design served to accomplish one important goal, it eliminated the vibrator power supply.

Soon after the adoption of the hybird radios, improvements were made in solid-state devices (in the early 1960's) and transistors replaced vacuum tubes altogether.

Currently, FETs show considerable promise and may, in a very short time replace transistors in some auto radio circuitry. The success of integrated circuitry in other products has also had an impact on thinking relative to auto radio design.

Auto radios of the near future will undoubtedly contain more and more integrated circuitry. Possibly, LSI (large scale integration) will be extended into auto sets. This could result in a set in which all the circuitry is on a single chip.

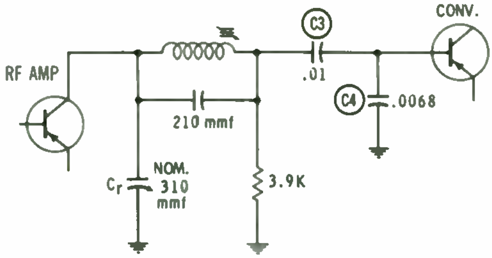


Figure 1 — Pi-coupled transistor RF-amplifier circuit with 30-ohm output.

TRANSISTOR RF CIRCUITS

In the transistor RF circuit the *pi* circuit is the "odds-on" favorite. The only difference from the tube circuit is that here the circuit is straightforward; that is, the signal goes in at high impedance and is transferred out at a lower impedance. In the circuit of Figure 1 the output impedance of the circuit is less than 50 ohms average across the broadcast band. Since the signal is tapped off to the base of the converter between the .01 mfd (C_3) and the .0068 mfd (C_4), the average impedance of the signal going into the base circuit is around 30 ohms. This is an ideal situation for a transistor since it requires a low-impedance input for good performance. The impedance is, or seems to be, low even for a transistor, but this improves the selectivity of the circuit, makes it more stable, and is necessary since the base circuit must be close to ground potential for the oscillator circuit to operate correctly.

The circuit of Figure 2 has an average impedance at the base of the transistor of about 75 ohms. Selectivity is improved in the RF collector circuit by bridging the tuned circuit with a 560-ohm resistor.

Neutralization

4

Transistors are sometimes neutralized, especially in RF amplifier circuits. Neutralization makes the circuit more stable (less tendency to oscillate) and also can improve the signal to noise ratio. Because of the low impedances of transistor circuits the neutralization can be rather broad and often no adjustment is provided. Figure 3 is a neutralized RF amplifier used by Bendix on Lincoln and other radios. The 27 mmf neutralization capacitor feeds back a portion of the signal from the collector circuit to the base circuit phased so as to be degenerative. The signal voltage is actually taken across the 390-ohm resistor in the collector circuit and across the .01 and .0068 mfd cap-

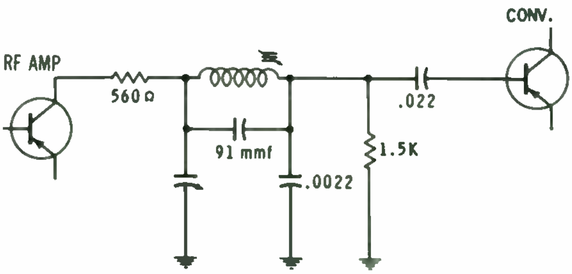


Figure 2 — Pi-coupled transistor RF-amplifier circuit with 75-ohm output.

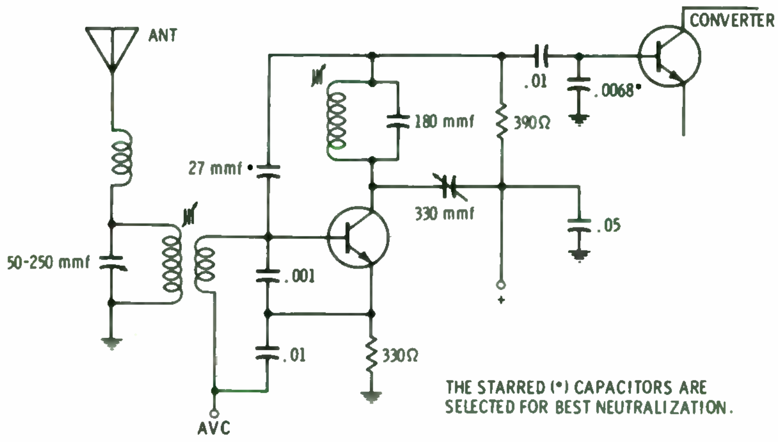


Figure 3 — Simplified neutralized RF amplifier circuit.

acitors. Since this is at the "cold" end of the collector coil it acts to cancel the signal fed back from the "hot" (collector) side of the coil through the capacity of the transistor back to the base. Both the 27 mmf and the .0068 mfd capacitor are selected in manufacture to provide the nominal feedback signal.

TRANSISTOR IF CIRCUITS

Most manufacturers of modern radios produce the all-transistor radio. Not many years ago it took about seven transistors to do the work of five tubes and even then the results were not as good because of the high internal noise in the earlier transistor. Today the five-transistor radio is common with two or three diodes used for detection and AVC and the performance easily rivals the tube counterpart.

The transistor IF stage today
5 uses only one transistor and two
6 *dual-tuned* IF transformers, usually with an IF of 262 kHz. This differs from the transistor portable where we usually find a two-stage IF with *single-tuning* 455 kHz. A typical car-radio transistor IF stage is shown in Figure 5. Since the base circuit is a low impedance, the

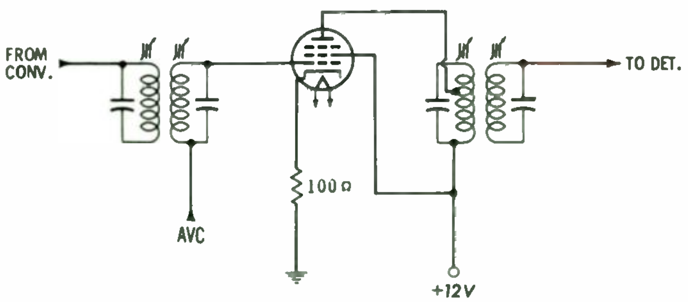


Figure 4 — Hybrid-tube IF amplifier.

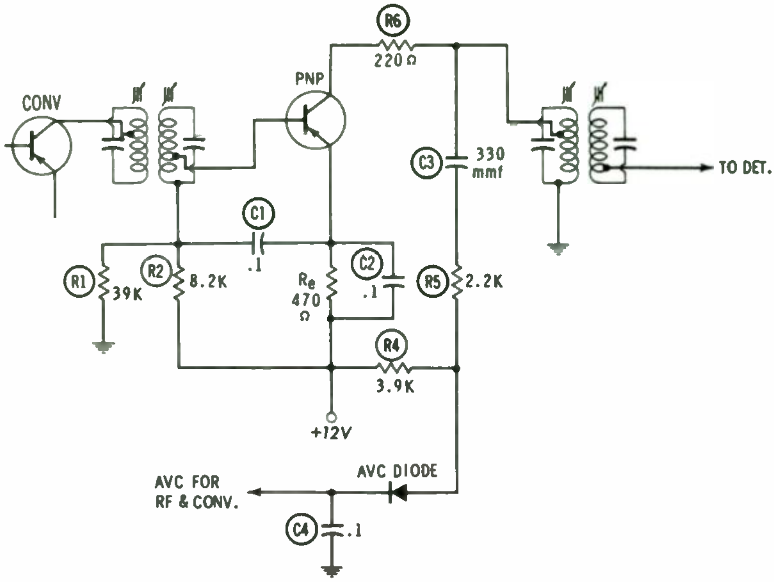


Figure 5 — Transistor IF stage.

7 tuned circuit of the IF transformer from the converter stage must be tapped down to match the input impedance of the transistor. Otherwise there would be virtually no signal transfer because the transistor would load, or "swamp out," the tuned circuit. The collector circuit is also tapped down to provide a better impedance match. Although this circuit is a much higher impedance than the base circuit, it still is considerably below the output impedance of a pentode tube.

If the collector circuit is connected directly to the "hot" side of a tuned circuit (it sometimes is), the

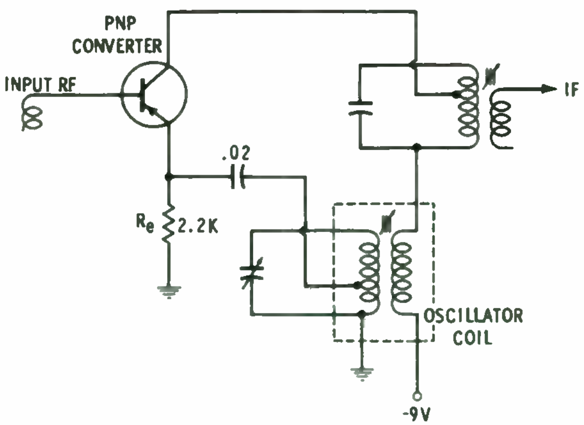


Figure 6 — Typical transistorized mixer-oscillator circuit.

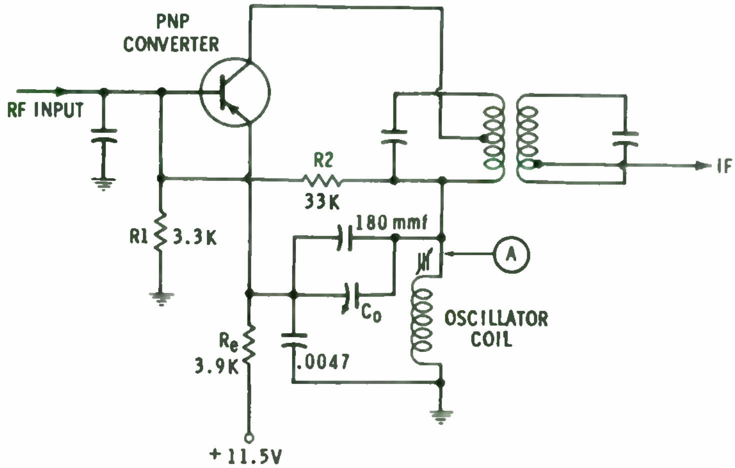


Figure 7 — Colpitts oscillator used in transistor converter stage.

transistor will load the circuit and decrease its gain and selectivity just the same as placing a shunt resistance across it. Sometimes, to further decrease loading, provide better stability, and lessen the tendency to oscillate, a resistor is connected in series with the oscillator and tuned circuit, as is the 220-ohm resistor in Figure 5.

AVC is not applied to this IF stage, but it is in other transistor designs. The base circuit of the transistor is biased by resistors R_1 and R_2. The 470-ohm emitter resistor provides stabilizing and protective bias for the transistor. Capacitor C_1 bypasses the base circuit, and C_2 bypasses the emitter circuit. If either of these capacitors open up in service it will cause degeneration and lower the stage gain.

Most transistor radios use a separate detector from the IF collector circuit to develop AVC voltage. This is covered in more detail later in this lesson.

TRANSISTOR CONVERTERS

The auto radio transistor converter is different from most other converters used in portable transistor radios. Most portables use a dual winding with one winding tapped, while the tuning is done with a variable capacitor; Figure 6 is a typical circuit. In car radios the oscillator is a transistorized version of the Colpitts. This is an ideal circuit for slug-tuning since it does not require that the oscillator coil either be tapped or have a secondary winding.

In the circuit of Figure 7 the oscillator circuit has the frequency-adjustment capacitor (C_o) in parallel with a 180-mmf capacitor. These two capacitors are in series with a .0047-mfd capacitor across the oscillator coil and make up the resonant circuit. The emitter is tapped at the junction of these capacitors and also has a 3.9K resistor back to the +11.5 volts. The resistor provides automatic bias for the circuit (similar to the grid resistor of the tube circuit). This keeps the converter circuit nonlinear, and therefore makes it a good mixer.

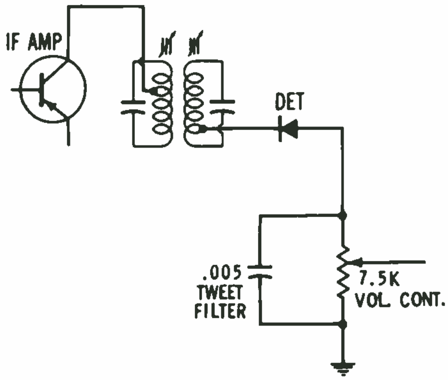


Figure 8 — "Tweet" filter in this transistor circuit is a .005-mfd capacitor.

The RF signal goes into the base of the converter. Since the base circuit is nearly at ground potential because of its low-impedance input, it has virtually no effect on the oscillator operation. Bias resistors R_1 and R_2 start and maintain conduction of the converter transistor by providing the necessary forward bias.

Difference of Transistor Circuits

One difference that is striking
9 about transistor circuits is the much larger bypass capacitors that are used as compared to tubes. This is true of the transistor tweet filter circuit. In transistor circuits this filter may simply be a .005-mfd capacitor connected directly across the volume control (Fig. 8). In tube circuits this size capacitor would be intolerable, but with the low-impedance circuits of the transistor it takes a capacitor 20 to 100 times larger to give the same effect as in a high-impedance tube circuit.

TRANSISTOR CIRCUITS

At the present time, transistor detector-AVC circuits in auto radios are not as simple as their tube counterparts; however, this isn't necessarily true of transistor portables. Many of the auto radios use PNP transistors requiring a positive polarity source of AVC voltage to the base of the transistor to reduce the gain. (Negative voltage could be applied to the emitter). Positive-polarity AVC voltage could be obtained by reversing the AVC diode in Figure 9; unfortunately, this won't solve the problem. Since most car radios use a negative ground, this requires that the emitter and base circuits of a PNP transistor be connected to the positive polarity source; this means that the AVC circuit must work against the 12-volt source rather than ground as in tube circuits. This would require that the detector also use 12 volts common if the detector diode is used as an AVC diode. This has been done successfully, but most designers seem to prefer the use of a separate diode (some use two or more) to supply the AVC voltage.

In Figure 9 the IF signal is taken off the collector of the IF transistor and fed through a 330-mmf capacitor C_3 and resistor R_7 to the AVC diode D_1. A 3.9k resistor (R_6) is connected back to the +12-volt source

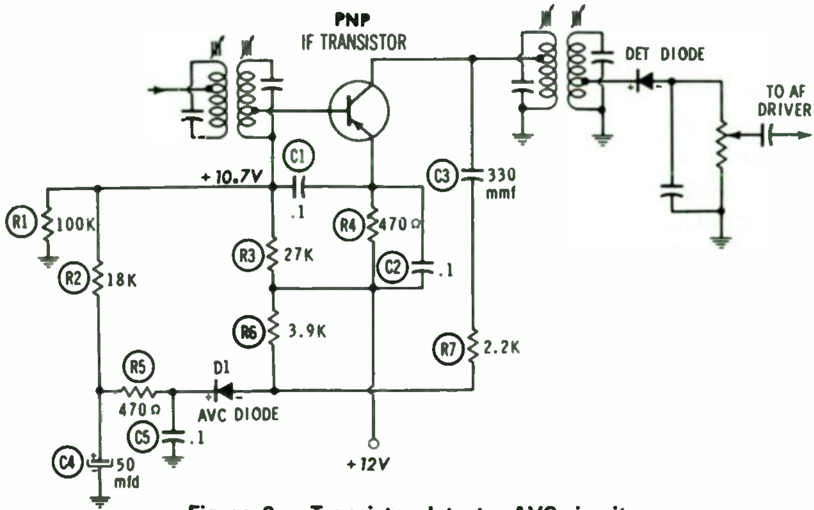


Figure 9 — Transistor detector-AVC circuit.

to bias the diode that conducts through R_5, R_2, and R_1 to ground. The base bias voltage is tapped off at the junction of R_1 and R_2. The no-signal voltage here is +10.7 volts. Now with a signal applied, diode D_1 will conduct even more, causing the base of the IF transistors to go even more positive. Since a more positive voltage at the base actually results in a less negative bias between the base and emitter (the emitter is +11 volts), the gain of the transistor is reduced in proportion to the strength of the IF signal. Resistor R_3 provides protective bias in case the AVC diode is open.

Two-Diode AVC Circuit

Figure 10 is another transistor detector-AVC circuit. It resembles

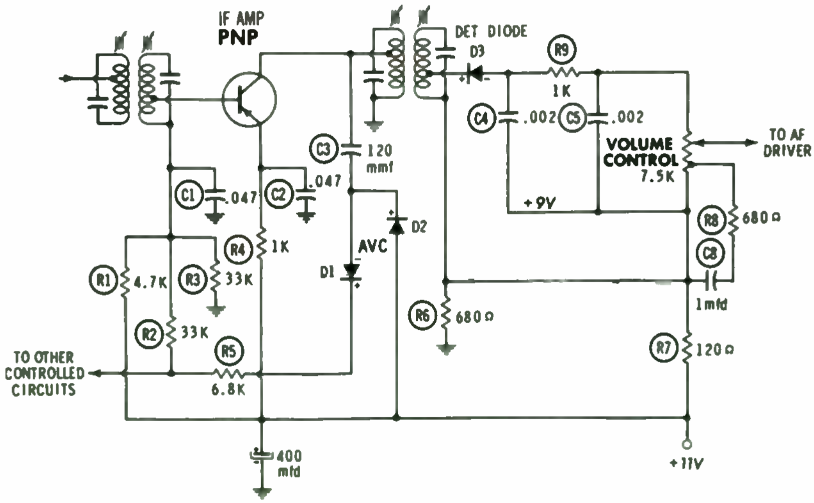


Figure 10 — A two-diode AVC circuit with separate detector.

Figure 9, except that a voltage-doubler circuit consisting of D_1 and D_2 is used to supply AVC voltage. Residual positive-polarity bias is supplied from the +11-volt line through the diodes in series. In the detector circuit the return circuit is not to ground but to +9 volts; this has no effect on the detector, but it does allow direct coupling to a PNP driver stage without the use of an electrolytic coupling capacitor. The tweet filter is a little more elaborate than some; a 1k resistor (R_9) is bypassed on each side by .002-mfd capacitors C_4 and C_5. A tapped volume control provides tone compensation at low volume. Note how much smaller resistor R_8 is (680 ohms) and how much larger capacitor C_8 is (1.0 mfd) than their counterparts in tube circuits.

UNUSUAL AVC CIRCUIT

An AVC circuit that might seem unusual will pop up now and then in transistor radios. At first glance it seems that the polarity of the AVC voltage is reversed, and indeed it is to the conventional AVC circuit. In Figure 11 a PNP transistor is used; with conventional circuits the polarity of the AVC would have to be positive in order to reduce the gain of the circuit by the reduction of the bias and the collector current. This positive bias counteracts the normal negative bias of a PNP transistor. In Figure 11 the AVC voltage is negative and increases in a negative direction with more signal. This seems to increase the gain of the transistor rather than reduce it as required for proper AVC action. To understand how this circuit can work, refer to Figure 12. Here is a gain curve (idealized somewhat) of a

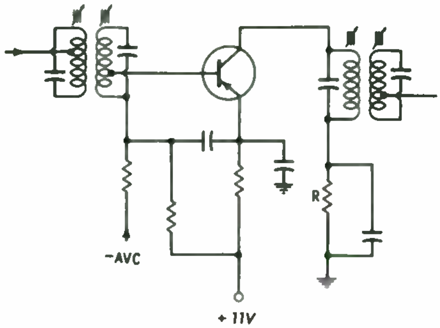


Figure 11 — Reverse AVC circuit.

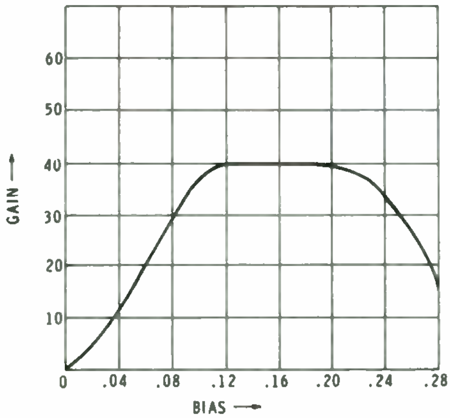


Figure 12 — Gain curve of circuit in Fig. 11.

typical transistor. Note that once the bias rises so high, an increase in bias does not increase the gain of the stage; if we increase the bias far enough and the circuit parameters are right, the gain will decrease. This decrease can be used for AVC action. Notice in Figure 11 that a resistor (R) is in series with the collector circuit. This resistor is the secret of reverse-bias AVC. As the bias increases, the current through the transistor increases,

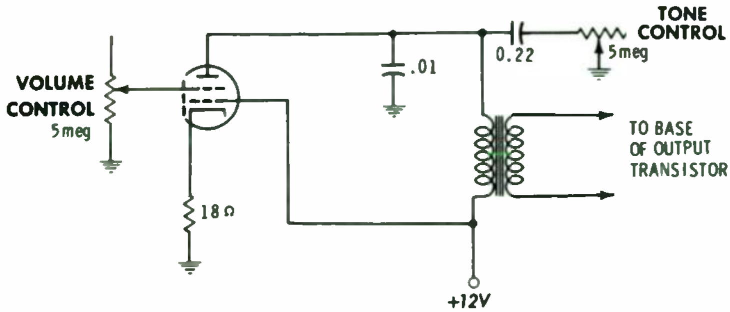


Figure 13 — Hybrid-tube audio driver—notice the position of the signal input grid.

thus increasing the voltage drop across *R* and reducing the collector voltage. The reduced collector voltage reduces the gain of the transistor. The emitter resistor alone will also produce this effect; since as the transistor current increases, the drop across the emitter resistor increases, the collector-to-emitter voltage is reduced, and the gain is reduced.

This circuit has some advantage since the impedance of the base circuit remains virtually unchanged because of the AVC voltage. Therefore the loading on the input transformer does not change, tending to upset the tuning. If a transistor is cut off (zero or reverse bias) with conventional AVC, the impedance of the circuit suddenly goes higher because there is no longer any base current. This means that with no load on the circuit the voltage is increased; this voltage tends to try to start the transistor conducting again. Of course, the equalizing action of the AVC circuit tends to correct these faults; consequently, they are usually not a problem in low-frequency circuits. In high-frequency circuits the change in loading could affect the selectivity and bandpass.

The important thing is to not be confused if the AVC voltage in some circuits seems to be operating with the wrong polarity.

Hybrid Drivers

Figure 13 is a special tube driver developed for low-voltage hybrid radios. In order for the driver tube to get enough current to adequately drive a transistor output stage with only 12 volts on the plate, the grid next to the cathode is not used as the signal input grid as in other tubes. Instead this grid is used as an accelerator grid by connecting directly to the +12 volts. A second grid between the accelerator grid and the plate is used as the signal input grid. This arrangement provides adequate output transistor current drive.

TUBE-TRANSISTOR DRIVER

Since by nature a transistor is a low-impedance device (current driven), it makes the ideal driver when a transistor output stage is used. Unfortunately, the detector circuit of a hybrid tube circuit has a

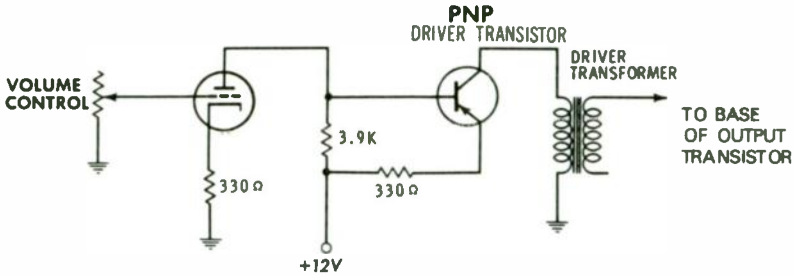


Figure 14 — A simple tube-transistor combination AF driver.

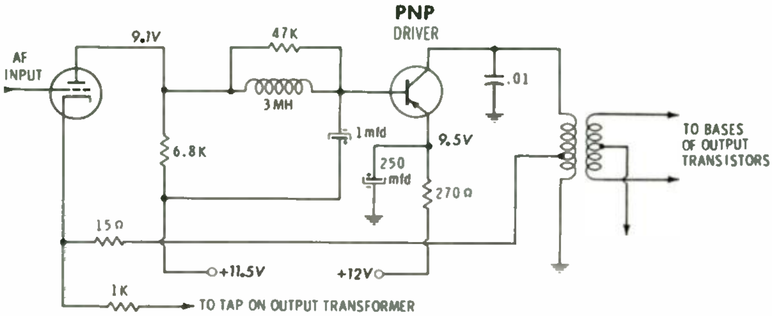


Figure 15 — A tube-transistor combination driving a push-pull transistorized output stage.

high impedance if it is to work best. The circuit of Figure 14 combines the good features of both the tube and transistor and provides good impedance matching in each case. The signal from the detector is fed through the volume control to the grid of the 12AE6 triode driver tube. To more nearly match the input impedance of the transistor, the tube uses a 3.9k resistor as a plate load. Since current through this plate-load resistor causes the plate side to be less positive (more negative), this voltage drop can be used to bias a PNP transistor. (The middle letter of a transistor type tells what the bias and collector voltage should be—PNP means Negative, NPN means Positive.) This makes direct coupling from the tube to the transistor possible and ensures a maximum transfer of power with a minimum of components. The collector circuit of the transistor drives the audio-output transistor through an AF transformer designed to match the collector-to-base impedance.

Figure 15 is a more elaborate driver circuit. The cathode of the driver tube is returned to a tap on the driver transformer through a 15-ohm resistor to provide some inverse feedback. The cathode is also returned to a tap on the output transformer through a 1k resistor for additional degenerative feedback. A 3-mh choke bypassed by a 47k resistor "cleans up" any IF signal that may have slipped through. It also prevents instability because of nonlinearity in the feedback circuits. The 1.0-mfd bypass capacitor gives some idea of how low the driver-stage base-circuit impedance is. If the 3-mh choke opens, the radio volume is reduced until it is only usable on strong stations where the audio sounds somewhat tinny.

TRANSISTOR DRIVER

Figure 16 is a transistor driver circuit as used in an all-transistor radio. The detector circuit is made to have a low impedance by tapping down on the last IF transformer. A 7,500-ohm tapped volume control feeds the base of the driver transistor through 3-mfd capacitor C_1. The transistor is biased from the +12-volt line through 5.6k resistor R_3 and 15k resistor R_2 to ground. Stabilization bias is provided by emitter resistor R_4.

Tone-Control Circuit

The tone-control circuit of Figure 16 is similar to circuits used with vacuum tubes The principle difference is that the sizes of the resistors are smaller, and the sizes of the capacitors are larger, because the transistor circuit has a lower impedance than the tube circuit.

In Figure 16 the tapped volume control circuit is in series with R_6 and C_4 to boost the bass response when the radio is playing at low volume. This compensates for the human ear, which tends to be less responsive to bass at low volume levels. The amount of bass boost is dependent on the position of the grounded center arm of the tone control R_7. When the center arm of the tone control is moved to the right, it has virtually no effect on the bass boost and the bass boost is at maximum. At the same time capacitor C_3 has very little resistance in series with it, and the high frequencies are bypassed to ground. When the center arm of the tone control is moved to the left, the bass boost circuit is shorted to ground and the entire resistance of R_7 is in series with C_3, so that only a small amount of the high frequencies are bypassed.

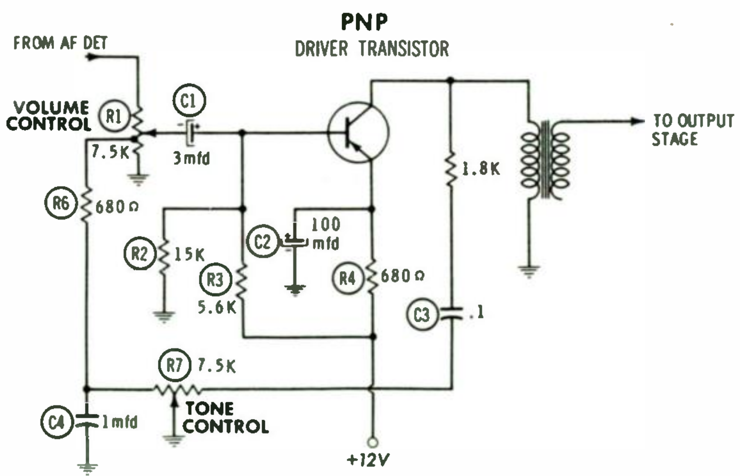


Figure 16 — Transistor driver stage with tone-compensated volume control and variable tone control.

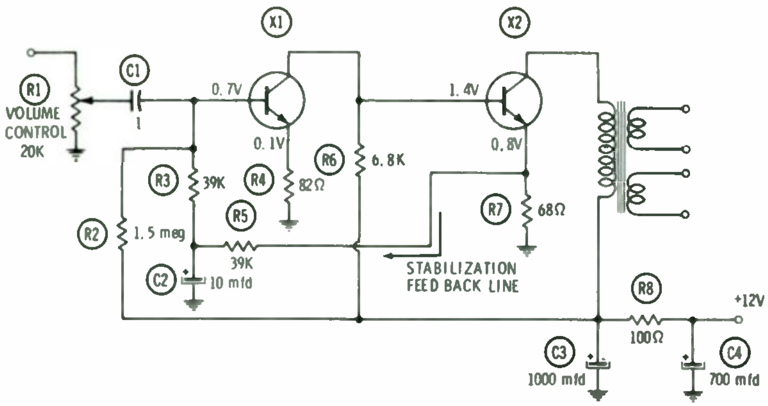


Figure 17 — A direct coupled driver circuit.

Direct-Coupled Driver

Transistors lend themselves to direct coupling and auto radio designers like to take advantage of the added gain of an extra transistor if they can do so without adding too many parts.

Figure 17 is a direct coupled driver. The bias for X_1 is taken through R_2 and the bias for X_2 is set by the collector voltage on X_1. Stabilization of this circuit is through the two 39k resistors (R_3 and R_5). The stabilization works this way: If the current increases through X_1, the current through the 6.8k collector resistor will increase, increasing the voltage drop across the resistor. This means there is less voltage at the collector and, consequently, on the base of X_2. This reduced voltage on the base of X_2 lowers the current through, and the voltage drop across, the emitter resistor. This reduces the bias for X_1 counteracting the original increase in current through X_1. To prevent the audio from also being reduced by degeneration through the 39k resistors, the audio change is bypassed by the 10-mfd capacitor so that there is only DC stabilization feedback.

All direct-coupled circuits must have some stabilization. In some circuits the audio output transistor is also direct coupled to the driver

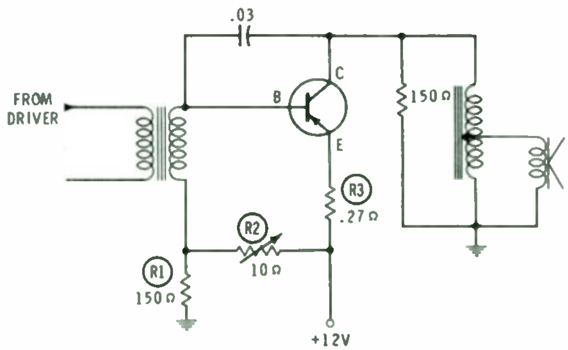


Figure 18 — Single-ended transistor output stage.

stage with the stabilization over three transistors instead of two.

TRANSISTOR OUTPUT

Figure 18 shows a single-ended transistor output stage. All audio power transistors used in car radios have been PNP types. A PNP must have negative collector voltage. The collector is always close to ground potential in American cars because all 12-volt American cars have negative-grounded batteries. The emitter circuit is then tied to the plus side of the battery, and bias, which must be negative (from base to emitter), is taken from the junction of R_1 and R_2. In this circuit R_2 is adjustable, although in many circuits R_2 is fixed and R_1 is adjustable; either method will adjust the collector current of the transistor by variation of the bias. Adjustment of the collector current is important since too little current will restrict the power output and cause distortion, while too much current can damage the transistor. The 0.27-ohm (notice the decimal) resistor is used more for protection than for bias. In the event of a transistor short, this resistor will open up and prevent damage to other parts. This resistor is used in most transistor output designs, and its size can range from .22 ohm to .8 ohm. It is nearly always a fusible resistor; that is, it will burn out like a fuse when overloaded, and in addition, it can also be temperature compensating to provide some protection against thermal runaway. However, to be temperature compensating in this circuit it would have to have a positive temperature coefficient (PTC). It should be replaced, if possible, by the same type of resistor used in the original equipment—and by all means it should be fusible. In most circuits a larger resistor than the original can be used at a slight sacrifice in power output. When the emitter resistor is checked in-circuit, be sure to reverse the ohmmeter leads and take a second reading. A fairly low reading in one direction may be obtained because of the diode action of the transistor.

The 150-ohm resistor from the collector circuit is used to minimize the pulse voltage when the radio volume is turned up or if the speaker is inadvertently opened, minimizing the danger of transis-

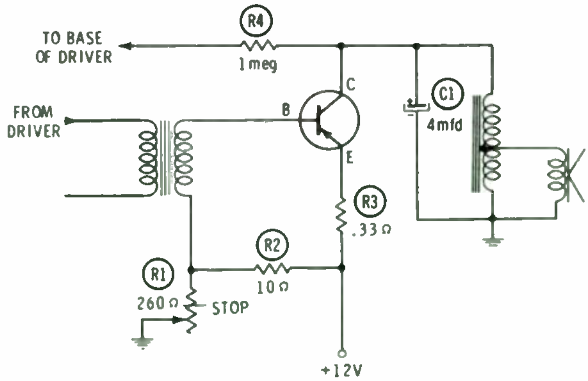


Figure 19 — Transistor output stage with inverse feedback.

tor breakdown. Removing the speaker is always treading on dangerous ground because the pulse voltages can destroy the transistor by causing an internal short.

The .03-mfd capacitor from the collector to the base makes an effective degenerative high-frequency bypass circuit. This is accomplished with a smaller size capacitor than would be required from collector to ground, as will be seen in the next circuit.

Another Single-Ended Circuit

Figure 19 is similar to Figure 18 except that R_1 is the bias adjustment and R_2 is fixed. A stop on the R_1 control prevents adjustment of the base voltage to zero. The collector in this circuit is bypassed to ground. Because the circuit has such a low impedance, a 4-mfd capacitor is required for the bypass action. This large bypass also helps to prevent transient pulse voltages that might damage the transistor since a resistor is not used across the output transformer.

A 1-meg resistor from the collector back to the base of the driver transistor gives some inverse feedback. Inverse, or degenerative, feedback reduces the harmonic and phase distortion and adds to the circuit stability; at the same time it reduces the sensitivity of the circuit in proportion to the feedback, but with ample audio drive this is no concern.

Figure 20 is similar to the other two transistor output circuits, except for the *thermistor* that is used in the base circuit. This thermistor has a negative temperature coefficient (NTC), which means that its resistance will decrease with an increase in the temperature around it. Since transistors draw more current with more heat, a temperature-sensitive thermistor is used to reduce the forward bias of the transistor as the heat goes up. A fixed resistor is connected across the thermistor to act as a safety valve on the circuit if the thermistor is open.

Inverse feedback in this circuit is taken from across the speaker and

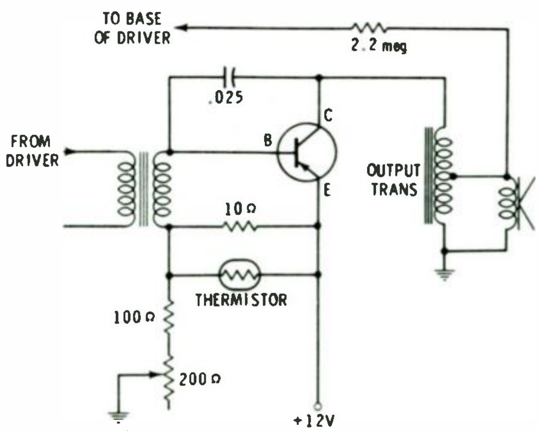


Figure 20 — Output stage with thermistor protection.

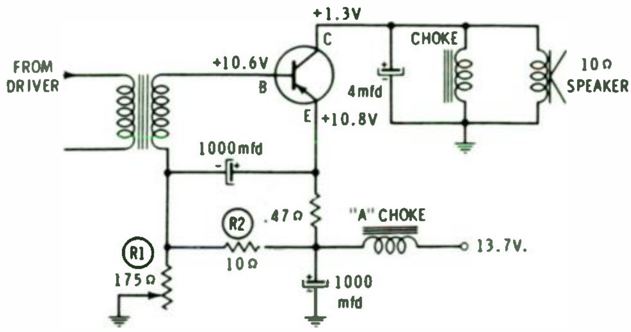


Figure 21 — Output stage feeding speaker directly with no output transformer.

fed back to the base of the driver transistor.

Figure 21 is still another circuit with the principle difference that the speaker is connected directly from the transistor collector to ground rather than from a tap on the output transformer. An audio choke impedance parallels the speaker. To have maximum output, the speaker should have the same impedance as the original—10 ohms in this case. A 1,000-mfd electrolytic from the emitter to the base circuit prevents any degeneration through the bias circuit and insures maximum sensitivity.

SETTING THE BIAS

Nearly all service literature explains how to set the bias on the transistor output stage. It may be by opening the collector circuit and reading the current with a milliammeter, or it may be suggested that the voltage from the collector to ground be read and the current calculated across the resistance in the collector circuit. If service literature is available make the adjustment as outlined; if the current is not known and there is trouble keeping output transistors in the set, here is a method that will work well and requires a minimum of equipment. This is how to quick set the bias:

1. Connect the radio to the shop power supply and adjust the voltage for exactly 12 volts.

2. Watch the ammeter on the power supply and turn the output-transistor bias adjustment to the point of lowest current drain.

   Note that it is sometimes better to watch the voltmeter and set the bias control for maximum voltage, since this represents minimum current.

3. The radio output should now be distorted. Turn the bias control until the distortion at normal volume just disappears, then advance the control just slightly past this point.

4. Check the radio for distortion at different volume levels. If there is none, the bias is set at the optimum point.

5. If there is still a noticeable or unusual amount of distortion at high volume, advance the bias control slightly more and see if there is an improvement. If there is no improvement, return the bias control to the original setting arrived at.

6. Caution: make sure the bias is set with the radio powered with not more than 12 volts—remember when the radio is installed in the car and the generator is charging, the voltage will go up to around 14 volts, increasing the bias and collector current.

Checking many radios in this manner has proven that this method is as good and sometimes better than setting the bias according to factory specifications. This is especially true for the installation of a new output transistor that is a substitute rather than an exact replacement.

PUSH-PULL TRANSISTOR OUTPUT

Figure 22 A is a class-B push-pull transistor output stage. Two special differences should be noted as contrasted with the single-ended stage. One, there will be little or no speaker "thump" when the radio is first turned on; second, the current of the class-B stages varies with signal input in accordance with modulation. Where the single-ended class-A stage may draw 1-amp or more of collector current, the idle (no signal) current of this class-B stage can be as little as 50 to 100 ma. Fortunately, the quick-set bias method can be used with this circuit too. Here's how:

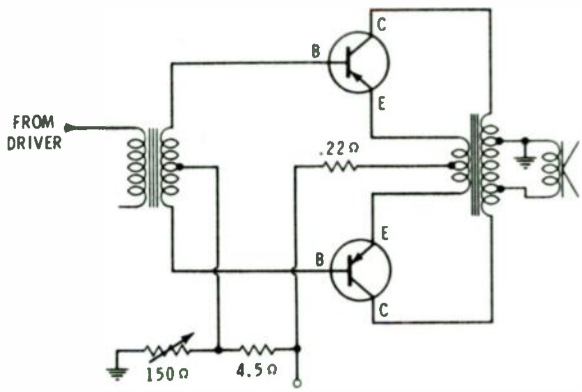
1. Set the power supply to exactly 12 volts.
2. Turn on the radio for low volume—just so you can hear it with your ear near the speaker.
3. Adjust the bias control for the least amount of current before distortion begins. The correct bias setting is when there is no detectable distortion at the lowest volume where the radio can be heard.

This particular circuit has another unusual feature; it uses a dual winding on the output transformer. The reason is to provide better linearity and less distortion since part of the output is fed back into the emitter circuits for inverse feedback. Obviously, should this transformer have to be replaced, the leads would have to be connected in the correct phase or oscillation would occur—if this should happen, reverse one set of leads to either the emitters or the collectors, but not to both.

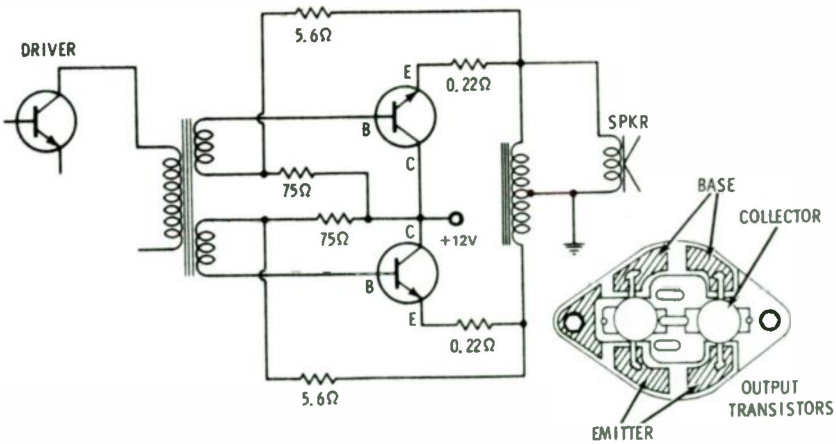
Another Kind of Class-B Output

Figure 22 B is a class-B push-pull transistor output stage. This Bendix circuit uses an emitter-follower output with a split-secondary driver transformer. This circuit is biased so that only one transistor works at a time. One transistor works on one half cycle and the other on the other half cycle as in all class-B circuits. The advantage of this circuit is that the efficiency is high and battery current is low when the volume is turned low. This would be a factor if the owner of an auto radio uses it quite a lot when the motor is not running.

The circuit also allows the use of smaller transistors and less bulky heat sinks. In the case of the Bendix and others the push-pull silicon transistors are both houses in the same housing which is about the size or slightly smaller than older single germanium output transistors. The idling current of these transistors operated class-B is less than 200 milliamperes compared to around 800 to 1500 milliamperes for a single germanium output



(A) Tapped secondary.



(B) Split secondary.

Figure 22 — Typical Class-B output stages.

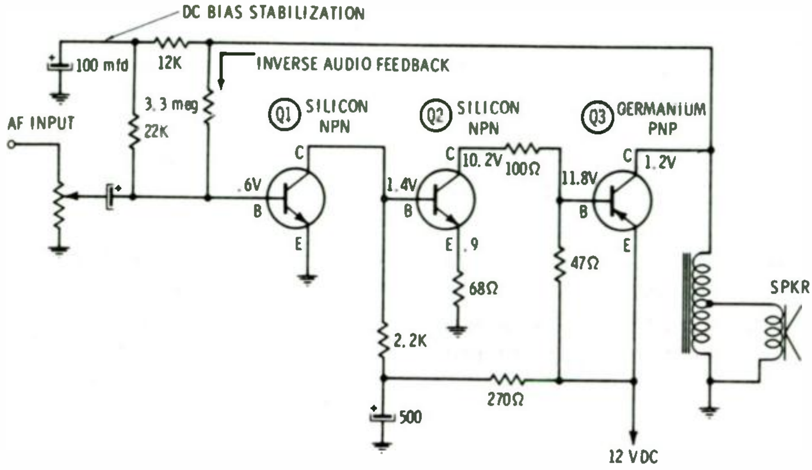


Figure 23 — A direct-coupled 3-transistor audio amplifier.

transistor operated class-A.

THREE-STAGE DIRECT- COUPLED AUDIO CIRCUIT

There have been many variations of the three-stage direct-coupled circuits but all work essentially the same way. Figure 23 is a typical circuit used in Motorola radios. Two silicon transistors are used as drivers and a germanium power output transistor completes the chain. You will note that no bias adjustment is used with this circuit. Some manufacturers place an adjustable pot in the emitter of the first driver stage to set the output transistor current but the inherent stability of the silicon transistors and feedback stabilization circuits have caused most manufacturers to drop the relatively expensive adjustment pot.

In Figure 23, Q_1 has the emitter grounded and bias is applied through the 12k and 22k resistors in the base circuit from the collector of the output transistor. The 100-mfd capacitor at the junction of these two resistors prevents any degenerative audio feedback from the collector of Q_3. A 3.3-megohm resistor does provide a slight amount of degenerative audio feedback and improves the frequency response of the amplifier.

The bias for Q2 is the same as the collector voltage of Q1. If Q1 draws more current the collector voltage is reduced (because of the added drop across the 2200-ohm collector-load resistor) and this, in turn lowers the bias on Q2, reducing the current through it. This would cause the collector voltage of Q2 to rise in a positive direction. Since Q3 is a PNP transistor a more positive voltage on its base will reduce the collector current. This, in turn, will cause less voltage drop across the output transformer and less voltage (+) at the collector. Since Q1 receives its bias from the collector of Q3, the bias on Q1 will be reduced and the original current increase in Q1 is counteracted.

This self-regulating feature of the direct-coupled audio circuit is one of the big reasons for its popularity. In addition, it is less expensive because no interstage transformers are needed. The gain of the three-stage direct-coupled circuit is about the same as a two-stage transformer-coupled circuit but, at present prices, a transistor is considerably less expensive than a transformer.

SUMMARY

In the lesson on Auto Radio Servicing you will be shown how to apply troubleshooting techniques to the servicing of both vacuum tube and transistor radios. If you are in doubt about how some of the circuitry operates review this lesson before proceeding. A thorough understanding of circuits and how they work can save much time in localizing a problem.

TEST

Lesson Number 70

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-070-1.

1. **An auto radio with a mixture of tubes and transistors is called a**
   A. conglomerate.
   / B. hybrid.
   C. mixed-breed.
   D. none of the above.

2. **The advantage of hybrid auto radios over all tube versions is that they**
   / A. do not require a vibrator supply.
   B. are more selective.
   C. are more sensitive.
   D. are all of the above.

3. **The most common method of connecting the RF to the converter is __________ coupling.**
   A. direct
   B. transformer
   C. Pi
   D. capacitive

4. **To prevent oscillation and improve signal-to-noise ratio, transistors in RF stages sometimes require**
   A. positive feedback.
   2 B. AVC.
   C. more bias.
   D. neutralization.

5. Transistor IF sections in modern auto radios use __________ transistor(s).

2 A. 1
B. 2
C. 3
D. 4

6. Auto radio IF stages generally use

A. capacitive coupling.
3 B. dual-tuned IF transformers.
C. single-tuned IF transformers.
D. LC coupling.

7. Tapped windings are often used on IF transformers in transistor radio to

A. improve fidelity.
4 B. conserve power.
C. match transistor impedances.
D. provide more output power.

8. Most transistor auto radios have

A. a separate AVC diode.
1 B. no AVC.
C. a common diode for the detector and AVC.
D. a vibrator power supply.

9. Capacitor values in transistor circuits are ________ those used in tube circuits.

6 A. larger than
B. smaller than
C. the same as
D. none of the above

10. Direct coupling with transistors has the advantage that extra gain can be added to a circuit with

A. no additional parts.
B. no additional transistors.
12 C. only a few additional parts.
D. no additional current drain.

Notes

Portrons of this lesson from
Auto Radio Servicing Made Easy
(2nd Edition) by Wayne Lemons
Courtesy of Howard W. Sams, Inc.

asi

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

OUR FEATHERED FRIENDS

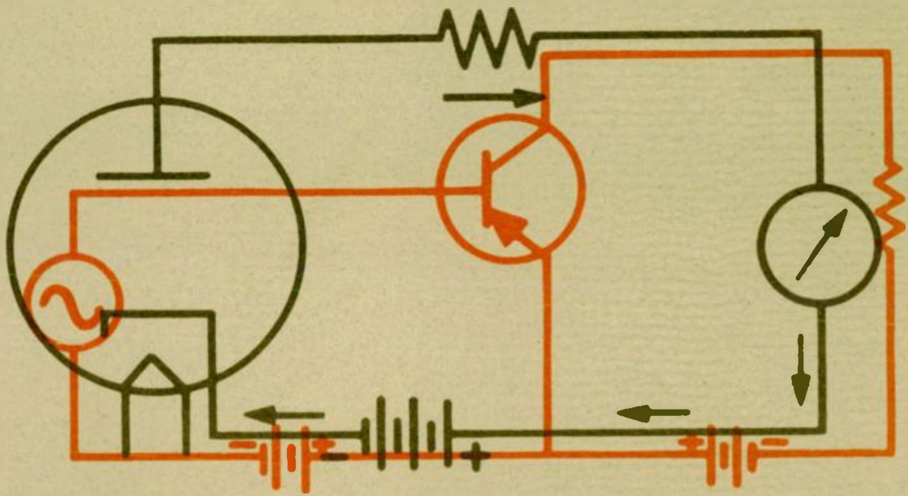
One day, many years ago, a group of airmen were preparing to fly out a hurricane when they noticed a flock of sea gulls that instead of moving away from the storm, leisurely flew right into its center. The gulls knew, what it took scientists years to discover, that because hurricanes move along in a whirling mass, the pivot or center of the hurricane is motion free and calm. Obviously a much safer place to fly.

We can all learn from this. Don't run away from a problem . . . meet it head on. Your lessons, the tough ones, tackle them head-on and soon you'll be "flying safely along."

S. T. Christensen

LESSON NO. 71

AUTO RADIOS SERVICING



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-071
407

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

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CONTENTS

AUTO RADIOS SERVICING

INTRODUCTION

Before starting any repair work, always find out as much as possible from the customer; the information he can give about the set will often aid the diagnosis. Besides, it is not unusual for the customer to have a complaint that may not be noticed when repairing the radio. The set may be intermittent, noisy in spots, fail to get certain stations, etc. Sometimes the customer will have to be led along to find out what his complaint really is. Ask him if it plays intermittently, or perhaps just when the engine is running or only when it is not running; see if he has a particular station or group of stations that are noisy or intermittent; or it may be that he's expecting too much. Whatever the trouble, it is your job to find out what the customer's complaint is—this is / what he will willingly pay you to repair and nothing else.

WHAT TO CHECK BEFORE PULLING THE RADIO

Turn the radio on and see if the tubes light (if used). In transistor and hybrid radios, a "thump" should be heard in the speaker when the switch is first turned on, if there is power to the radio and the output stage is OK (does not hold true for push-pull transistor output stages). If tubes do not light or no thump is heard in the speaker, check the fuse. If the fuse is good, check the speaker by connecting a substitute speaker across the present speaker terminals. In the case of hybrid or transistor radios, a speaker can be connected from the case of the transistor to ground in most circuits, and the radio will play if either the speaker or the output transformer is defective.

Disturb the Circuit

If the tubes can be reached, use a circuit-disturbance test to find the part of the radio that may be bad. When a tube is pulled and there is a crack or a popping noise in the speaker, that tube is drawing current and likely is working. (If the noise is abnormally high, the tube may be shorted or leaky.) Start at the audio output stage; if there is no pop in the speaker, check the audio output tube and the rectifier. If there is a noise when you pull the audio tube, then move back to the driver (first audio) tube, then to the IF amplifier, converter, etc. until you find a tube that gives little or no noise when removed from its socket. Either that tube is bad, or the one just ahead of it (toward the speaker) is bad, or there is trouble in the associated circuits, which means that the radio will have to be pulled for further diagnosis.

TEST EQUIPMENT

The servicing of car radios is similar to the servicing of house or portable receivers. All servicing requires specific types of test equipment, and this is especially true of equipment used to service auto radios. The equipment bench should have available a signal tracer, signal generator, vacuum tube voltmeter, test speaker, auto antenna, and a battery eliminator. The last two items are necessary as substitutes for the car antenna and the 12 volt car battery.

CHECKING A DEAD RADIO

The dead radio is the easiest of all to repair since it is simply a matter of localizing the defective stage and then checking individual parts for a defect. Finding this dead stage usually takes one of three forms, signal injection, signal tracing, or taking educated guesses.

Signal Injection

This technique uses either a signal or a noise generator and, beginning at the speaker, works back toward the antenna until the signal is no longer heard in the speaker (Fig. 1). This technique was described in a previous lesson.

Signal Tracing

Signal tracing is preferred over signal injection by many technicians (Fig. 2). This technique was also described in a previous lesson.

WEAK RADIO

A weak radio can considerably tax the technician who has not developed a system for checking it. This system is best developed by setting up performance standards and using the technician's own equipment.

The signal tracer is an ideal instrument for checking stage gain.

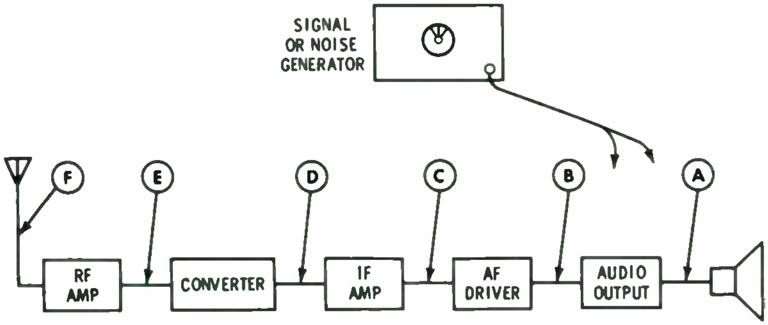


Figure 1 — Progress of signal injection.

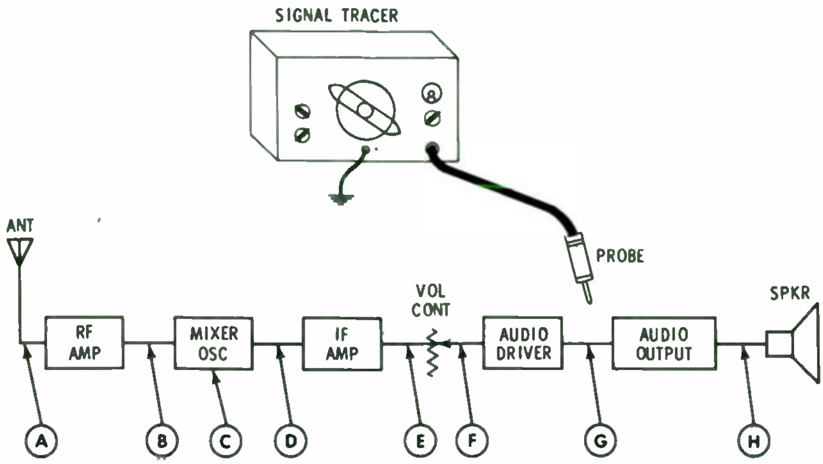


Figure 2 — Progress of signal tracing.

The best way to do this is to first take measurements on radios that are working well at each of the test points listed in Figure 2. After some experience, the technician will know what to expect from a radio, since all radios (within limits) will have similar gains—if not at individual test points, at least at the output of the second IF transformer. This gain should be checked with a signal from a station that has very little fading, but not on one so strong that the AVC is overactive. Try to pick a moderately strong station that has its transmitting tower 15 to 30 miles away from your location.

DISTORTED RADIO

Distortion is nearly always found in the audio stages of a radio; however, some transistor radios may have distortion on strong signals when the AVC is not working properly. This may also happen in hybrid radios when the radio is close to a transmitting station, since the AVC in these radios may not prevent the first stage or stages of the radio from blocking. This kind of distortion, called overload distortion, can be checked by tuning to a weaker station and seeing if the problem disappears. If the radio is still distorted, then look for trouble in the AF amplifier stages.

Distortion occurs whenever a stage is nonlinear, that is, it does not reproduce an exact replica of the signal introduced into the input. This may be caused by weak tubes (though not usually), by incorrect bias voltages, low plate voltage, low screen voltage, all of which are, in turn, caused by leaky capacitors, open or changed-value resistors, etc. When there is a distortion problem, checking the voltages in the suspected stage will usually point the way to the trouble.

Distortion that cannot be attributed to incorrect voltages is likely caused by mismatch of impedances somewhere in the circuit.

This may be a defective interstage or output transformer.

Localizing Distortion

An AF signal tracer monitoring different points in the circuit with the radio playing is one of the best ways to localize a distorting stage. You can actually hear the defect at its point of origin, or at least near it. A signal tracer can sometimes be a little misleading in transistor circuits because of the much lower impedances involved; this is especially true of "dual-purpose" RF-AF probes where the input capacitor is small. With a tracer of this type, it will probably pay to bring out a separate AF probe and use at least a 0.1-mfd coupling capacitor—larger if possible.

Distortion is easier to hear when listening to speech or music at low volume. A steady audio tone signal will not sound distorted through an amplifier that may be severely distorting music or speech. When using a tone signal for distortion measurements, use an oscilloscope and first monitor the signal put in and then the one coming out of the stage; the two signals should be identical, except for gain. Caution: Keep the input low to prevent possible overloading and a false indication. Of course, the stage must be able to handle a reasonable amount of signal without overload. Use a tone that gives a comfortable output in the speaker of the radio.

Speakers may cause distortion. Look for loose voice-coil suspension diaphragms or cones where they are glued to the frame. These will cause "paper" rattles at low frequencies. To reglue a cone edge, place speaker cement between it and the frame and then use a small battery or alligator clips as clamps to hold the cone down while the glue dries.

INTERMITTENT RADIO

The intermittent is the most exasperating of all radio troubles to repair, but even the intermittent responds to the technician with a system. Don't forget to "pump" the customer for information about the history of the radio—be a good listener, as it may save you hours of work later.

If the radio seems to play well on the bench despite all the bumps and vibration given it, and it plays at high and low supply voltage, yet the customer claims it is intermittent in the car, check the antenna system on the car carefully. Use a heavy, insulated tool, such as a screwdriver handle, to bump the antenna pole from different angles and directions; if there is any noise the antenna is ready for replacement.

If this doesn't turn up the trouble, start checking the radio as soon as the reinstallation starts; connect the radio to the battery and to the antenna as soon as the radio is set in the car. Now while tightening up the mounting bolts, it may be noticed that a certain strain will cause the radio to act up. On one or two occasions, it was found that mounting bolts that were too long had reached too far inside the radio, causing intermittent, or erratic, operation. At other times, when the nuts on the front of the radio are snugged up tight, terminals on the volume control may rub against the case, or the case may be distorted so that two noncompatible terminals are brought within sparring distance.

The speaker is one source of an intermittent that shouldn't be overlooked. To test for intermittents, manually move the speaker cone while the speaker is playing, and wiggle the leads going to the voice coil. One of these two tests should cause the speaker to cut off if it is intermittent. Also, try playing the radio at very low volume to see if words are missed. A speaker with a narrow discontinuity in either the coil or connecting lead may operate OK at high volume because of the added vibration and voltage, but these props are taken away when you play the radio softly.

Poorly installed back-seat speakers and switches are hotbeds of intermittents. Often the "do-it-yourselfer," without the benefit of a soldering iron, lackadaisically wraps the wires loosely around the terminals with the individual strands spewing in every direction.

Back on the bench with the intermittent, the most important progress that can be made is to get the set to "act up." For intermittents, it is best to inject a steady signal into or before a suspected stage; connect an output meter across the speaker voice coil. (The output meter is essential since it may show up sudden and short-lived intermittents that escape the notice of the ear.) While the radio is playing, gently move parts in the suspected area while watching the output meter. Push on the printed circuits with the eraser of a pencil. Increase the heat on suspected parts by bringing a soldering iron close by. If no intermittent appears, move the signal injection back a stage and try again.

Signal injection and signal tracing together are best for localizing long term intermittents that give no idea of which stage has the trouble spot. As shown in Figure 3, in-

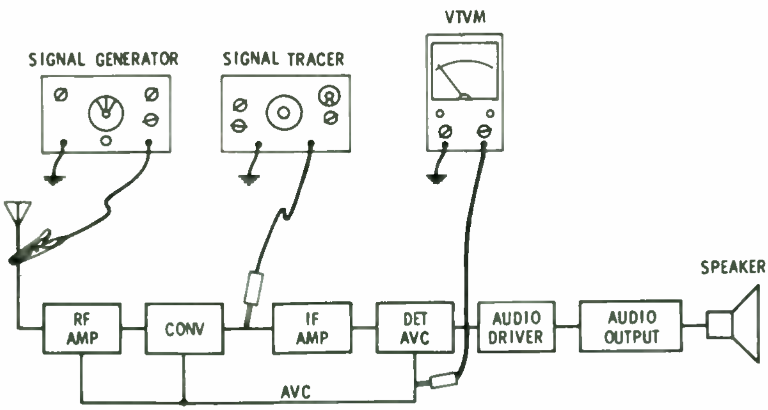


Figure 3 — Dividing the radio in three parts to monitor and localize an intermittent when it occurs.

ject a [illegible] low-level signal into the antenna, connect the signal tracer at the input of the IF amplifier, connect the VTVM to read the AVC voltage, and listen to the audio from the speaker. Now go about other business while the radio plays; as soon as it drops off, take a check on the VTVM and signal tracer. If both the VTVM and signal tracer indications have changed, then the trouble is before the IF amplifier. If only the VTVM is changed, the trouble is in the IF amplifier or detector. If neither the VTVM nor the signal tracer has changed, the trouble is in the audio amplifiers.

BROKEN PRINTED CIRCUITS

Broken printed circuits can set up conditions that defy description or sane troubleshooting procedures at times. If the "output meter" technique described does not find the broken circuit, a "brute force" technique may be used. First, check for any crack in the *board* from either the top or bottom side; quite often a crack in the board will lead directly to a crack in the conductor that may be overlooked in checking conductors alone.

A brute force or "check and hope" technique works sometimes when other resources have been exhausted. The idea is to use the VTVM to measure a suspected broken conductor while the radio is turned on. As shown in Figure 4, a break is suspected in the circuit between points A and B. First take a reading at point A to ground and then at point B to ground—the

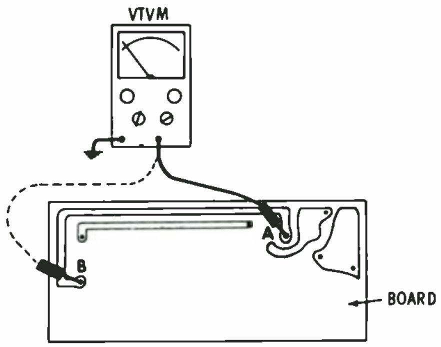


Figure 4 — Brute-force method of checking open printed circuits.

readings should be identical. If there is the least discrepancy, the printed circuit is open. Of course, it is possible that the voltage readings would be identical even with the printed conductor open, but the possibility is extremely rare.

The reason that the voltmeter check is so much better than an ohmmeter test is that the circuits are actually working under their normal operating conditions, drawing the normal amount of current. In addition, with power on, the radio may suddenly start playing when the probe touches a sensitive spot and thus increase the odds of stumbling onto the trouble.

NOISE

To localize noise, the signal tracer is ideal since it can follow noise (in most cases) exactly to its point of origination. Noise can be localized in another way. Starting at the speaker, ground out each successive stage (use an electrolytic for transistors) until coming to one that does not stop the noise—that stage is the place where the noise is starting. Noise may be caused by leaky capacitors, bad resistors, arcing or leaking transformers. In transistor and hybird radios, using certain circuits, the radio will be extremely noisy if the speaker voice coil gets a slight short to the frame because it upsets the output current division.

CHECKING PARTS IN-CIRCUIT

Checking the parts *in-circuit* is not always accurate, but when it can be done with reasonable accuracy, it is always profitable. To open up a printed circuit for troubleshooting checks, use the system described below under "Checking Transistors." If the component cannot be unsoldered, then the conductor foil may be cut to isolate the part.

Checking Transistors

In most car radios, the transistors will be wired in permanently and, of course, you will want to be reasonably sure that the transistor is the likely trouble before you pull it. The best bet is usually to make a substitute test with a "known good" transistor. You can often do this easily with a razor blade or pen knife, severing two of the foil paths to the old transistor and temporarily spotting in a new transistor to see if the trouble is corrected (Fig. 5).

Repairing the Slots

After you have made your tests or installed a new transistor, simply apply a drop of solder across the slit to return the circuit to "like new" condition (Fig. 6). You can use a wire jumper if you like, but it isn't necessary. It will be easier, though, to make the repair if you will scrape the printed conductor on each side of the point at which you intend to make the slit *before* you do make the slit. Scraping the residue from the conductor after you make the slit is more difficult, and

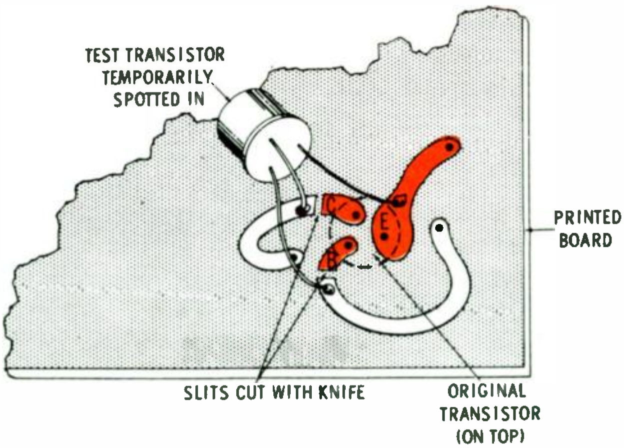


Figure 5 — Opening two of the printed conductors to the original transistor makes substitution of the transistor easy.

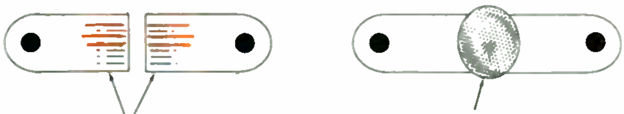


Figure 6 — Repairing slit in printed circuit after testing is finished.

you are more likely to pull the conductor from the board.

AVC Diodes

At least two diodes are used in the AVC circuits of most auto radios. If the diodes open, depending on the circuit, you may get distortion (due to overload) or weak signals. In some cases, oscillation or whistles may occur. Diodes may either short or open; usually no other troubles develop. Because of this, you can nearly always check the diode with an ohmmeter, probably, in almost every circuit, without having to disconnect the diode. Just measure for "diode action" by placing the ohmmeter across the diodes and then reversing the leads. If you get a considerable difference in the readings you can probably assume that the diode is okay.

Occasionally diodes develop a rather low leakage resistance, in which case an ohmmeter check (in circuit) is invalid. If you have suspicions that the diode is causing the trouble, disconnect one end and again check it with the ohmmeter and then reverse the leads. The front to back ratio should be at least 500 to 1—that is, if the diode measures 200 ohms in one direction, it should read 100,000 ohms in the other direction (with the *diode* out of the circuit).

Oscillation

The most common cause of oscillation is open capacitors, especially electrolytics, though the paper or ceramic types sometimes open also. Brute force methods are perhaps as good as any method for finding the defective capacitor; simply shunt each suspected capacitor with a known good one of approximately the same size.

Another cause of oscillation can be the installation of the wrong type of transistor as a replacement. Sometimes oscillation may be caused by incorrect biasing, but this is unusual.

Breaks in printed circuits are the source of the most difficult oscillations, especially the intermittent ones. If you can move the radio around, or if the radio works well on the bench but not in the auto, try gently pushing the board at various places using an insulated tool. You may be able to localize the trouble.

Sometimes, windings inside an IF transformer can develop a short or partial short and cause oscillations (but they also may cause loss of gain). Place an alignment tool inside the slug and tug it gently from side to side. This may show up a defective transformer, but don't overlook the fact that this also puts stress on the printed board and may be misleading as to the actual location.

In a few cases, transistors (original ones) may develop an internal condition that will cause oscillation. Often this oscillation occurs intermittently, for example, when the radio has been turned on for a while, or when the car engine is started (because of the increase in voltage supplied by the generator or alternator with the engine running). If you pull a radio such as this and find that it works all right on the bench, try increasing the input voltage to 16 volts. If the trouble does not occur with higher input voltage, try covering the radio with a cloth for a short period of time and see if the increased heat causes the oscillation. If it does, see if you can localize the transistor or circuit causing it by using a soldering iron to heat near each suspected part. (Sometimes a chemical "cold" solution can be sprayed on to reduce the temperature of a suspected part and make the trouble show up but usually the trouble is caused by heat and some localized heat will find the trouble in the shortest time.)

Distortion

Distortion in transistor radios is nearly always caused by incorrect bias. Transistors, like tubes, must operate in the linear portion of their gain curve. When the trouble is distortion, the first check is the transistor bias. Transistors themselves may develop excessive leakage and cause the bias voltages to be upset, but often it is caused by *changed value, open,* or *broken resistors,* as well as by leaky electrolytics.

If the distortion occurs only on strong stations, the trouble is probably the AVC circuit. Transistors overload more easily than tubes, and thus the AVC stage is more critical in adjustment. Check the diodes as indicated earlier; also check for other defective parts in the AVC circuit (such as an open resistor or broken printed circuit board).

TROUBLESHOOTING CHECK POINTS

1. Turn on radio. Listen, or watch for speaker cone movement. (Radios with twin transistor output will have little or no speaker cone movement when the radio is turned on.) If you get no speaker action on single output transistor radios, check the speaker for an open with an ohmmeter or, better still, touch the collector and ground of the output transistor with the two ohmmeter leads and you should hear a scratching noise in the speaker.

2. Make sure that all controls are working.

3. Visually check the radio. Remove the top and bottom covers and look for broken wires, burned parts, damage, etc.

4. Check the voltages inside the radio, beginning with the collector, emitter, and base bias voltages on the output transistor.

5. Measure the collector or emitter voltage of the RF transistor. When you tune through a signal, you should have a reduction in voltage because of the AVC action. If the voltage drops, you can be fairly sure that the RF, converter, oscillator, IF and AVC are all working normally.

6. Use signal tracing or signal injection to determine where the loss or weakening of the signal occurs.

7. After repair, check peaking of trimmers (antenna trimmer after reinstalled in auto).

CIRCUIT OPERATION

Because most modern car radios are completely transistorized, troubleshooting will require an understanding of the operation of each of the transistorized circuits. Understanding how each circuit operates will make it easier to understand the effect produced when a component in the circuit changes value. As an example, when a resistor changes value because of aging, or is broken by vibration, the bias might be changed enough to render a particular stage in the receiver completely inoperative. When a coil has a broken connection, there might be enough capacitive effect to produce a low level of output, with the result that the search for the trouble is centered elsewhere.

Effects such as these are commonplace in service work, but an understanding of the basic operation of the major circuits used in radios will make troubleshooting much easier. In each of the descriptions that follow, the function of the circuit is analyzed, and then various defects and their effect on circuit operation are explained.

TUNED COMMON BASE RF AMPLIFIER.

The tuned common-base RF amplifier is used in receiver input stages to provide low noise and good selectivity, (rather than high RF gain), and to eliminate images and spurious signals in superheterodyne receivers.

Circuit Analysis.

Because of its lack of gain, the tuned common-base RF amplifier is generally used as an isolation stage between the antenna and mixer stage, particularly in broadcast receivers. While the tuned circuits offer some increase in signal gain, the transistor gain is always less than one. Since images and spurious signals are not discriminated against in receivers having their inputs coupled to the mixer stage, the selectivity and noise reduction effects of the tuned RF amplifier provide better performance.

Circuit Operation.

The schematic diagram in Figure 7 illustrates a typical common-base RF amplifier using fixed base bias. For simplicity of circuit discussion, it is assumed that no automatic-

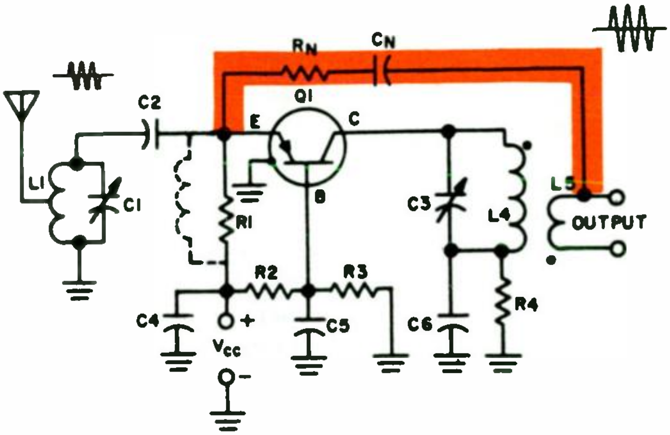


Figure 7 — Typical common-base RF amplifier.

volume-control (AVC) voltage is applied. The tuned input circuit consists of parallel-resonant tank L_1C_1, with the antenna tapped at the lower end for proper input matching and maximum power transfer. The circuit is arranged for negative ground, which allows both tuned circuit tanks to be grounded in order to avoid body capacitance effects. The input tank is coupled to the base by capacitor C_2, thus avoiding shunting of the emitter to ground through the low value of DC coil resistance. The emitter DC return is completed by R_1. This is essentially shunt feed bias. While R_1 could be replaced with an RF choke (shown in dotted lines in the figure), it is made resistive to avoid "dead spots" caused by any spurious resonances formed by the stray and element capacitance with the RFC, since the stage usually must be tunable over a wide range of frequencies. Fixed voltage divider bias is provided by R_2 and R_3. C_5 places the base at RF ground and removes the DC bias circuits from the radio-frequency path, so that the initial bias is unaffected by signal variations. Output tank C_3L_4 is tuned to obtain maximum selectivity, and the collector output is matched to the base of the next stage through RF transformer secondary L_5. The tuned circuit is placed in the primary rather than the secondary, since tuning the secondary would tend to shift the phase relationships between the primary and secondary. Thus, feedback loop C_NR_N, provided for neutralization and cancellation of internally developed feedback, remains unaffected by circuit tuning. Transistor Q1 is a high-frequency type of transistor; the case is grounded to provide further shielding and isolation between the input and output circuits. Capacitor C_4 bypasses any RF around the supply, and prevents it from entering the bias circuit.

The functioning of the RF amplifier is basically the same as that of an RC-coupled audio amplifier, with tuned tank circuits L_1C_1 and L_4C_3 acting in place of the base and collector resistors, respectively. The difference is that the operation occurs at radio-frequency rates rather than at audio-frequency rates. Instead of the amplitude of the audio signal itself causing the emitter and collector currents to vary, it is the amplitude of the RF envelope at any particular instant which causes these currents to vary. In the case of modulated emissions, the modulation varies the amplitude of the RF envelope in proportion to the modulation. Thus, the received signal can be considered an RF carrier which rises and falls sinusoidally in accordance with the amplitude of the modulation, and is amplified exactly as if it were a single audio frequency (assuming that the input and output circuits are properly tuned and have the required bandwidth). If these conditions are not met, the RF envelope becomes distorted—that is, a differently shaped signal is formed. The RF envelope is produced by individual radio-frequency cycles varying above and below the zero carrier level. Each cycle produces equal positive and negative alternations, and causes the transistor bias to be increased and decreased equally. The average value over a half-cycle of modulation determines whether the total effect is that of an increased or a decreased signal. Thus, the tips of the RF pulses trace out a relatively slowly varying signal, which is the audio modulation, and occurs at an audio rate, not at an RF rate. Depending upon the rapidity of rate of change of the audio modulation, a few of the RF cycles could be lost without significantly affecting the over-all modulation waveshape. Figure 8 shows the concept of an RF envelope and the manner in which it is formed, using a single carrier frequency and a single 400-hertz sinusoidal modulation frequency for ease of explanation. Other more complex waveforms also produce a similar result.

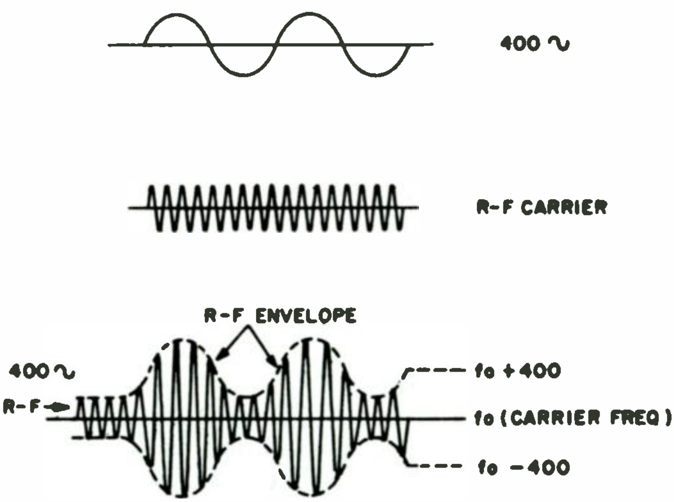


Figure 8 — Development of an RF envelope.

With no signal applied (Fig. 7), Q1 rests at its quiescent value of emitter and collector current as determined by base bias divider R_2 R_3, together with emitter resistor R_1 and collector resistor R_4. Since the quiescent current is steady, no output is produced. When a signal is applied to L_1 from the antenna, a large resonant voltage is developed across tank L_1C_1, and is applied through C_2 to the emitter of Q1. For ease of discussion, the input tank can be considered as an RF generator connected between emitter and ground, with an output amplitude equal to the RF envelope of the signal.

Assume that the input signal amplitude is increasing and becoming more positive, and that the instantaneous value of the signal adds to the emitter bias. As the emitter bias increases in a forward direction, the emitter and collector current increase. Internally in transistor Q1, there is a flow of holes from emitter to collector; externally, the flow consists of electrons from emitter to collector. A small base current flows from base to emitter (through the base junction). Note that in the common base circuit the collector current is always less than the emitter current ($I_C = I_E - I_B$). When the collector current increases with a signal, a large voltage drop is produced across the output tank impedance, thus developing a positive output signal. (The common-base input and output polarities are identical.) Since the L_5 secondary is coupled to the L_4 primary, current flow through the primary induces an output voltage in the secondary by transformer action. The secondary output may be either in-phase or out-of-phase, depending upon the connections.

Assume now that the input signal amplitude decreases and goes negative. The emitter forward bias is reduced and less collector current flows. As the input signal goes negative, the collector voltage rises toward the supply value. Since the collector is reverse-biased by the negative supply, a negative output signal is produced. Collector resistor R_4 prevents large positive swings from dropping the collector voltage past zero, and causing an overshoot which would drive the collector positive and produce a forward collector bias with consequent high current pulse and distortion, by limiting the total available supply voltage. Thus, a large signal can drop the collector voltage to zero, but the supply voltage will still be less than zero by the drop in R_4. (This resistor may not be used in some circuits.) Capacitor C_6 bypasses the RF around R_4 so that it remains unaffected by signal variations, and in effect grounds tank capacitor C_3 to avoid body capacitance effects when the capacitor is tuned.

Neutralizing network C_NR_N is connected between the secondary of the output transformer and the emitter so that it feeds back an out-of-phase voltage to the emitter and prevents oscillation due to internal feedback within Q1. In RF amplifiers operating over large frequency ranges, this neutralizing network is usually replaced by a more complicated unilateralization network. Thus, the input circuit remains unaffected by any changes in output or tuning over the entire range of operation.

Circuit Failure

When making voltage checks, use a vacuum-tube voltmeter to avoid the low values of shunting resistance employed on the low-voltage ranges of volt-ohmmeters. Be careful also to observe proper polarity when checking continuity with the ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

When checking RF voltages, always use a vacuum-tube voltmeter (VTVM) or an electronic voltmeter with an RF probe. The conventional voltmeter only indicates DC. Therefore, it is necessary to first rectify the RF before the voltmeter will indicate properly. This is done automatically in the VTVM, and separately by the RF probe when the electronic voltmeter is used.

No Output. No input signal, a shorted input or output tank, an open emitter circuit or defective transistor, as well as improper bias, can cause "no output." If R_1 is open, the emitter circuit will be open, and if R_4 is open, the collector circuit will be open; in either case, there will be no output. If R_2 is open, Q1 will operate at approximately zero bias and no output will occur except for extremely strong signals. Check the DC voltages on Q1 to determine the bias. With a normal supply voltage, for a PNP transistor (with negative ground), all voltages will read positive with respect to ground. The emitter will always be a few tenths of a volt more positive than the base, and the collector will read the lowest (sometimes zero). For example, if R_4 were shorted, L_4 would be connected to ground, the collector would be at ground potential, and the meter would indicate zero, even though full collector voltage would still be applied.

The tank coils can be checked for continuity with an ohmmeter to determine whether they are open; they must be disconnected when the tuning capacitors are checked. If coupling capacitor C_2 is defective, there will be no output. If C_2 is open, the emitter voltage will be normal, but there will be no output. If C_2 is shorted, the emitter voltage will be low (depending on the resistance of R_1), and no output will be obtained. In this case R_1 will get hot and possibly burn out.

If bypass capacitor C_4 is shorted, the supply will be shorted, with consequent loss of output; if the capacitor is open, only a reduced output may occur. If capacitor C_5 is open, the base will be connected to ground through the bias network, and the RF signal between emitter and base will be attenuated (depending upon the frequency) and will produce either a very weak or practically no output at all. If L_5 is open, no output will be obtained (provided that the capacitive coupling between the primary and secondary is very small). Oscillation caused by a defective neutralizing network, if sufficiently strong, can bias off and block the transistor and thus reduce the output to zero. Check the value of R_N with an ohmmeter, and check C_N with a capacitance checker.

Defective RF tanks can cause a no-output condition. Defective tanks are most easily located in an operating amplifier by observing whether they tune to a specific frequency, particularly when the tuning dial is calibrated, since any change in component values will change the resonant frequency. If the circuit bias voltages appear to be normal and there is no output, connect a modulated RF signal generator to the antenna, the emitter, the collector, and the output winding, successively. If the input circuit is defective, the signal will appear when the generator is connected to the emitter. If the transistor is defective, the signal will appear after the generator is connected to the collector. With a defective collector tank, the signal will appear when the generator is connected to the output winding. If the signal does not appear, the output coil is open.

It is important to keep in mind that any slight capacitive coupling at radio frequencies will pass a weak signal, so that a weak output is possible under circumstances which at audio frequencies would be impossible. Thus, where more than one RF stage is used, it is possible to have a "dead" input stage and yet, through stray capacitive coupling, obtain sufficient signal "leak-through" into the following amplifier to produce a weak output.

Low Output. Low output can be caused by improper bias or supply voltage, a defective transistor, high series resistance or impedance, or a low shunting impedance or resistance. The bias and supply voltage can be checked with a voltmeter. If the value of R_1 increases, the emitter bias will be increased, and if the value of R_4 increases, the collector voltage range will be reduced; both cases will cause reduced output, and can be checked by using an ohmmeter. If C_5 opens, the base return to ground will be through R_3, which places it in series with the input signal; thus, the input signal, as well as the output signal, will be reduced. High resistances produced by poorly soldered connections can also cause reduced output. Applying a hot iron to the defective joint will usually restore operation to normal. If R_1 deteriorates to a very low value, the input signal will be partially shunted to ground and the output will be reduced. Where the transistor seems to be defective (less signal appears on the collector side than on the emitter side), replace it with one known to be good. No current gain is obtained through the transistor in the common-base circuit, since the collector current is always less than the emitter current by the amount of base current. Nevertheless, when low impedance is used in the input and high impedance in the output, a relative voltage gain will be obtained because of the greater voltage drop across the larger impedance.

Distorted Output. Receiver RF amplifiers are operated Class A to avoid distortion. If the bias is too high, the peaks will be clipped; if the bias is too low, a similar effect will be caused by overdriving, and saturation will occur on strong signals. Both effects are forms of amplitude distortion. If the selectivity is too sharp, frequencies outside the bandpass will be cut off entirely, or partially attenuated. Thus, on modulated signals some of the sideband frequencies will be lost, and frequency distortion will occur because of the loss of some of the audio signals. Normally, deterioration of parts caused by aging, moisture absorption, etc., will produce a reduction in the tuning circuit Q, and thus result in reduced performance and decreased selectivity, but this will not cause distortion. On the other hand, parts value changes can cause regeneration (positive feedback) at certain frequencies or over a range of frequencies. Such feedback increases the sharpness of tuning and can cause distortion due to sideband cutting. The prime cause is failure of the neutralizing or unilateralization network. Such effects can also be caused by a defective transistor. First check the neutralization network for proper component values, and then check the supply and bias bypass capacitors. In multiple stage receivers, common impedance coupling can occur through deterioration of the power supply bypass capacitor, thus producing unwanted feedback similar to that encountered in electron tube operation. In cases of this kind it is usually necessary to remove the defective capacitor and replace it with a new one in order to cure the trouble. Just placing the new capacitor across the defective one will not always correct the trouble.

Distortion caused by "cross modulation" from strong local signals sometimes exists, and is primarily a fault in design (lack of sufficient selectivity) or the result of too close coupling to the antenna, which produces fundamental overload. Thus, saturation occurs, and the nonlinearity produced causes the unwanted signal to appear on the desired signal as cross modulation.

TUNED COMMON EMITTER RF AMPLIFIER.

The tuned common-emitter RF amplifier is universally used in receivers and test equipment to provide high RF gain and selectivity, and to eliminate images or other spurious responses.

Circuit Analysis.

The large collector-to-base capacitance of the transistor tends to shunt the output to ground, when connected in the common-emitter configuration. Therefore, the amplification tends to drop at the higher radio frequencies. On the other hand, a small change in base current causes a very large relative change in collector current. Thus, the small signal input controls a large current which develops the output voltage; this action is similar to electron tube operation using the grounded-cathode configuration. Although the output impedance of the common-emitter circuit is not as high as that of the common-base circuit, the large collector current flow through a moderate output impedance produces a much larger output. Hence, the common-emitter circuit always gives a large gain. Even at the higher radio frequencies where the gain drops off, it may be possible to obtain sufficient gain over that of the common-base circuit to justify use of the common-emitter circuit instead.

- The common-emitter circuit also has a higher input impedance than that of the common-base circuit (on the order of a few hundred ohms). Consequently, it is easier to match the input (and the output) circuit for efficient power transfer. As a result, the common-emitter circuit, rather than the common-base circuit, tends to be used universally.

Circuit Operation.

The circuit in Figure 9 shows a typical tuned amplifier using the common-emitter configuration. L_1 and C_1 form the input tuning circuit, with both the antenna and the base tapped onto L_1 to provide a proper impedance match. Capacitor C_2 bypasses the lower end of L_1 to ground for RF, and also bypasses bias resistor R_1. Fixed base bias is provided by voltage divider R_1, R_2. Thermal stabilization is provided by emitter swamping resistor R_3 which is bypassed by C_3. The output tank consists of C_4 and L_2, with the supply voltage fed at approximately the center of the coil. Thus, an out-of-phase voltage is obtained and fed through C_N for neutralizing the transistor. L_2 is also tapped at appropriate points to match the collector and the output circuit. The

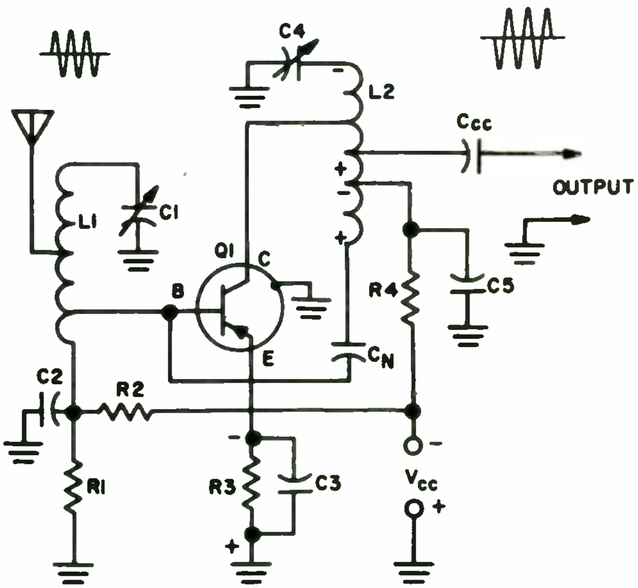


Figure 9 — Typical tuned common-emitter RF stage.

output is capacitively coupled through C_{cc}. Capacitor C_5 functions to bypass RF around collector resistor R_4 and the supply, and also to maintain the center of the coil at ground potential, in order to insure the proper phase relationships between the ends of the tank coil. R_4 is a voltage-dropping and isolation resistor in the collector circuit (it is not always necessary to use R_4).

At the start of the cycle of operation the transistor is resting in a quiescent condition, with the collector current determined by the DC base bias, which is fixed for a specific supply voltage by voltage divider resistors R_1 and R_2. It is usual practice to bias the base negative with respect to the emitter (forward bias). The difference in potential is normally only a few tenths of a volt, and is set at the center of the forward transfer characteristic curve for Class A operation. Since the received signal is normally on the order of microvolts, the low bias value is adequate in preventing overloading (except in the case of strong local signals). Either automatic or manual gain control is usually provided in practical RF stages to accommodate large signals; this is not shown in the schematic in order to avoid circuit complication and for ease of discussion.

Assume that an RF signal within the bandpass of the tuned input tank circuit, consisting of L_1 and C_1, appears at the antenna. With the antenna tapped onto L_1 at the proper number of turns to match its impedance, the low-impedance antenna resistance is transformed by autotransformer action to match the large parallel resonant impedance of the tank. Thus, maximum signal transfer from the antenna to the coil is obtained. In turn, the base is also tapped onto L_1 for a proper impedance match, to change the low input resistance offered by the common-emitter circuit to a value that more closely matches the high impedance of the tuned input circuit. With bypass capacitors C_2 and C_3 effectively grounding the bottom of L_1 and the emitter, respectively, as far as RF is concerned, the tuned input circuit is connected between the base and the emitter. Thus, the RF signal does not flow through the bias voltage divider or the emitter swamping resistor (R_3).

Assume, for the moment, that the input signal is swinging negative and adds to the forward base bias, thus producing an increase in collector current (which is a flow of electrons from the supply through L_2 to the collector). Application of the instantaneous negative signal voltage to the base of Q1 causes a flow of holes from emitter to base. This is the same as a flow of electrons from base to emitter, and a circulating base current flow occurs. On the positive half of the input signal, the forward bias is reduced and the collector current, likewise, is reduced. Electron flow and base current flow are through the same path as given previously for the negative half-cycle, but are diminished in value. With equal positive and negative swings, an average value of base current flow occurs, and varies in accordance with the signal amplitude. The collector current follows, but it is larger in amplitude since it is approximately equal to beta times the input signal.

Since the input tank circuit is tuned to the frequency of the incoming signal, only RF signals within the bandpass of the tuned circuit appear at the base and affect the collector current. The amount of selectivity of the tuned circuit depends upon the unloaded Q of the tank. When this Q is high, the tuned circuit is highly selective, and only a narrow band of frequencies is accepted by the tuned circuit. Thus, the base current is controlled by the tuning of the tank circuit. When the tank circuit is resonant to the signal, a base current is injected into the transistor; when it is nonresonant, only the DC bias value of base current flow exists.

In the collector circuit, the load impedance across which the output is developed consists of tuned tank circuit L_2C_4. Coil L_2 is bypassed to ground for RF at the supply voltage tap by C_5. Thus, the rotor of tuning capacitor C_4 can be grounded to avoid body capacitance effects when tuning. The portion of L_2 between the supply and the lower end of L_2 forms a neutralizing winding, which furnishes 180-degree phase shift and supplies an out-of-phase voltage back to the base through C_N. Thus, the effect of the tuned input and output circuits being coupled through the transistor collector-to-base capacitance and the internal base spreading resistance of Q1, which causes positive feedback and oscillation, are cancelled out. Since the output impedance is the low input resistance of a following common-emitter stage, the coupling capacitor is tapped at some intermediate value of turns ratio between the supply and collector taps. Thus, a step-down ratio is provided to match the transistor output for maximum power transfer and gain. The collector is also shown tapped down on L_2 for proper matching, assuming that the tuned tank impedance is higher than the collector impedance.

Regardless of the impedance-matching or neutralizing methods used, however, the output signal is developed across the impedance provided by the parallel tuned tank circuit. At resonance the impedance is high, and off resonance it is a lower value. Thus, for frequencies within the bandpass of the tuned circuit, the impedance is high, and a large voltage drop occurs across this impedance. With a negative-going input signal the collector current flow causes a drop across the parallel-tuned tank which reduces the collector voltage toward zero. Since the collector is reverse-biased, the output is positive-going. When the input signal swings positive, the forward bias is reduced, which reduces the collector current also. Less voltage drop occurs across the output tank, and the collector voltage increases in a negative direction, thus producing a negative output signal (common-emitter output and input polarities are always opposite). These positive and negative signal excursions occur at an RF rate. For a constant-amplitude input, a constant, amplified output signal is developed. If the signal is modulated, the output amplitude follows the waveform envelope, and the output amplitude varies in accordance with the modulation. With signal swings less than the applied base bias, no distortion is produced. If the input signal is greater than the bias, or if the collector voltage is dropped to zero before the peak occurs, then clipping and distortion effects are produced. Resistor R_4 is used to drop the collector voltage to the proper value and to act as a decoupling resistor. It also prevents the collector voltage from being driven positive by strong signals, which would forward-bias the collector and cause heavy current flow with distortion. The transistor case is grounded to provide better shielding and prevent RF feedback.

Normally, swamping resistor R_3 is affected only by slow DC variations of emitter current caused by ambient temperature changes. The increased emitter current flow with temperature produces a voltage across R_3 which opposes the bias voltage and reduces the emitter current to its original value. Any RF signal is bypassed across R_3 by C_3. This is conventional emitter swamping action.

The output is shown capacitively coupled since it is usually more economical than providing a secondary winding to couple out of L_2, in addition to the fact that at high frequencies it is sometimes difficult to obtain optimum coupling between windings because of high-frequency effects. Any of the tapped tanks shown in the schematic can be replaced by tuned transformers without any change in operation, if they have sufficient coupling, if they tune to the same frequencies, and if they tune over the same range. Circuit cost and designer's preference usually determine which are used.

Circuit Failure

When making voltage checks, use a vacuum-tube voltmeter to avoid the low values of shunting resistance employed on the low-voltage ranges of volt-ohmmeters. Be careful also to observe proper polarity when checking continuity with the ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

When checking RF voltages, always use a vacuum-tube voltmeter (VTVM) or an electronic voltmeter with an RF probe. The conventional voltmeter indicates only DC. Therefore, it is necessary first to rectify the RF before the voltmeter will indicate properly. This is done automatically in the VTVM, and separately by the RF probe when the electronic voltmeter is used.

No Output. Open base, emitter, or collector circuits or short-circuited input or output circuits, as well as lack of supply voltage or a defective transistor, can cause no output. If either L_1 is open or C_1 is shorted, no output will be obtained. If L_1 is disconnected from C_1, both the continuity of L_1 and the shorting of C_1 can be checked with an ohmmeter. Lack of supply voltage as well as bias voltage can be determined by use of a voltmeter. Proper base bias indicates that the bias divider and lower part of L_1 are connected to the base. Likewise, proper collector voltage indicates that R_4 and L_2 are satisfactory and that tuning capacitor C_4 is not shorted. If C_5 is shorted, the full supply voltage will be dropped across R_4, and there will be no ouput. If coupling capacitor C_{cc} is open, no output will be obtained (although there is a possibility that a strong signal may still feed through as a weak signal by stray capacitive coupling). If emitter resistor R_3 is open, there can be no output. If neutralizing capacitor C_N is open and the feedback is sufficient, the transistor may be blocked, with consequent loss of output, although it is more likely that a low output with squeal and distortion will be obtained. However, if C_N is shorted, the base and collector will be shorted through the neutralization coil and no output will be obtained.

Normally, the collector voltage will be lower than the supply voltage because of the drop across R_4. A high collector voltage will indicate improper bias on the base, or lack of collector current due to a defective transistor or an open emitter resistor R_3. If the transistor is in doubt, replace it with one known to be in good operating condition.

Low Output. If the forward bias is too low, if the collector voltage is low, or if the transistor gain has deteriorated, a low output will be obtained. High-resistance soldered connections in the input and output tanks or nonresonance can also cause a reduction of the output. If emitter resistor R_3 increases in value or bypass capacitor C_3 opens, the output will likewise be reduced by emitter degeneration effects. The bias and collector voltages can be checked with a voltmeter, and R_3 can be checked with an ohmmeter. An open bypass capacitor C_2, C_3, or C_5 can cause a reduction of the output through loss of RF signal in the bias and supply circuits and by emitter degeneration; a bypass capacitor can be quickly checked by temporarily shunting an equivalent capacitor across it. An increase in output, when this is done, indicates that the original capacitance is insufficient. To determine that the tuned circuits are operating properly, insert a modulated signal from a signal generator into the antenna, and use an oscilloscope with an RF probe to determine whether the signal appears at the base and the collector. Tuning the tank circuits will cause the signal to increase in amplitude at the resonant frequency. If the tuning has no effect, the tanks are open or shorted and must be disconnected and checked individually. When the circuit components appear to be operating normally and the output is low, substitute a transistor known to be good to determine whether the original transistor is at fault.

Where AVC voltage is fed into the base circuit to control the volume automatically, do not neglect the possibility that too great an AVC voltage may be biasing-off the stage. With a properly functioning circuit, the AVC voltage will vary in accordance with the strength of the input signal, or with the tuning, as the desired signal is selected. With delayed AVC, it is normal for the AVC bias voltage to be almost zero with weak signals so that full sensitivity is obtained.

Distorted Output or Poor Selectivity. If the bias is too high or too low, the signal may be clipped by operating at or near saturation or cutoff, respectively. If there is excessive regeneration at some frequency, the tuning may be sharpened sufficiently to cause sideband cutoff, and frequency distortion will result from the loss of original frequencies now outside the reduced passband. Poor selectivity (broad tuning) is usually caused by high resistance in the tuned circuits due to poorly soldered joints or aging. A lowering of the tuned circuit Q can also cause a broadening of the selectivity curve and reduce the apparent gain. With calibrated dials, reception of the signal at the wrong frequency indicates a change in circuit constants in the tank, or a change in the stray and distributed shunt capacitance in the tuned circuit. Usually, a readjustment of the trimmer capacitors will restore the calibration to normal. It is particularly important while repairing or troubleshooting RF circuits not to disturb the lead dress or reroute the wiring; otherwise, a change in stray capacitance (or inductance) will cause improper tracking of the tuned circuit. Moisture absorption in coils and dielectrics, plus aging effects, can cause a loss of Q, which can be restored only by replacing the tuned circuits or by removing them and baking them in an oven to remove the moisture.

DIODE DETECTORS.

Detector circuits are used to remove the modulation from the received modulated RF signal and transfer it back to its original form, so that it may be used for listening, viewing, communication, or other purposes. There are many forms of detector circuits and many variations of these circuits. The circuits used in the semiconductor field are similar to those used in the electron-tube field.

The semiconductor diode detector with a voltage output is usually used as the second detector in superheterodyne receivers, or as a linear detector where large input signals are supplied. It is also used in test equipment where linear response is desired, as in VTVMs and field strength indicators.

Circuit Analysis.

The electron tube diode detector is practically identical with the voltage-output semiconductor diode, but the principal difference between a tube diode and a semiconductor diode is the reverse-leakage current of the semiconductor, plus a difference in current and voltage ratings. As far as the diode detector is concerned, the reverse-leakage current is usually negligible. Although it does produce a slightly increased loading effect on the input circuit, this increased loading is of interest only when the diode is operated as a small-signal detector.

In this instance, operation is not linear, but observes a square-law response (output varies as the square of the input voltage). It is this weak-signal, square-law response which creates the inherent distortion in the diode detector. As normally operated, the diode voltage-output detector is employed after a number of stages of amplification. Thus, the input signal to the detector is relatively large in amplitude, the response is relatively linear, and the basic fidelity of the diode detector is achieved.

Circuit Operation.

A schematic diagram of the voltage-output diode detector is shown in Figure 10.

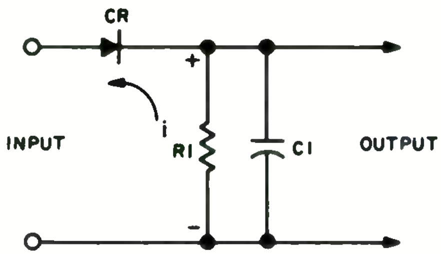


Figure 10 — Voltage-output diode detector.

From this figure it can be seen that diode CR is in series with the input voltage; it acts as a simple rectifier, with R_1 as the load and C_1 as the filter. The diode conducts only during the positive half-cycle of the input signal. During the negative half-cycle it remains inoperative, since it is then reverse-biased. When the diode conducts, current flows through R_1 and produces a voltage drop across the resistor. The voltage developed across R_1 is equal to the peak value minus the drop across the diode (which is very small and much less than in an electron tube diode). Since capacitor C_1 is connected in parallel with R_1, it charges to the same voltage. Since the diode response is considered linear, the larger the input voltage, the greater the current through R_1 and the larger the charge on C_1. As the positive half-cycle ceases, the diode ceases conducting and capacitor C_1 discharges through R_1 for the duration of the negative half-cycle. The capacitor discharge is controlled by the time constant of R_1 and C_1, and is not quite completed before the positive half-cycle again begins. The diode again conducts, and capacitor C_1 is again charged for the duration of the positive half-cycle. Since these alternations are at radio-frequency rates and the RC time constant is on the order of seconds, the voltage to which C_1 is charged never has time enough to reach the full peak value of the input voltage, and the voltage to which C_1 is discharged never has time enough to reach zero value. The voltage is, however, proportional to the envelope of the modulation, rising as the input signal amplitude increases, and falling as the input signal amplitude decreases, as shown in Figure 11. Thus, the voltage across C_1 is a nearly linear replica of the original modulation.

When the time constant of R_1 and C_1 is too short (capacitor, resistor, or both are too small), the capacitor voltage cannot follow the envelope (it reaches full charge before the signal reaches its peak), part of the signal is lost, and the

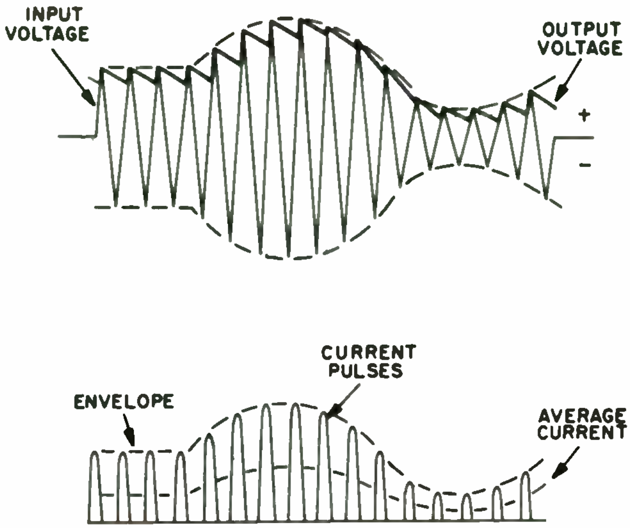


Figure 11 — Detector waveforms.

detected modulation is distorted. When the time constant is too long, the capacitor tends to smooth out variations in the modulation (it cannot respond to very fast voltage variations—only slow variations), and distortion occurs. With the proper time constant, the capacitor is never fully charged or fully discharged, but rather follows the peak excursions of the envelope in accordance with the audio modulation.

Circuit Failure

No Output. A no-output condition can occur from failure of the diode to conduct, from an open or shorted load resistor, or from a defective capacitor. A resistance and continuity check will determine whether the resistor is satisfactory, whether the diode front-to-back resistance is normal, and whether the capacitor is short-circuited. With the resistor and diode checked out, it is a simple matter to connect a capacitor in parallel with the suspected capacitor to determine whether it is open (an output will now appear if the original capacitor was open). If an oscilloscope is available, it may be used to observe the waveform across the load resistor.

Low Output. Low output can occur from a change in the time constant of the circuit, or from a lack of sufficient input to the detector, to produce the desired output amplitude. Poorly soldered connections, a leaky capacitor, or a defective diode can cause this condition. Under normal operation, the amplitude of the signal across the detector should be from 80 to 90 percent of the input amplitude. Less than this value indicates lack of efficiency due to increased resistance in the diode or leakage in the capacitor.

Distorted Output. This can result from a change in capacitor value. Either too large or too small a capacitor will cause distortion. A change in a resistor or capacitor value, producing too short or too long a time constant, will also cause distortion. The parts should be within 10 to 15 percent of their rated values. If the values are normal, the trouble must be in the diode. A high-resistance condition caused by a poorly soldered joint is always a possibility.

AUDIO POWER AMPLIFIERS PUSH PULL

The push-pull transformer-coupled transistor audio amplifier is used where high power output and good fidelity are required, and it is used in receiver output stages.

Circuit Analysis.

The push-pull transformer-coupled transistor amplifier is similar in a general sense to the push-pull transformer-coupled electron tube audio amplifier. Use of the common grounded emitter circuit allows use of the analogy that the base of the transistor is equivalent to the electron tube grid, the emitter equivalent to the cathode, and the collector equivalent to the tube plate. Examination of the accompanying schematic reveals that the transistor push-pull circuit is practically identical to the electron tube push-pull circuit. Any differences are due to the internal parameters of the transistor and the matching requirements for obtaining maximum power output with minimum distortion.

Push-pull amplifiers can be operated Class A, Class AB, or Class B, as determined by the amount of forward bias. Like the electron tube push-pull circuit, the least amount of distortion and power output is produced in Class A operation, and the greatest amount of distortion and power output is obtained in Class B operation. Class AB stages operate between these levels of distortion and power output. For a given equipment and type of transistor, selection of the operating bias, distortion, and power output is a design problem. The following discussion will cover each type of operation; although the different types of operation are similar, there are significant differences among them.

Circuit Operation.

The circuit diagram in Figure 12 shows a PNP push-pull, transformer-coupled output stage, and the load resistance R_L may be a loudspeaker.

The input signal is applied to the base of both transistors through transformer T_1. The polarity for the positive half-cycle of input is shown on the schematic to facilitate proper understanding of the operation. Note that when the top end of the secondary of T_1 is positive, the bottom end is negative. Thus, equal and oppositely polarized signals are applied to the base of transistors Q1 and Q2 when an input signal appears in the primary of T_1.

The input signal is obtained from a preceding driver power amplifier stage. Very little power is required

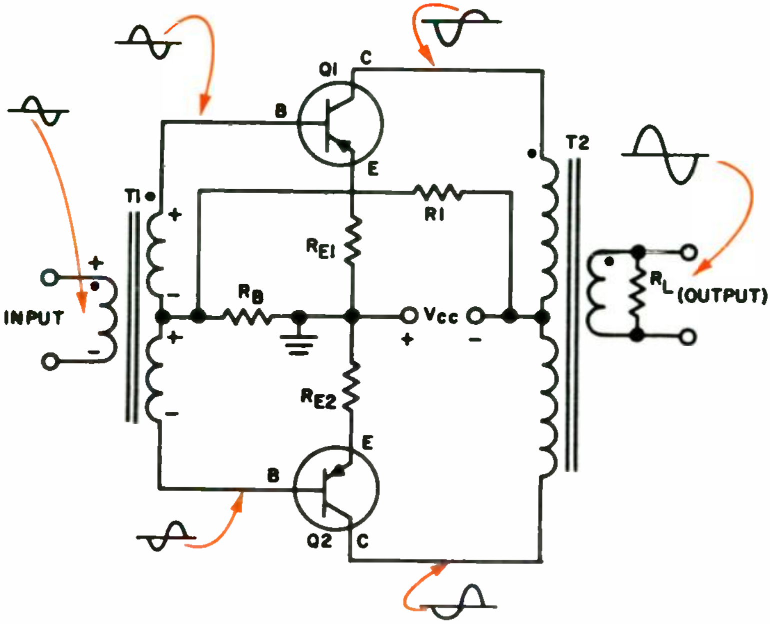


Figure 12 — Push-pull transformer-coupled transistor power amplifier.

for Class A operation; increasingly more drive power is required for Class AB and Class B operation. The actual amount of drive power needed depends upon the circuit design and the transistors used; it is on the order of two or three percent of the output. Transformer input coupling is used to provide maximum drive power and proper matching of the driver stage. Fixed bias from the collector supply is applied through voltage divider resistors R_1 and R_B. Resistors R_{E1} and R_{E2} are the emitter swamping resistors, which are left unbypassed to provide a slight amount of degeneration. The collector load consists of the primary resistance of output transformer T_2, plus the resistance reflected from the load connected across the secondary.

Class A Operation. With no input signal, the stage is resting in its quiescent condition, drawing heavy collector current and operating at the point of lowest efficiency. Since no change in collector current occurs, no output voltage is induced in the secondary of T_2. Assuming a positive input swing on the base of Q1 and an in-phase connection of T_1, the positive voltage of the signal subtracts from the normal forward (negative) bias, effectively reducing the base bias and causing less collector current to flow in Q1. As the collector current is reduced, the changing lines of magnetic flux between the primary and secondary of T_2 induce a voltage in the secondary. At the peak of the input signal, the collector current of Q1 is reduced to a small value, and the collector voltage approaches the supply voltage (reaches its most negative value). Thus, the common emitter circuit makes the polarity of the output signal opposite that of the input signal. Simultaneously, the input signal in T_1 is applied as a negative voltage swing to the base of Q2 (the ends of the secondary winding are oppositely polarized when a voltage is induced), which adds to the forward bias of Q2. The increase in forward bias causes an increase in the collector current through the primary of T_2, and induces an in-phase voltage in the secondary of the output load.

The net result of the input signal is to decrease the signal output of Q1 and to increase the output of Q2. These induced output voltages are combined in the secondary of T_2 to produce the effect of a collector current equivalent to twice that of a single transistor.

During the negative half-cycle of input signal excursion, the opposite action occurs. The negative signal adds to the negative forward bias and increases the collector current of Q1. Meanwhile, the base of Q2 is driven positive at the same time Q1 is driven negative. The positive increase in the input signal reduces the forward bias and causes the Q2 collector current to decrease. Again, the net result is the same as if twice the collector current of a single stage were involved in flowing through T_2. Note also that the collector current flows in opposite directions through the two halves of the primary of T_1, so that any in-phase primary-induced voltage components are cancelled out (second and all even harmonics); thus, the output voltage induced in the secondary consists of the fundamental component and any odd harmonics.

Since much heat is dissipated at the collector for large power outputs, the shell of the power transistor is usually connected firmly to the chassis for direct conduction and reduction of heat (chassis acts as a heat sink). Where the shell must be insulated from the chassis, it is usually separated by a thin wafer of mica (or other suitable material) to provide insulation and yet allow full heat transfer.

Class B Operation. In true Class B operation, the bias is such that no collector current flows for one-half of the cycle. Thus, each transistor reproduces only half of the cycle, and two transistors are required to faithfully reproduce any signal. Since at cutoff a reverse current flows in the transistor, collector current is never completely cut off, and a small quiescent current flows during the inactive half-cycles of transistor operation.

The circuit in Figure 13 is that of a typical Class B stage operated with zero bias. Emitter swamping resistors R_1 and R_2 are used for thermal compensation, and are unbypassed to provide a slight amount of degeneration.

Note here one of the differences between the electron tube and the transistor. At zero bias, the conventional electron tube conducts heavily, and it is necessary to apply considerable negative bias to achieve Class B operation. On the other hand, the transistor always has the collector reverse-biased; thus, in the absence of a forward base bias (that is, at zero bias), no collector current can flow. In this respect,

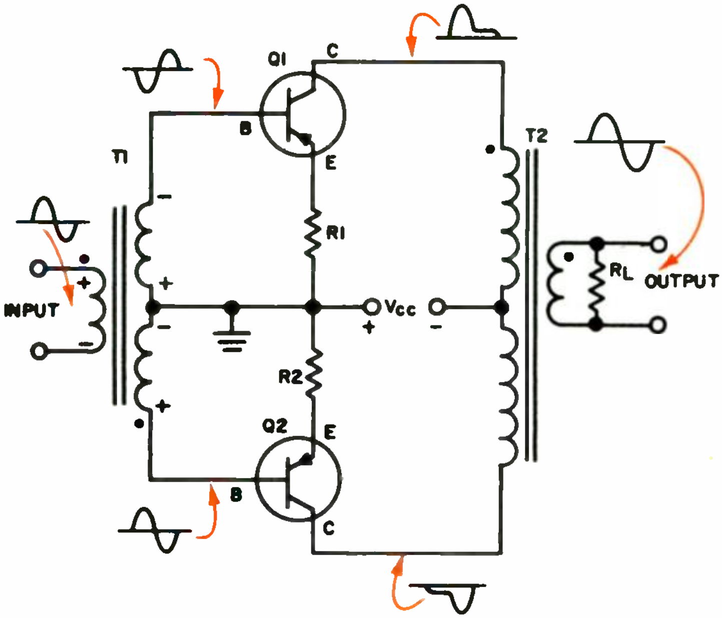


Figure 13 — Class B push-pull stage.

the transistor is similar to specially constructed Class B (zero bias) electron tubes.

When a signal is applied to input transformer T_1 (Figure 13), a voltage is applied to the base of transistor Q1 and an oppositely polarized voltage is applied to the base of Q2 (the polarity for the initial half cycle is shown on the schematic). With transistors Q1 and Q2 at zero bias, only reverse leakage collector current flows in the absence of a signal. When the input signal is applied, the flow of current in the primary of T_1 induces an oppositely polarized signal on the base of Q1 (transformer connected out-of-phase). Thus, the positively swinging input appears as a negative (forward) bias on the base of Q1, causing collector current to flow in the top half of the primary of T_2, and induces an output voltage in the secondary. At the same time, the input voltage applied to Q2 is opposite in polarity and produces a reverse bias, keeping Q2 cut off. During the entire half-cycle, Q1 conducts while Q2 remains cut off. When the input signal reverses polarity, reverse bias is applied to cut off Q1 collector current, and forward bias is applied to Q2. Consequently, Q2 conducts and the increasing collector current through the bottom half of the primary of T_2 induces a voltage in the secondary of the output transformer. During this half-cycle Q1 remains cut off while Q2 conducts. Thus, Q1 and Q2 alternately conduct when the input signal produces a forward bias. Since the outputs of Q1 and Q2 are combined in the secondary of the output transformer, the input signal is reproduced in amplified form, but of opposite polarity. If the output transformer is connected in-phase, the same polarity of output exists as in the primary; when it is connected out-of-phase, the opposite polarity exists. This transformer action is identical with that occurring in the electron tube push-pull circuit.

Since audio power is produced, the transistors heat during operation (a maximum of 78 percent efficiency is theoretically obtainable) and the reverse leakage current increases. Emitter swamping resistors R_1 and R_2 provide a small opposing bias voltage to prevent thermal runaway. They are not bypassed with capacitors as in Class A operation because the capacitors would charge during the operative half-cycle and discharge during the inoperative half-cycle, thus causing a change in bias. Because of the large peak current which flows through these resistors, they are kept to a very low value of resistance to prevent excessive degeneration and loss of amplification. In some applications, by proper selection of transistor types and good design, they are not needed. In any event, when used, their main function is to provide thermal stabilization; any beneficial degeneration which may occur from their use is only a secondary consideration. Otherwise, they have no effect on the operation of the circuit.

Class AB Operation. The schematic of the Class AB amplifier is basically identical with that of the Class A amplifier shown previously. The only difference is that bias voltage divider resistors R_1 and R_B are of different values. Only a slight forward bias is applied, and only a small collector current flows with no signal applied. Class AB operation produces slightly less output than Class B operation. Because of the small resting current, the transistor can be driven harder than the Class A stage; consequently, greater output can be obtained than for Class A operation. The efficiency averages about 65 percent for a well designed Class AB stage.

Circuit Failure

When making voltage checks, use a vacuum-tube voltmeter to avoid the low values of shunting resistance ordinarily employed on the low-voltage ranges. Be careful also to observe proper polarity when checking continuity with the ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

No Output. A no-output condition can be caused by an open circuit in either the input transformer, T_1, or output transformer, T_2, or in the swamping resistors, R_{E1} and R_{E2}, as well as by lack of supply voltage. The supply voltage can be checked with a voltmeter, and lack of collector or base bias voltage can also be determined. Continuity checks of the transformers (WITH THE POWER TURNED OFF) will determine whether one or more of the windings are open, and the resistors can be checked for proper resistance with the ohmmeter. Normally, failure of the transistors will not cause complete loss of output unless both transistors fail completely.

Low Output. Lack of sufficient drive power, low supply voltage, improper bias, or a defective transistor can cause reduced output. The supply voltage and bias can be checked with a voltmeter. Lack of drive power can be determined by observing the waveform with an oscilloscope and noting whether there is sufficient drive to cause eventual flat-topping or bottoming of the output waveform. A shorted or inoperative transistor can also cause low output. Depending upon conditions, removing the transistor (from a plug-in socket) will either increase or reduce the output. In the case of a shorted transistor, the output will probably increase when it is removed. A transistor with low gain or poor performance, when removed, will probably cause further reduction of the output. If the shorted transistor is left in the circuit and the good one is removed, there will also be a decrease in the output. Thus, it can be seen that where a transistor is suspected, both transistors should be replaced with ones known to be good in order to determine whether the output comes up to a normal level. Further checking with a transistor tester will determine the defective one.

Distorted Output. Distorted output may be caused by lack of proper bias or supply voltage, by underdrive or overdrive, or by defective transistors or transformers. If one half of a transformer is open or shorted, one transistor will not operate properly and distortion will occur. Likewise, if the bias is too high, clipping will occur on the peak of the input signal, and if it is too low, collector bottoming will produce the same effect at the troughs of the signal. Transformer resistance and continuity can be checked with an ohmmeter, while the bias and voltage can be checked with a voltmeter. In Class A or Class AB stages, one half of the circuit can be inoperative and the unit will function with reduced output and increased distortion. Use an oscilloscope to observe the waveform, checking from input to output. When the waveform departs from normal, the cause of the trouble will usually be obvious.

AUDIO POWER AMPLIFIERS COMPLEMENTARY

The push-pull, single-ended complementary audio amplifier is used where high power output and fidelity are required, as in receiver output stages.

Circuit Analysis.

Complementary symmetry is unique with transistors, and has no electron-tube counterpart. Recall from basic theory that a transistor may be either the PNP or NPN type, and that the bias and polarities are opposite. Thus, two different types of transistors may be used back-to-back to provide push-pull operation without the necessity for phase-inverting input and output transformers. An economic advantage is gained as the cost of the transformers is eliminated, and a more uniform response is obtained since the reactive effects of the transformers are also removed from the circuit.

Circuit Operation

Figure 14 shows a typical single-ended push-pull complementary symmetry circuit. The operation is Class B at zero bias.

Resistance-capacitance input coupling is used, with Ccc acting as the coupling capacitor and R_B as the base return resistance across which the input signal is applied. With both emitters grounded and no bias applied, the bases of the transistors are zero-biased at cutoff. No current flows in the absence of an input signal. When an input is applied, both bases are biased in the same direction. Since Q1 is an NPN transistor, the positive-going input signal produces a forward bias. Q2 is a PNP transistor and requires a negative potential for forward bias; the input signal has no effect other than to reverse-bias Q2 and hold Q2 in a cutoff condition. Thus, during the positive half of the input signal only Q1 conducts. During the negative portion of the input signal, Q1 is biased off beyond cutoff by a reverse bias, and a forward bias is applied to Q2, causing collector current to flow for the entire negative half-cycle. Thus, each transistor conducts alternately for half of the cycle, and two transistors are

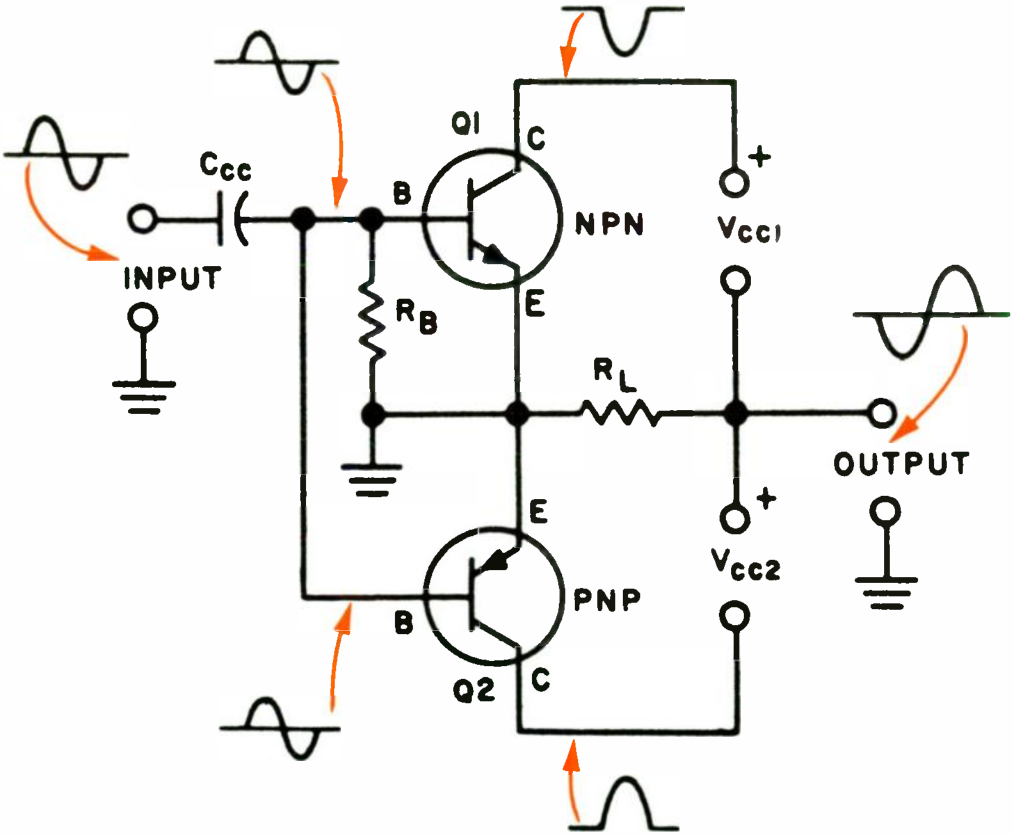


Figure 14 — Zero bias complementary symmetry push-pull circuit.

required to reproduce the input signal. Note that the bases are connected in parallel, and, since only one transistor operates at a time, only enough drive for a single stage is required instead of twice the drive as in normal push-pull operation.

Because the transistors are of opposite types, two equal-voltage collector power supplies are required, one negatively polarized and the other positively polarized. (A single supply can be used with proper circuit changes, but twice the collector voltage of a single stage is required.) The load resistor, R_L (which may be the voice coil of a loud-speaker), is connected from the common connection between the power supplies and the emitters. In this instance the emitter end is grounded, so that the power supplies are actually floating above ground. When the input signal is applied and develops an output for each half-cycle, the output is added together in the common load and no transformer is required. To develop maximum power, a low-impedance is needed. Otherwise, if high-impedance loads are used, an output transformer will be required for proper load matching. In this instance, however, the winding need not be center-tapped since the output is single-ended. Because the output is single-ended (taken between the collector and ground), the collector load is calculated on the basis of the full primary-to-secondary turns ratio—not on one-half the primary-to-secondary turns ratio as in the conventional push-pull stage. Thus, the loading is 1/4 the normal push-pull output, which accounts for the low-impedance output.

In most electron tube or transistor circuits, it is necessary to separate the DC component in the output from the AC component by capacitive or transformer coupling. In the complementary-symmetry arrangement, such provisions are unnecessary. Both DC power supplies are connected in series with the transistors, and only one transistor is operative at a time; thus, there is no net flow of DC around the circuit. When Q1 conducts, there is a flow of current through R_L, the transistor, and the power supply in one direction. When Q2 conducts, the flow is through R_L, Q2 and the power supply in the opposite direction; thus, there is no circulating current, and the DC is effectively removed from the load circuit since only the continuously varying AC component flows through the load. Likewise, in the base circuit there is no continuous flow of DC, since the current flows out of the base when Q2 conducts, and into the base when Q1 conducts. Therefore, the charging and discharging of the coupling capacitor and its possible effect on changing the base bias are of no consequence in this circuit.

In the preceding discussion, it was assumed that the transistors are balanced (or matched), having identical gain and collector currents. Like the conventional push-pull amplifier, this matching is necessary to obtain maximum output with minimum distortion. Unlike the electron tube circuit, which uses identical plate voltages and matches the plate current, the complementary symmetry circuit has identical collector (plate) currents since the transistors are series-connected and the biasing is adjusted to equalize the collector voltages. In the case of Class A or AB operation, the bias point in the base circuit is affected by drive and base current drain. Thus, keeping the signal from affecting the bias is one of the important design problems. As far as the service technician is concerned, the practical effect is that, with better design, less distortion is obtained, with a maximum of amplification.

While the common-emitter circuit is used in most transistor amplifiers, better performance is obtained from the common-collector circuit when complementary symmetry is employed. Although the over-all gain and output are slightly less, the stability of the circuit is improved; the collector supply can be grounded instead of floating (which reduces power supply ripple), and the effect of negative feedback is obtained, thus requiring less closely balanced transistors and improving fidelity and response characteristics. Both circuits are identical, except that the ground is removed from the emitters and placed on the common power supply connection, as shown in Figure 15. As in other common-collector circuits, no polarity inversion of the output signal occurs, so that the inputs and outputs are of the same polarity. In operation, the circuit functions in the same manner as the common-emitter push-

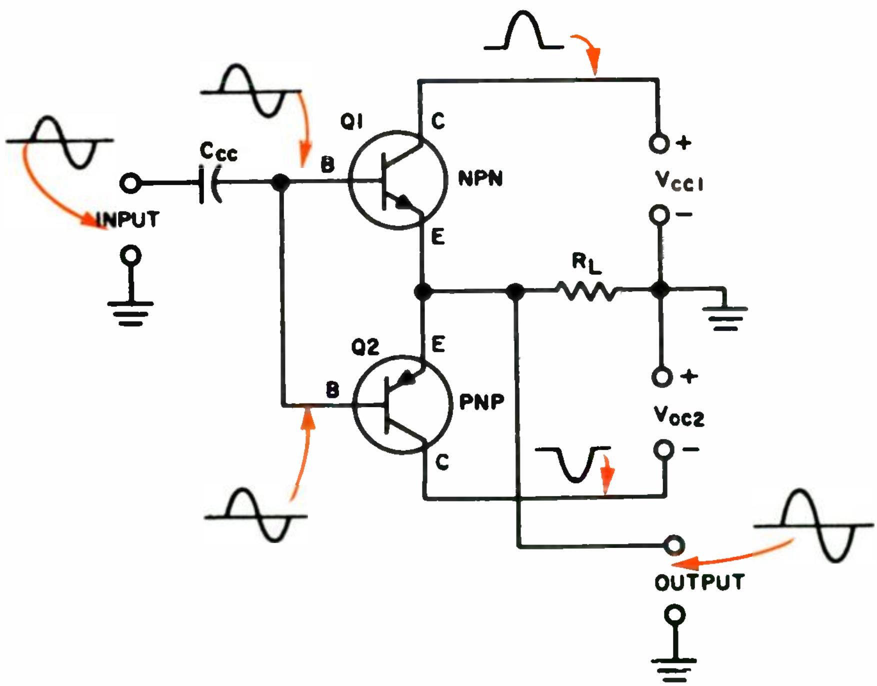


Figure 15 — Common (grounded) collector complementary symmetry push-pull circuit.

pull complementary-symmetry amplifier previously described. Only one transistor operates at a time, zero bias is employed, and the output is taken from the emitters to ground. Collector current flows through Q1, power supply V_{cc1}, and load resistor R_L in one direction, and through V_{cc2}, Q2, and R_L in the opposite direction, as the transistors are alternately forward-biased by the input signal. There is one difference, however, in that more input (drive) voltage is required to obtain full output because of the degenerative effect of connecting the load between the emitters and ground.

The schematic diagram in Figure 16 shows the complementary symmetry push-pull circuit connected for use with a single power supply, and with feedback from collector to base. Connecting capacitor C_1 in series with load resistor R_L permits the use of a single power supply. Since no DC normally flows through the load, the insertion of the blocking capacitor has no effect on either AC or DC operation. Since both transistors are connected in series with the power supply, twice the DC voltage of one supply is necessary. In addition, resistors R_1 and R_2 are employed to provide a fixed base bias and a slight amount of feedback from collector to base. The feedback reduces the matching requirements, and the DC bias is adjusted by selecting the values of R_1 and R_2 so that equal collector voltages are obtained (with the series connection of transistors, the same value of current flows throughout the circuit).

As far as dynamic operation is concerned, it is also identical with that of the previously discussed common-emitter complementary symmetry circuit. When a forward bias is applied by the signal, the transistor conducts. With a sine-

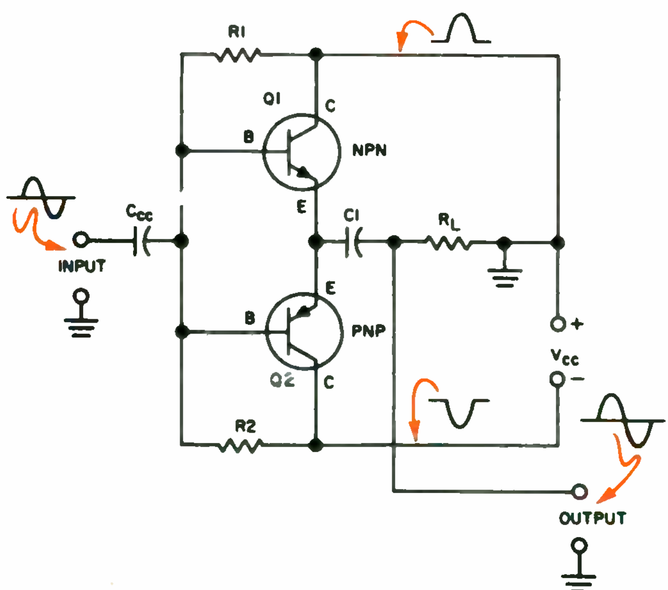


Figure 16 — Complementary symmetry push-pull amplifier with common power supply.

wave input signal applied, a sine wave of current flows (at audio frequencies) through capacitor C_1 and load R_L to develop the output signal.

Circuit Failure

When making voltage checks, use a vacuum-tube voltmeter to avoid the low values of shunting resistance employed on the low-voltage ranges of most volt-ohm-milliammeter testers. Be careful, also, to observe proper polarity when checking continuity or making resistance measurements with the ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

No Output. An open or short circuit in the power supplies or transistors, or an open coupling capacitor or load resistance can cause no output. A voltage check will indicate whether the proper voltage and polarities are applied. Since Class B zero bias operation is normally employed, no base-to-emitter (or ground) voltage exists in the absence of a signal. However, if an attempt is made to measure this voltage with a meter, a false reading may be obtained through the voltmeter shunting resistance. Therefore, only the polarity and supply voltage should be checked, and the input signal should be observed with an oscilloscope. Lack of input signal on the oscilloscope indicates an open coupling capacitor, C_{cc}, or a shorted input circuit caused by a defective transistor. If the supply voltage and polarity are correct and a signal is visible at the input, but not in the load, either the transistor is defective or the load is shorted. A resistance or continuity check will determine whether the load is normal. If it is normal, only the transistors can be at fault. Since only one transistor is operative at a time, both transistors must be defective to cause a loss of output; otherwise, a reduced or distorted output exists. When in doubt, replace the transistors with ones known to be good.

Reduced Output. If one of the transistors is defective, or if one of the supply voltages is low or the supply is defective, a loss of output will occur. Use an oscilloscope to observe where the input waveform or output waveform departs from normal. Check to make sure that there is sufficient drive in the preceding stages. A leaky coupling capacitor will place a fixed bias on the base circuit, causing conduction in one transistor and rendering the other inoperative. Depending on the amount of bias, the circuit may be such as to very slightly reduce the output or to cause severe distortion. Unbalanced collector voltages, if sufficiently different, will cause loss of amplification and distortion on one side of the circuit, which can be observed on the oscilloscope. Since there are only a few components in the circuit, a resistance and voltage check should quickly indicate whether the power supply or components are defective. When the transistors are suspected, replace both with ones known to be good, or remove them separately and check them on a transistor checker.

Distorted Output. Improper bias or load resistance can cause a distorted output. Use an oscilloscope to determine where the signal departs from normal. The trouble will then be localized to that portion of the circuit showing the distorted waveform. In the common-emitter circuit, if the distortion occurs on the negative portion of the waveform, the trouble is in the PNP transistor circuit; if it is on the positive portion of the waveform, the trouble is in the NPN transistor circuit. Since there is no inversion of polarity in the common-collector circuit, the indications will be the opposite. That is, distortion on the positive waveform indicates trouble in the NPN transistor circuit, and distortion on the negative waveform indicates trouble in the PNP circuit.

SUMMARY

Auto radio servicing is similar to the repair of home radios, with the additional problem of removing the radio for bench repair. An auto radio should never be removed before attempting to locate and fix the trouble while the radio is still in the car. An antenna can be the only defect in the entire system, if the radio plays with only low volume, so an external antenna with a long lead should be tried first. Then routine checking of fuses, rocking tubes in their sockets, and in-place brute force checks should be made before removing the radio.

The use of signal tracers, signal generators, and VTVMs has the same advantage in auto servicing as in home radio servicing. Once the general area of the trouble has been located, an understanding of the circuit operation and the effects of changed component values will lead to a solution of the difficulty.

TEST

Lesson Number 71

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-071-1.

1. **When a tube is removed from a radio, the tube may be considered to be**
   A. good, if a crackling noise is heard in the speaker.
   B. bad, if a crackling noise is heard in the speaker.
   C. unstable, if a crackling noise is heard in the speaker after the radio is operating on the bench.
   D. none of the above.

2. **Distortion may be found in**
   A. the audio stages.
   B. those stages controlling AVC.
   C. hybrid radios close to a station.
   D. all of the above.

3. **Checking parts while they are still connected into the radio**
   A. is always an accurate way to check them.
   B. should never be done, and they must always be taken out of the receiver before checking them.
   C. should be done first, if the part can be checked with reasonable accuracy.
   D. none of the above.

4. **An output meter connected across the speaker coil**
   A. can show sudden voltage increases or decreases that generally won't be heard.
   B. cannot be helpful, even if watched.
   C. is *only* helpful when parts are being moved to discover defects.
   D. can only be used when listening to strong stations.

5. **Checking diodes in an AVC circuit**
   A. can generally be done with an ohmmeter without unsoldering them from the receiver.
   B. will indicate a front-to-back ratio of at least 1000 to 1, when the diode is in the circuit.
   C. will cause oscillation or whistling in the radio.
   D. will always show that one of them is defective.

6. The difference between a common-base and a common-emitter RF amplifier is

A. that the common-base amplifier provides high gain, while the common-emitter provides low gain.

B. that the common-emitter amplifier provides high RF gain while the common-base amplifier provides lower gain.

C. that the common-emitter amplifier provides high RF gain but poor selectivity, while the common-base amplifier provides lower gain and poor selectivity.

D. not noticeable in an RF amplifier stage.

7. The common-emitter RF stage

A. has a higher output impedance than the common-base circuit.

B. output transformer is tapped to divide the collector.

C. has a higher input impedance than that of the common-base circuit.

D. is never tuned.

8. When making voltage checks in RF circuits,

A. use a VTVM for reading AC only.

B. use a VTVM for reading DC only.

C. use a VTVM to avoid the low values of the input shunting resistance on VOMs.

D. a VOM may be used.

9. A diode detector operates as a rectifier

A. only when a vacuum tube diode is used.

B. with the load in series with the diode, and a capacitor across the load.

C. only if the RC time is very short.

D. only when the capacitor remains fully charged.

10. Push-pull audio amplifiers are *never* operated

A. Class A.

B. Class AB.

C. Class B.

D. Class C.

Portions of this lesson from
Audio Radio Servicing Made Easy
(2nd Edition) by Wayne Lemons
Courtesy of Howard W. Sams, Inc.

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

HAND IN HAND

Hard work goes hand in hand with success. There are a few rare instances when a person will inherit a successful business or stumble into an opportunity—but in the majority of cases, the successful person is the one who knuckled down and worked hard.

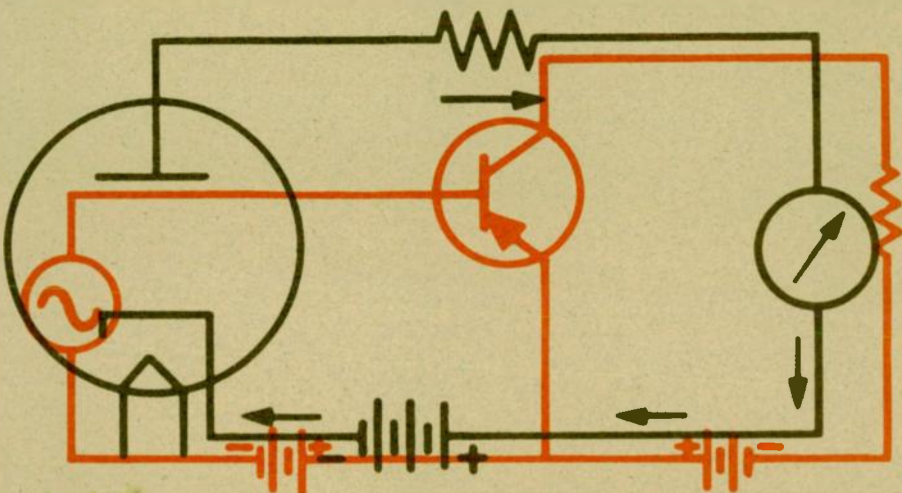
Learn everything you can about your job and then put what you learn into actual practice.

Make the most of your spare time. Put what you learn into actual practice. Work at it and you will be successful.

S. T. Christensen

LESSON NO. 72

REVIEW FILM OF LESSONS 69 THROUGH 71



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-072
407

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

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REVIEW FILM TEST

Lesson Number 72

The ten questions enclosed are review questions of lessons 69, 70, & 71 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and Film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER: YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-072-1.

1. **The component used in a tube type auto radio to produce AC voltage from DC battery voltage is a**
   A. vibrator.
   B. rectifier.
   C. FET.
   D. magamp.

2. **An OZ4 is a**
   A. solid-state rectifier.
   B. cold cathode rectifier tube.
   C. filament type rectifier.
   D. five-element rectifier.

3. **The antenna compensator**
   A. tunes the IF strip.
   B. increases overall antenna wavelength.
   C. matches the antenna and cable to the antenna circuit.
   D. must be adjusted to control AVC.

4. **A neutralizing capacitor**
   A. is only used in a low level audio amplifier.
   B. increases the gain of an RF amplifier stage.
   C. reduces the tendency of a circuit to oscillate.
   D. all of the above.

5. Permeability-tuning is
- A. the only method ever used in car radios.
- B. the same as slug-tuning.
- C. not as good as capacitor-tuning.
- D. only used in IF stages.

6. AVC voltage
- A. increases volume when strong signals are received.
- B. decreases volume when weak signals are received.
- C. is always negative.
- D. may be positive or negative in a transistorized receiver.

7. A push-pull output stage
- A. generally has low-distortion.
- B. has more power output.
- C. is used with both transistors and tubes.
- D. all of the above.

8. When a signal seeking radio is searching for a station, you
- A. cannot hear stations.
- B. can hear stations.
- C. can hear strong stations.
- D. none of the above.

9. A Class-B audio amplifier
- A. draws large current with no signal.
- B. draws small current with no signal.
- C. can be single-ended.
- D. none of the above.

10. The use of a resistor as a fuse in a transistorized circuit
- A. will only protect itself.
- B. is only effective if it has a value of 5k ohms or more.
- C. will provide protection for other components if the transistor in series with it develops a short.
- D. is to provide bias.

Notes

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

PROGRESS THROUGH PRACTICE

The procedures outlined in your ASI troubleshooting lessons will be practiced time and again during servicing of radios, TVs, etc.

Study the material carefully. Practice the procedures until you understand them thoroughly and can do them easily.

ASI provides good instructional material and practice equipment. The rest is up to you. Use what you have to good advantage. The way you use your time, energy, and supplies will determine future success.

S. T. Christensen